ASSESSING THE NEED FOR ADDITIVE MANUFACTURING METHODS IN THE MARITIME INDUSTRY IN THE GREATER METROPOLITAN REGION OF HAMBURG

On behalf of Maritimes Cluster Norddeutschland e. V.

April 2019

Fraunhofer
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maritimes cluster
norddeutschland

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The maritime industry network

Shipbuilding, suppliers, marine engineering, shipping, offshore... the maritime sector is a multifaceted entity that has tremendous potential for the future. It is a key industry in Northern Germany and is a decisive factor in the region's economic development.

The association Maritimes Cluster Norddeutschland (MCN) promotes and fosters cooperation in the industry. We pool strengths from across the country. We promote cooperation and innovation across industries. We provide assistance with the search for innovation partners, advise on funding and connect actors within the maritime industry.

Operating regionally and nationally

The MCN is a maritime network with roughly 350 employees from finance, science and politics. With branch offices in Bremen, Hamburg, Lower Saxony, Mecklenburg-West Pomerania and Schleswig-Holstein – we are never far away. Because we know that it is only through continuous dialogue with all actors that we can determine which course to set, which locks to open and which ports to call at.

Maritimes Cluster Norddeutschland was founded in 2011. It started off with the states of Hamburg, Lower Saxony and Schleswig-Holstein working together – then in September 2014 Bremen and Mecklenburg-West Pomerania jumped on board. The MCN has been operating as an association since the start of 2017.

Contractor

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The Fraunhofer Research Institution for Additive Manufacturing Technologies (IAPT) is part of the Fraunhofer Society – a leading organisation for applied research with roughly 25,000 employees in Europe. The Fraunhofer IAPT was formed from LZN Laser Zentrum Nord GmbH and parts of the Institute of Laser and System Technologies at the Hamburg University of Technology and became a world leader in scientific-industrial technology transfer in the field of 3D printing. It also engages in the research and development of additive production technologies with the core areas of Design, Process and Factory and has roughly 100 employees at locations in Hamburg and Lüneburg. Its focus is on applying additive technologies in the manufacture of aircraft, vehicles, trains, ships, tools and machines as well as on medical and plastics technology for series production within the scope of rapid and bionic manufacturing. The Fraunhofer IAPT aims to give its clients the means necessary for making products of the highest quality at the lowest possible cost using additive serial production technology of unparalleled efficiency and to open up new, profitable business opportunities with unique selling points through application-oriented research.

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List of abbreviations

AM	Additive Manufacturing
AMP	Additive Manufacturing Plant
AMT	Additive Manufacturing Technology
AMP	Additive Manufacturing Process
BJ	Binder Jetting
CNC	Computerised Numerical Control
DED	Directed Energy Deposition
EBM	Electron Beam Melting
FDM	Fused Deposition Modelling
HP	Hewlett Packard
IAPT	Fraunhofer Research Institution for Additive Manufacturing Technologies
CM	Conventional Manufacturing
CMP	Conventional Manufacturing Process
SME	Small and Medium-sized Enterprises
LBM	Laser Beam Melting
LMD	Laser Metal Deposition
MAG	Metal Active Gas welding
MCN	Maritimes Cluster Norddeutschland e. V.
MJF	Multi Jet Fusion
OEM	Original Equipment Manufacturer
PA	Polyamide (e.g. PA6, PA11, PA12)
PP	Polypropylene
PE	Polyethylene
PEEK	Polyether ether ketone
SLS	Selective Laser Sintering
TPU	Thermoplastic Polyurethane
WAAM	Wire Arc Additive Manufacturing

Introduction

Industrial production is constantly evolving and adapting to technical innovations and changing client needs. We are currently seeing a transition from mass production to flexible, customised production. Industry is moving towards shortened product life cycles and development times, higher product complexity and smaller quantities per product variant. Additive manufacturing is also part of this trend, and it can help businesses adapt to the new production requirements. Additive manufacturing denotes a manufacturing process in which components are produced by depositing layers of material made from a formless raw material, for example metal powder. In contrast to conventional manufacturing processes such as turning, milling or casting, additive manufacturing processes make it possible to produce complex, organic structures in small quantities and right down to lot size 1 in a cost-effective manner.

Additive manufacturing is already widely used in many industries. In the maritime sector, the exact potential and opportunities offered by the technology are still relatively unknown and not fully exploited. Furthermore, very few actors in the maritime industry know which companies and expertise they can draw on for additive manufacturing in the region and in Germany.

The present study therefore aims to give companies from the maritime industry a deeper understanding of additive manufacturing and to reveal the full potential of additive manufacturing, with a focus on maritime applications. The first chapter will explain applications of additive manufacturing. This includes cross-sector application examples of additive manufacturing as well as an overview of the additive manufacturing technologies available. The cross-sector potential of additive manufacturing will then be transposed onto the maritime sector and explained in a category-specific manner. In the last part of the first chapter, the theoretically analysed potential for the maritime industry will be demonstrated using practical component analyses for companies from the maritime industry.

The second chapter will provide an overview of the service providers currently offering additive manufacturing in Germany, and in particular in the catchment area of the Marimites Cluster Norddeutschland. These service providers are potential cooperation partners for projects involving additive manufacturing.

The third chapter will consider the implementation of additive manufacturing in industrial companies, with a focus on SMEs. Firstly, current obstacles that could hinder the implementation process in a company will be investigated. And secondly, methods for the successful implementation of additive manufacturing will be presented based on concrete best practice examples. In both cases, a light will be shone on the progression from initial idea to full implementation of series additive manufacturing.

1 Applying additive manufacturing

1.1 Potential cross-sector applications of additive manufacturing processes

Chapter 1.1 will give a general overview of the fundamental potential of additive manufacturing processes. The first part (chapter 1.1.1) will outline sector-specific application examples. Based on these examples, the benefits associated with the use of additive manufacturing as compared to conventional manufacturing shall then be expounded. In the following chapter 1.1.2, the various plastic- and metal-based additive manufacturing technologies will be compared and the relevant field of application identified. This therefore provides inspiration for choosing relevant components for additive manufacturing and offers a recommendation as to which additive manufacturing technology best suits a particular application.

1.1.1 Potential industrial applications of additive manufacturing

This chapter will delve deeper into the potential of additive manufacturing (AM for short) for industry. Application examples from selected industrial sectors will be used in order to ensure that the analysis of this potential remains practically relevant. The chapter is structured by sector. Application examples from a specific sector will be presented in each of the subsequent sub-chapters and the corresponding potential offered by additive manufacturing technology (AMT for short) in the relevant field of application will be analysed. Then, in chapter 1.2, the potential of additive manufacturing for the maritime sector will be identified and conclusions will be drawn on applications of additive manufacturing in a maritime context.

Cross-sector examples

Product development and after-sales service are two areas in the value chain in which AM is already being used in many sectors. Since the use of AM in these two areas is similar in all sectors, it is described in a sector-neutral manner in this chapter.

The use of AM assists with the product development process thanks to the creation of prototypes. The iteration cycles throughout the course of the product development process can be shortened using AM, as prototypes can be built far quicker using tool-less manufacturing as compared to conventional manufacturing processes (CMP). By shortening the product development phase, the challenge of shrinking product life cycles can be effectively countered. AM therefore contributes to process optimisation thanks to the quick and simple creation of prototypes, which provide important information during product development. Physical prototypes of components help to uncover possible design flaws not detected during examination of the digital component model as early as during the development process. As a result, the quality of the finished product can be significantly increased during the early stages of product development.[1] A distinction is made between geometric prototypes and functional prototypes. With geometric prototypes, the focus is on assessing the dimensions, shape and position of a component. The mechanical and functional properties are an afterthought.[2] In the field of medical technology, geometric prototypes of this kind are used for operation planning, for example. The doctor can accurately simulate an operation down to the last detail using an additively manufactured model of the body part to be operated on. In this way, each individual operation can be planned in order to achieve more efficient results for the hospital and for the patient. Any risks associated with surgery are reduced by very specific training options.[3] Geometric prototypes are also used in mechanical and plant engineering. In this case, prototypes can help with layout planning of a factory and the spatial arrangement of system components, since the planners get a better feel for the spatial dimensions with physical objects than they would with digital planning software. In light of the high degree of design freedom offered by additively manufactured components, the prototypes have a much higher level of detail than if they were manufactured in the conventional manner.[4] Functional prototypes can also be manufactured using AM. One example application is that of a newly developed gearbox. Conventional manufacture of highly complex housing parts would be cost-intensive and involve long lead times. As the functionality of the newly developed gearbox is uncertain, this poses a huge financial risk. But thanks to AM, the housing parts can be made more cheaply and quickly than with CM. Although the mechanical loading capacity of additively manufactured housing parts is lower (albeit still sufficient for withstanding the pre-series tests), the quality of the final gearbox can in this way be increased in a cost-effective manner.[5]

AM can also be of use in the field of spare parts management. This applies in particular to spare parts that cannot be stored or manufactured by conventional means cheaply as and when required, because the useful life of the component in question is hard to predict or because the spare parts are one-off products. Thanks to AM, spare parts such as these can be manufactured decentrally when and where they are needed. Transport distances and delivery times can therefore be kept to a minimum. As a result, the downtime of the machine or system to be repaired is reduced.[6] Deutsche Bahn, for example, relies on the constant operability of their trains. When their trains break down, their profits take a hit. Therefore, it is essential that spare parts are supplied quickly. Critical train components can be manufactured as and when required thanks to AM. Furthermore, Deutsche Bahn can provide replacement parts no longer available from external suppliers for old train models thanks to AM.[7]

Transportable additive manufacturing centres in shipping containers open up the possibility of on-site production (see Figure 1). Ideally, these types of additive manufacturing cell can

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[1] [Feld 16] – Feldmann, Pumpe: 3D-Druck – Verfahrensauswahl und Wirtschaftlichkeit. 2016, p. 8/9

[2] [VDI 3404] – VDI-Richtlinie 3404: Generative Fertigungsverfahren Rapid-Technologien (Rapid Prototyping). 2009, p. 5

[3] [3dgr 17d] – 3d-grenzenlos.de: Britisches Krankenhaus spart bis zu 20.000 Euro pro Operation dank des 3D-Drucks, 2017
[Deut 15] – Deutsches Ärzteblatt: 3D-Drucker hilft bei der OP-Planung, 2015

[4] [3trp 17a] – 3T Building Success Layer by Layer: 3D Printing for Oil Rig model, 2017

[5] [3trp 17b] – 3T Building Success Layer by Layer: Plastic AM gearbox prototype gives superb results, 2017

[6] [Verb 17] – Verband Deutscher Maschinen- und Anlagenbau: AM für die Luftfahrt, 2017

[7] [Deut 17a] – Deutsche Bahn: 3D-Druck: Neue Fertigungungstechnik für Ersatzteile, 2017

cover the entire additive process chain, such that spare parts can be manufactured even in environments unsuitable for production. An engineer trained in how to use the plant technology can operate the AM cell.

Figure 1: Transportable additive manufacturing cell[8]

Even car manufacturer Mercedes-Benz produces spare parts using AM. Thermostat covers for lorries from older ranges are additively manufactured from metal and retain original-part quality. The need for this spare part is low due to the age of the series, and therefore it would not be economically feasible to store a large number of conventionally manufactured thermostat covers. By using AM, Mercedes-Benz can reduce their stock of spare parts and still be able to provide spare parts when they need them.[9]

Another field of application for additive manufacturing is mould-making for sand-casting processes. In this case, it is not the final component but the sand-casting mould required for casting that is additively produced. As a result, it is now possible to produce sand-casting moulds that were previously impossible to make due to the highly complex core shapes that feature undercuts. The drafts previously required for removing the models from the mould, for example, have thus declined in importance. Additively manufactured moulds can also be produced more cost-effectively and with shorter provisioning times than conventionally manufactured moulds.

Deposition welding is an additive manufacturing technology that is particularly suitable for the manufacture of large metal structures. This technology is typically used for repair work, for example for additively restoring worn regions of turbine blades. Instead of replacing the entire turbine blade with a new one, additive manufacturing makes it possible to build up the worn regions of the blade on-site once the affected regions have been face-milled. Another use for deposition welding is the manufacture of component blanks (see Figure 2). In contrast to milling, deposition welding is more material-efficient, as hardly any swarf is produced. In comparison to casting, even very small quantities of a component can be manufactured economically, since no initial tool-forming costs are incurred. Once the component blank has

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[8] [Hens 18] – Hensoldt: “AM Suite – Die 3D-Druck Lösung”, 2018

[9] [Daim 17] – Daimler AG: Mercedes-Benz Lkw: Neu aus dem 3D-Drucker: erstes Lkw-Ersatzteil aus Metall, 2017

been completed, its joint surfaces are machined in order to ensure that the component is exactly the right size.

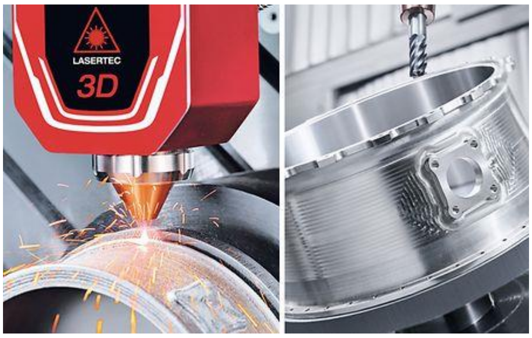

Figure 2: Additive manufacturing of a blank (left) and post-machining of the blank (right)[10]

Table 1 summarises the capabilities offered by AM for the fields of application of prototyping (1.1), spare parts supply (1.2), mould-making (1.3) and blanks for large structures (1.4). The capabilities are assigned based on a three-step scale. If a particular application example does not lend itself to a particular AM capability, then “No realisation potential” applies. If a particular AM capability has a direct and significant effect on the optimisation of the application example, then “High realisation potential” applies. This is the case, for example, for the AM capability “Lead time reduction” in “Prototyping”. AM also makes it possible to shorten the product development process by means of physical verification models and thus speed up product launch. For cases where an AM capability has an indirect effect on the optimisation of the application example, then “Medium realisation potential” applies.

Table 1: Cross-sector capabilities of additive manufacturing

Evaluation system
■ = High realisation potential
▨ = Medium realisation potential
□ = No realisation potential

			Capabilities of additive manufacturing in industrial application								
Sector	**No.**	**Application example**	Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Lead time reduction
All sectors	1.1	Prototypes	▨	▨	□	□	□	▨	□	■	■
	1.2	Spare parts	▨	□	□	▨	■	■	■	□	■
	1.3	Mould-making	■	□	▨	□	□	■	□	□	■
	1.4	Blank for large structure	▨	□	□	□	■	▨	▨	□	▨

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[10] [Dmg 19] – DMG Mori: “LASERTEC 65 3D hybrid - Hybride Komplettbearbeitung”, 2019

Examples from the mechanical and plant engineering sector

AM is also used in the mechanical and plant engineering sector. The advantages offered by AM in this sector will be outlined based on five application examples: tool-making, valve blocks, can-filling valves and gas turbine combustors.

The scope of what is possible in processes typical to tool-making, such as the creation of injection moulds and die-casting cores, can be expanded by means of AM. Tool inserts for the injection-moulding process can be additively produced in an efficient, fast and flexible manner, since AM offers new design possibilities at low manufacturing costs compared with CM. A characteristic example of this is the injection mould shown in Figure 3.

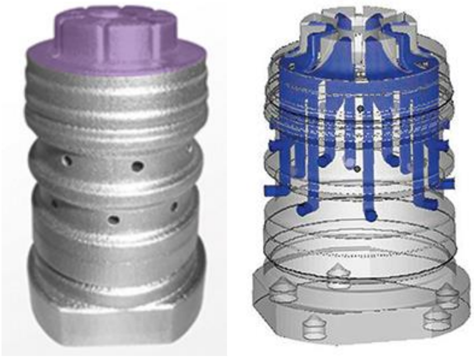

Figure 3: Injection mould (left) and cooling channels in the injection mould (right)[11]

By using AM, it is possible to provide the mould with internal cooling channels and ultra-thin walls. The function “targeted cooling” is therefore integrated into the component. As a result, injection moulding cycles can be sped up while also improving the quality of the component, since an injection-moulded component can be cooled more quickly. Moreover, the constant cooling substantially prolongs the lifetime of the injection mould, because the temperature profiles are homogenised.[12]

In the case of metal die-casting, too, casting cores can be individually and flexibly manufactured using AM. When casting hollow components, cores referred to as “lost moulds” are used. Typically, these cores are produced by means of the core-shooting process. A special mould is required for producing the core. However, this can be dispensed with by using AM. Furthermore, when it comes to more complex cores produced in small quantities, the conventional process quickly runs up against its limits, since the conventional method for producing a core mould is cost-intensive. In contrast, thanks to the mould-free additive manufacturing process (AMP), it is possible to modify or scale the core without incurring additional costs.[13]

Another example of the successful implementation of AM is valve blocks. Conventionally manufactured valve blocks are milled from a block of raw material and the corresponding channels are bored into the block (see left-hand image in Figure 4). AM makes it possible to

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[11] [Eos 17] – EOS GmbH: Powerful EOSINT M 280 supersedes hybrid solution of the tool insert, 2017

[12] [Arbe 17] – Arbeitsgemeinschaft Additive Manufacturing: Technology Scout. 2017, p. 21
[Eos 17] – EOS GmbH: Powerful EOSINT M 280 supersedes hybrid solution of the tool insert, 2017

[13] [Arbe 17] – Arbeitsgemeinschaft Additive Manufacturing: Technology Scout. 2017, p. 20

profoundly reshape the valve block and thus optimise the properties thereof. With AM, the channels do not have to be round and straight, but rather can be oval in flow-critical regions or shaped in any other desired manner.[14] These new construction possibilities increase the flow rate through the valve block. In addition, topological optimisation is possible thanks to AM software. Based on a finite element calculation, areas of material that do not contribute to the strength of the component can be eliminated. In this way, the weight of the valve block can be reduced by over 75 %, which saves a significant amount of material (see right-hand image in Figure 4).[15] In spite of this topological optimisation, the additively manufactured valve block has the same strength and density properties as a valve block manufactured by conventional means from solid material. Furthermore, by using AM, the design of the valve block can be adapted to customer requirements without incurring additional costs, since the process does not require a mould.

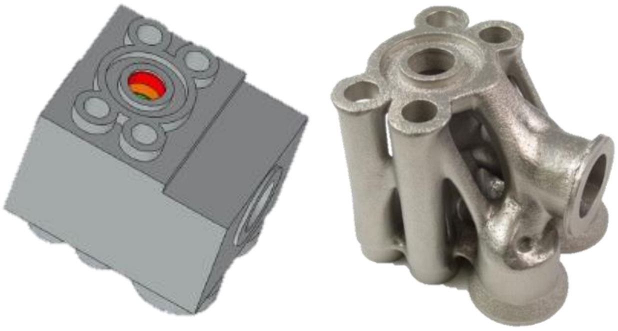

Figure 4: Conventionally manufactured valve block (left) and additively manufactured valve block (right)[16]

Filling valves of filling machines for drinks cans are another example that showcases the potential of AM. Traditionally, can-filling valves are assembled from seven components, e.g. milled parts, seals and screws (see left-hand image in Figure 5). By redesigning the can-filling valve, it can be manufactured additively in one work step (see right-hand image in Figure 5). As a result, the seals and joints are no longer needed. Simplifying the assembly process not only brings manufacturing cost benefits, it also reduces the downtime of the filling plant. The production time can be reduced by up to 90 % to one week thanks to AM.[17] It is therefore possible to manufacture the valve when it is needed, instead of having to store it. At the same time, the can-filling valve is now 35 % lighter and it is also possible to integrate other functions, such as cooling and sensors, if needed.[18]

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[14] [Vtt 17] – VTT Technical Research Centre of Finland Ltd: Case Study: Hydraulic valve block. 2017, p. 2

[15] [Vtt 17] – VTT Technical Research Centre of Finland Ltd: Case Study: Hydraulic valve block. 2017, p. 7

[16] [Vtt 17] – VTT Technical Research Centre of Finland Ltd: Case Study: Hydraulic valve block. 2017, p. 2/9

[17] [Verp 17] – Verpackungsrundschau: Ersatzteile on demand im 3D-Metalldruck, 2017

[18] [Arbe 17] – Arbeitsgemeinschaft Additive Manufacturing: Technology Scout 2017. 2017, p.18

Figure 5: Conventionally manufactured can-filling valve (left) and additively manufactured can-filling valve (right)[19]

Additively manufactured components are also integrated into technologically sophisticated machinery, such as gas turbines. Components installed in gas turbines are exposed to extremely high temperatures, centrifugal forces and speeds.[20] The accordingly stringent mechanical requirements can be met by additively manufactured components. Previously, the combustor of a gas turbine was produced from 13 separate parts, but an AMP can manufacture it in one piece, with a weight reduction of 25 %.

The fuel and air pipes, which were previously located outside the combustor, can be integrated into the combustor housing thanks to AM, which significantly reduces the risk of damage. Furthermore, the lattice structure of the combustor, which saves fuel and increases the efficiency of the turbine, can only be produced by means of AM.[21]

Table 2 summarises the capabilities offered by AM for the fields of application of tool-making (2.1), valve blocks (2.2), can-filling valves (2.3) and gas turbine combustors (2.4).

Table 2: Capabilities of additive manufacturing in the mechanical and plant engineering sector

Evaluation system
🟩 = High realisation potential
▨ = Medium realisation potential
☐ = No realisation potential

			Capabilities of additive manufacturing in industrial application								
Sector	**No.**	**Application example**	Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Lead time reduction
Mechanical and plant engineering sector	2.1	Tool-making	🟩	☐	☐	🟩	☐	🟩	▨	🟩	☐
	2.2	Valve blocks	🟩	☐	▨	☐	🟩	☐	▨	🟩	☐
	2.3	Can-filling valves	🟩	☐	▨	▨	🟩	▨	▨	▨	🟩
	2.4	Gas turbine combustors	🟩	☐	▨	🟩	☐	▨	☐	🟩	🟩

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[19] [Vtt 17] – VTT Technical Research Centre of Finland Ltd: Case Study: Hydraulic valve block. 2017, p. 2ff

[20] [Siem 17a] – Siemens AG: Zahlen und Fakten zum Mehrwert von Additive Manufacturing, 2017

[21] [Siem 17] – Siemens AG: Additive Manufacturing für Gasturbinen, 2017

Examples from the aerospace sector

AM is also used in the aviation industry. The core aim of this sector is to reduce the operating costs of aeroplanes. By reducing the weight of components, fuel consumption can be reduced significantly. For this reason, the lightweight construction opportunities offered by AM are exploited in the aviation industry as a matter of priority.

The cabin bracket shown in Figure 6 is a typical example of this. This cabin bracket is used to secure the crew rest area in long-haul aircraft of the aeroplane manufacturer Airbus.[22] By optimising the topology of the bracket, forces can be absorbed in a targeted manner and, as a result, a more efficient, lightweight structure can be achieved (see the bottom image in Figure 6). The overhauled cabin bracket thus weighs one third less than the conventionally manufactured bracket. Just one kilogram less saves 30 tonnes of kerosene per year.[23] Moreover, the amount of material used is vastly reduced, since the component no longer has to be milled from solid material.

Figure 6: Conventionally manufactured cabin bracket (top) and additively manufactured cabin bracket (bottom)[24]

The reliability of components is especially important in the aviation industry. Unlike vehicles that move on the ground, failure of a component can have devastating consequences in an aeroplane. For this reason, the list of approval requirements is particularly extensive in this sector. Because AMT is a recent development, the quality tests for additively manufactured aircraft components are correspondingly rigorous, and each individual component is subjected to a mechanical properties test. In order to reduce the amount of quality assurance work, active quality checks are increasingly being carried out as early as during the manufacturing process. Cameras monitor the manufacturing process live, producing a 3D map of the component and indicating flaws therein.[25] In future, the use of AM components is expected to gain even more momentum in the aviation industry. Furthermore, as the process stability of

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[22] [Verb 17] – Verband Deutscher Maschinen- und Anlagenbau: AM für die Luftfahrt, 2017

[23] [Scit 16] – Scitec-media: 3D-Druck – Evolution statt Revolution, 2016

[24] [Scit 16] – Scitec-media: 3D-Druck – Evolution statt Revolution, 2016

[25] [Inge 16] – Ingenieur.de: 3D-Drucker aus Franken checkt Haltbarkeit schon beim Drucken, 2016

AMT improves, it will also be possible to additively manufacture safety-critical structural components in addition to components not critical to safety, e.g. cabin brackets.

A double-walled military transport plane pipe elbow integrated into the fuel system is an example of an additively manufactured component for which the highest safety requirements are set (see Figure 7).[26] The pipe elbow qualification phase lasted just under one year and involved proving to the German Federal Aviation Office (Luftfahrt-Bundesamt) and the European Aviation Safety Agency that the additively manufactured components met all requirements for aviation. So that not every single pipe elbow has to be approved one by one in the future, the manufacturers are working on a single qualification for the entire manufacturing process.[27] Conventionally, the pipe elbow is composed of two titanium cast parts that are welded together and then machined. The provisioning process, which involves several suppliers, takes over one year with this method. But with the additive method, the pipe elbow can be manufactured in one piece and the production process – including all subsequent post-processing steps – can be shortened by up to 60 %.[28] Furthermore, the material utilisation rate in the additive pipe elbow variant is significantly higher, since much less material is stripped off during machining. In the conventional process, roughly ten kilograms of material is required for one kilogram of component, whereas additive manufacturing requires just 1.2 kilograms of material.

Figure 7: Additively manufactured pipe elbow[29]

AM is also used in the space industry due to its potential for lightweight construction. One application example from this sector is the antenna arm for a radar satellite. Until now, the antenna arm was always manufactured as a riveted sheet metal structure (see left-hand image in Figure 8). At approximately 40 cm in length, this component almost completely takes up the maximum construction space of the AMPs available on the market. By using AM, the antenna arm can be manufactured in one piece and does not need an additional mounting wall.[30] However, the decisive change with respect to the conventionally manufactured antenna arm is the topological optimisation (see right-hand image in Figure 8).

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[26] [Kons 16] – Konstruktionspraxis.de: Laserschmelzen für den Airbus, 2016

[27] [Flug 16] – Flug Revue: Flugzeugbau - 3D-Druck mit Metallen, 2016

[28] [Vere 17] – Verein Deutscher Ingenieure: Additive Fertigung von Ti-Bauteilen in der Luftfahrt, 2017

[29] [Vere 17] – Verein Deutscher Ingenieure: Additive Fertigung von Ti-Bauteilen in der Luftfahrt, 2017

[30] [Alta 14] – Altair Engineering: From the 3D Printer into Space, 2014

Figure 8: Conventionally manufactured antenna arm (left) and additively manufactured antenna arm (right)[31]

The forces acting on the antenna arm are identified using finite element simulation. Based on this simulation, special topological optimisation software generates a lattice structure in which the superfluous areas of material are weeded out.

The topological optimisation reduces the weight of the component by 50 % while also increasing its rigidity.[32]

Table 3 summarises the capabilities offered by AM for the fields of application of cabin brackets (5.1), pipe elbows (5.2) and antenna holders (5.3).

Table 3: Capabilities of additive manufacturing in the aerospace sector

Evaluation system
■ = High realisation potential
▒ = Medium realisation potential
□ = No realisation potential

			Capabilities of additive manufacturing in industrial application								
Sector	**No.**	**Application example**	Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Lead time reduction
Aerospace sector	5.1	Cabin bracket	▒	□	■	□	■	□	□	■	▒
	5.2	Pipe elbow	■	□	□	□	■	□	□	□	■
	5.3	Antenna arm	■	□	■	□	▒	□	□	▒	□

1.1.2 Comparison of additive manufacturing technologies

There are various methods with different characteristics in the additive manufacturing market. It is hard for newcomers to the market to distinguish between technologies and to know which is best suited for their individual purposes. In the following, the most common plastic- and metal-based additive manufacturing methods that are most promising for the maritime industry will be compared. More detailed information and the technical background behind

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[31] [Berg 16] – Roland Berger: Additive Manufacturing – next generation AMnx. 2016, p. 21/22

[32] [Berg 16] – Roland Berger: Additive Manufacturing – next generation AMnx. 2016, p. 20/22

the operating principles of the individual additive manufacturing processes can be found in the following sources:

Additive manufacturing processes: Additive Manufacturing und 3D-Drucken für Prototyping – Tooling – Produktion (2016, A. Gebhardt)

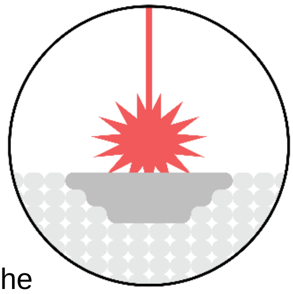
Training courses from the Additive Academy (https://additive-academy.com/)

The 3D Printing Handbook: Technologies, design and applications (2017, B. Redwood; F. Schöffer; B. Garret)

Wohlers Report 2018 (2018, T. Wohlers)

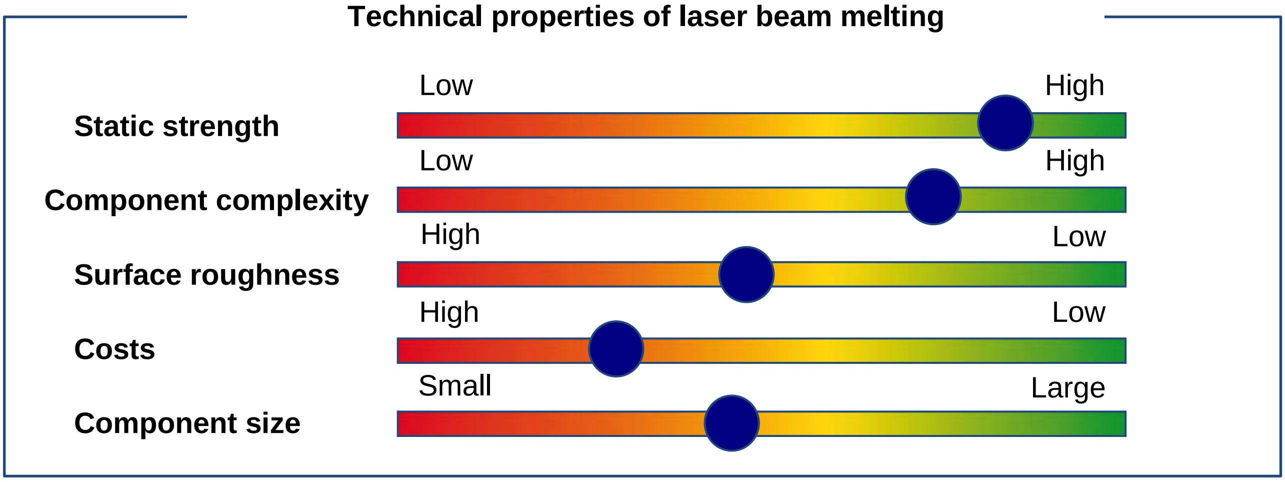
Comparison of metal additive manufacturing processes

Laser beam melting (LBM)



The process of laser beam melting (LBM for short) is the most widely used additive technology for metals. The technology has already proven its worth in many industrial applications. First movers in aviation and medical engineering are already using this method for series production of individually qualified components. Other sectors such as mechanical engineering or the automotive industry are already manufacturing short runs and individual parts using LBM methods. The technology can also be applied to spare parts in the rail vehicle industry, for example. However, in order for it to be more widely used, the component costs in particular must be lowered further and the qualifiability of the process chain must be simplified.[33]

Technical properties of laser beam melting



Advantages and disadvantages of laser beam melting

- Intricate, filigree components with a high level of complexity can be made
- Good material properties
- Large number of available materials
- Exceptionally high technological maturity of all additive (metal) processes
- High potential for development, in particular in terms of cost reduction

- Support structures required for securing the component to the construction platform
- Post-processing work required (surface treatment, heat treatment and removal of support structures)
- High costs on account of low productivity and high machine costs
- Construction size limited on account of construction space and component stresses

Figure 9: Overview of laser beam melting

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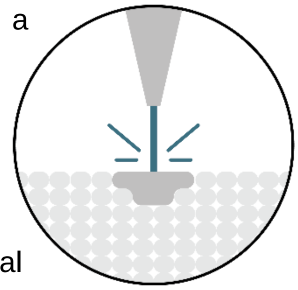
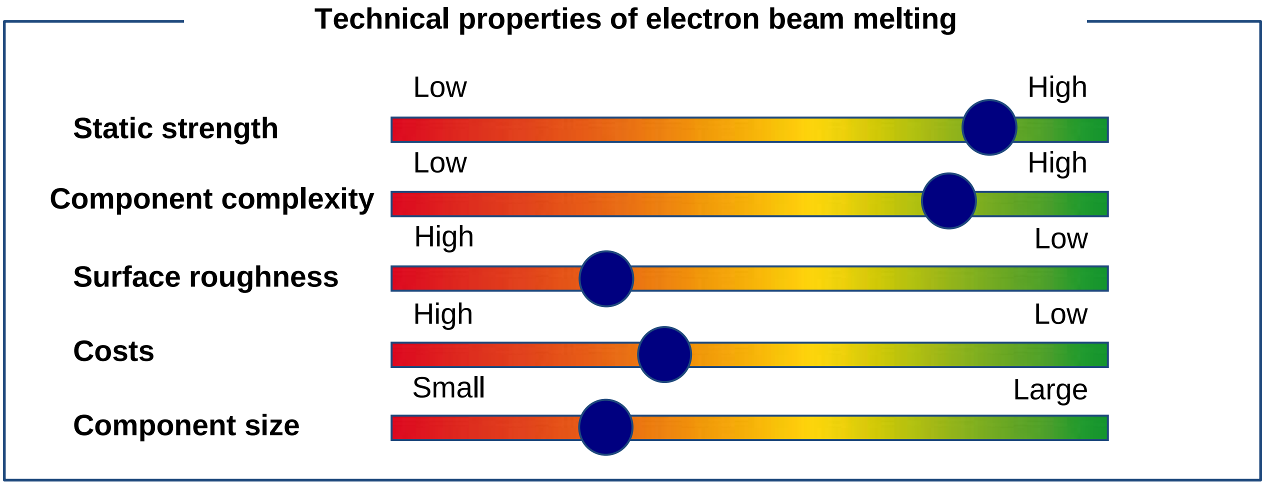
[33] Cf. sources on page 12 for a detailed process description of this AMP

Electron beam melting



The powder-based electron beam melting (EBM for short) method is a complementary procedure to laser beam melting. By guiding the electron beam using coils, a quicker construction speed compared to the LBM process can be achieved. Moreover, there is hardly any residual stress, which is why the method is especially suitable for solid, complex titanium components. Qualified series applications can already be found in aviation (in particular in turbine construction) and medical implants. However, on account of the limited range of materials (titanium and cobalt-chromium), the complex process control and restricted construction space, electron beam melting is only really suitable for niche applications.[34]


Technical properties of electron beam melting

Advantages and disadvantages of electron beam melting

☺

- Fast production speed and high construction space utilisation
- High construction space utilisation possible
- Good material properties (density > 99.9 % possible)
- No component residual stresses
- Solid components possible
- No stress relief annealing required
- Fewer support structures than LBM

☹

- Support structures required for conducting heat away
- Post-processing work required
- Limited component size
- Restricted to titanium and cobalt-chromium alloys
- Surface quality and level of detail lower than in LBM

Figure 10: Overview of electron beam melting

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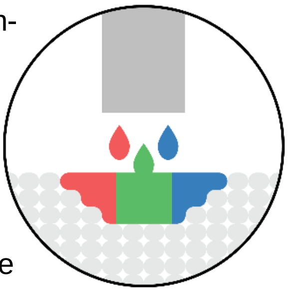
[34] Cf. sources on page 12 for a detailed process description of this AMP

Binder jetting (BJ)



Binder jetting, which is a powder bed method based on sintering technology, is an emerging additive manufacturing process. The productivity of additive manufacturing processes is expected to improve in leaps and bounds over the coming 2 to 5 years thanks to process innovations. Another argument in favour of this process is that cheap sintering powder (MIM) is used as the starting material. Apart from aluminium, which cannot be sintered, many common materials can be used. However, the process is restrictive in terms of the component characteristics and in that sintering is only possible for small components.

Today, binder jetting is primarily used for making tools. Due to its scalability and cost-saving potential, this method is already well-established in the automotive industry for series production.

A special binder jetting process can be used when producing sand-casting moulds measuring up to 4 x 2 x 1 m. Instead of metal, sand is bound using a resin.

Another similar group of technologies are the metal fused deposition methods, in which the metal material is bound to a plastic. These methods offer the advantage that a plant can be acquired at lower prices compared with BJ. The biggest drawbacks are due to the two-stage sintering process, which restricts the component size, and the fact that shrinkage can be even greater (up to 30 %) than in BJ.[35]

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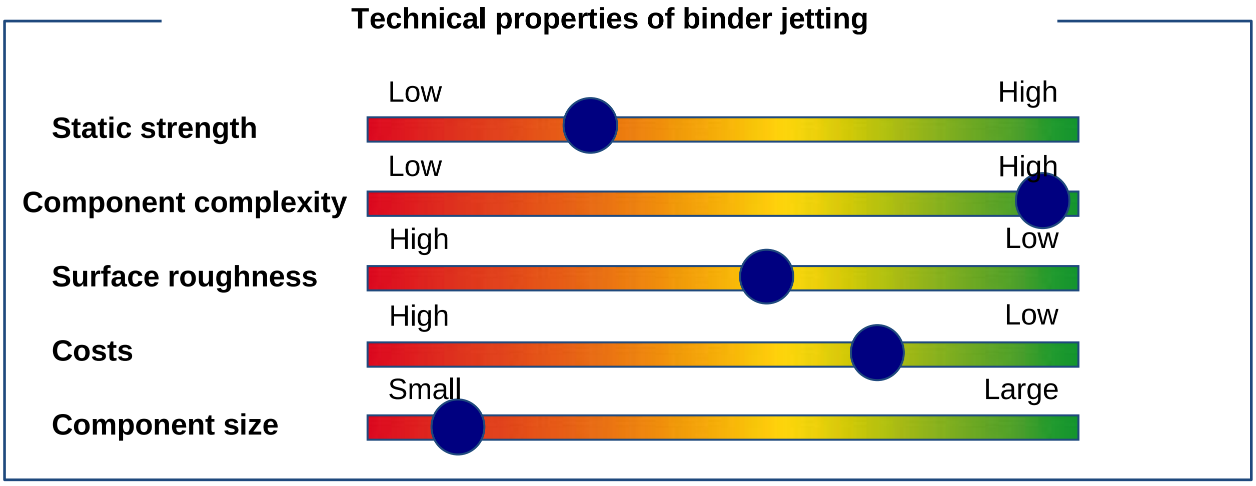
[35] Cf. sources on page 12 for a detailed process description of this AMP



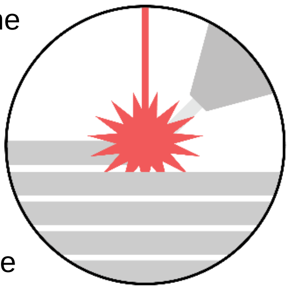
Advantages and disadvantages of binder jetting

- All sinterable materials can potentially be used
- Low material costs
- Scalability of construction space and construction speed
- Low component stresses
- High degree of design freedom
- Possible to produce very fine structures and functions

- Complex post-manufacturing work required
- Mechanical properties comparable to metal injection-moulded components (density > 95 %)
- Sintering restricted to small objects
- Reactive materials are difficult to work with (titanium materials) or impossible to work with (aluminium)
- Dimensional accuracy tricky on account of shrinkage during sintering

Figure 11: Overview of binder jetting

Directed energy deposition (DED)



Directed energy deposition (DED) technologies, which are based on the classic deposition welding technique, complete the set of powder bed methods. They can be used to build very large structures that are only limited by the range of the handling system (robot or gantry). In addition, the component costs are significantly lower and the construction rate is several times faster. The drawbacks of the process lie in the level of component complexity that can be achieved, since overhang support is not conducive to this and the surface generally has to be completely reworked. The variety of materials that can be used is very wide and depends on the DED process used. This method is frequently used with materials that are hard to machine, such as titanium and Inconel, since the DED processes do not require tools and thus offer a cost advantage over CM due to the absence of tool wear.

Classic, established applications include tool-making, coating and repairing worn areas. The first titanium structural components were made by Boeing and Norsk Titanium for use in aviation.

The group of directed energy deposition methods comprises various processes based on different operating principles. Electric arc-based DED processes (WAAM, or Wire Arc Additive Manufacturing) are characterised by low plant costs and quick construction of large, crude structures. Any weldable material can be used as the starting material. However, the use of a wire poses certain problems in terms of the materials that can be used. Brittle materials such as hard metals or Stellite alloys cannot be made into a wire and are therefore unsuitable for the wire-based DED processes.

The applications of laser-based DED processes (LMD, or Laser Metal Deposition) are on a somewhat smaller scale than with electric arc technologies. Therefore, comparatively finer structures can be produced. Furthermore, it is also possible to use powder as the starting material for laser-based DED in addition to the wire. Brittle materials can also be used with the powder-based process and more complex structures can be formed. DMG Mori also offers hybrid systems in which 5-axis milling and laser deposition are integrated into one machine. The advantage of the hybrid method is that the surface can be reworked directly during the construction process and the control mechanism is sophisticated. However, they also incur high plant costs, construction space is limited and the mechanical properties are inferior on account of impurities (swarf).

The following tables give an overview of the differences between the most relevant DED processes. There are also other DED processes, such as friction stir welding and electron beam welding.[36]

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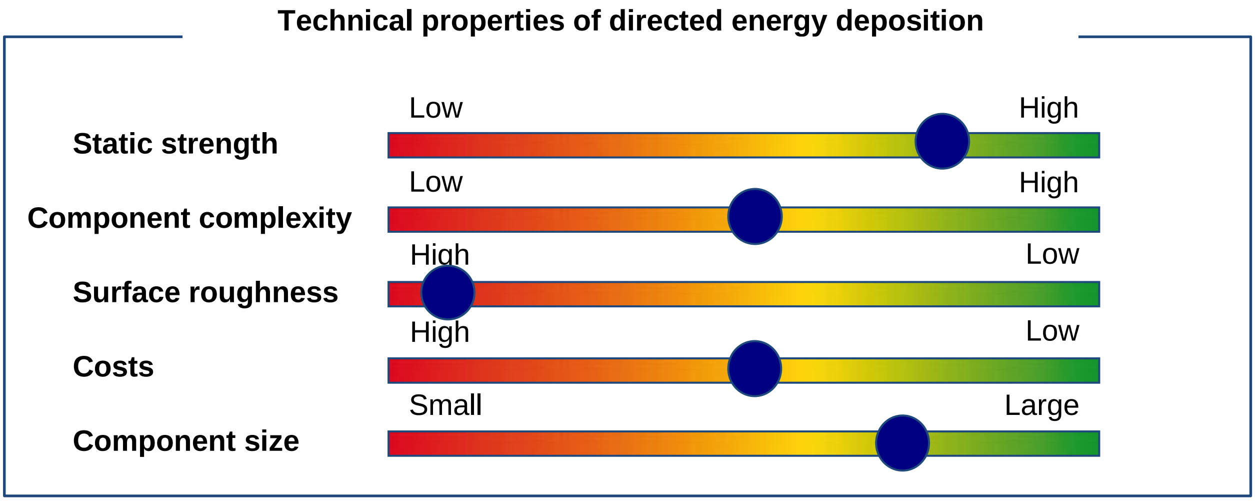
[36] Cf. sources on page 12 for a detailed process description of this AMP



Advantages and disadvantages of directed energy deposition

- High layer thickness allows for quick construction speed
- Scalable construction space allows for large components
- High material variety
- Good mechanical properties
- Construction on existing structures possible

- Low process resolution
- Low surface quality and requires subsequent milling work
- Machining of surface restricts complexity of component
- Lack of standards and low level of industrialisation

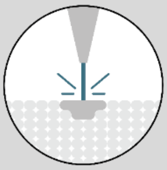
Figure 12: Overview of directed energy deposition

Table 4: Comparison of directed energy deposition processes

Technology	Laser-based DED		Electric arc-based DED with wire	
	With wire	With powder	MAG methods	Plasma methods
Component complexity	-	O	-	-
Industrialisation	-	-	-	+
Component size	+	+	++	++
Selection of materials	+	++	+	+
Material properties	+	+	+	+
Achievable construction rates	O	O	+	+
Material costs	+	O	+	+
Machine costs	O	O	++	+
Process controllability	-	-	O	O
Suitability for repair applications & coating	++	++	++	++
Construction on existing structures	++	++	O	O
Propensity for stresses & warpage	O	O	-	-

++	Very good characteristics
+	Good characteristics
O	Average characteristics
-	Bad characteristics
--	Very bad characteristics

Table 5: Comparison of metal-based additive manufacturing technologies

Technology	Laser beam melting (LBM)	Electron beam melting (EMB)	Binder jetting (BJ)	Directed energy deposition (DED)
				
Static strength	++	++	-	+
Component complexity	++	++	++	O
Surface roughness	O	-	+	--
Costs	-	-	O	O/+
Component size	O	-	--	++

++	Very good characteristics
+	Good characteristics
O	Average characteristics
-	Bad characteristics
--	Very bad characteristics

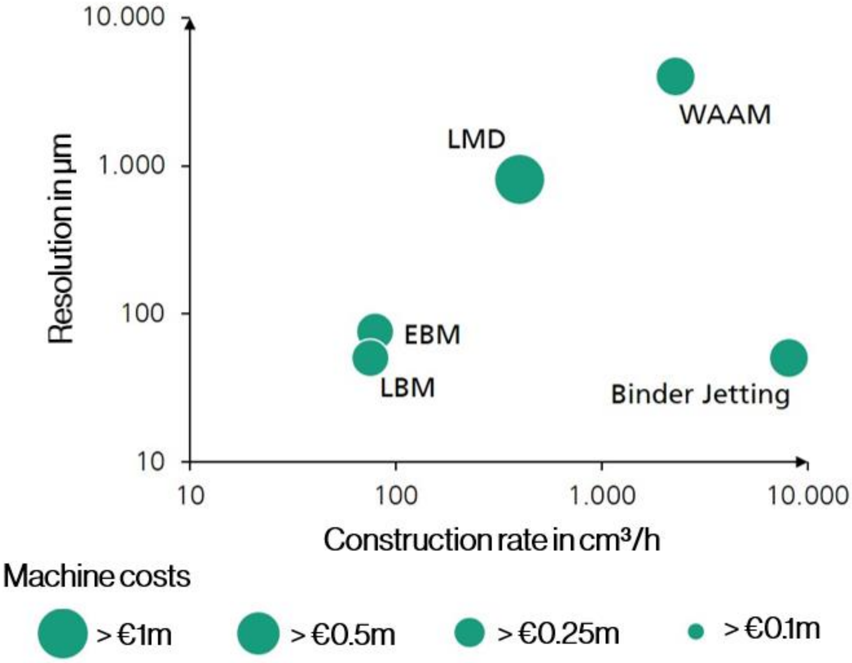
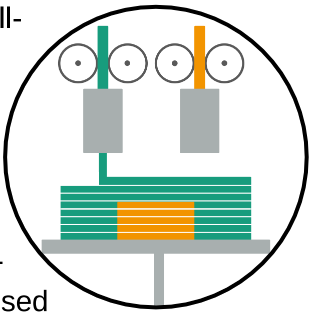


Figure 13: Construction rates, resolution and investment costs of additive manufacturing processes (metal)

Comparison of plastic-based additive manufacturing processes

Fused deposition modelling (FDM)



The nozzle-based method of fused deposition modelling (FDM) is well-known as a hobby and for prototyping. Simple devices can be bought for under €1000, which is why this technology is very well suited for additive manufacturing novices. In industry, FDM is used for larger plastic parts and for manufacturing small series of products in a cost-effective manner. It also offers the advantage of a wide array of possible materials containing high-performance materials (PEK, PEI, PEKK, ASA, PC, PETG). The main drawback of fused deposition modelling is the limited material properties, characterised by pronounced anisotropy.

Thanks to the availability of high-performance polymers such as the temperature-resistant, inflammable PEI, this technology can also be used in critical applications, such as in cabin components. It is therefore already qualified for series application in the aviation sector. There are also diverse applications for fused deposition modelling in all sectors when it comes to the manufacture of prototypes, devices and installation aids.[37]

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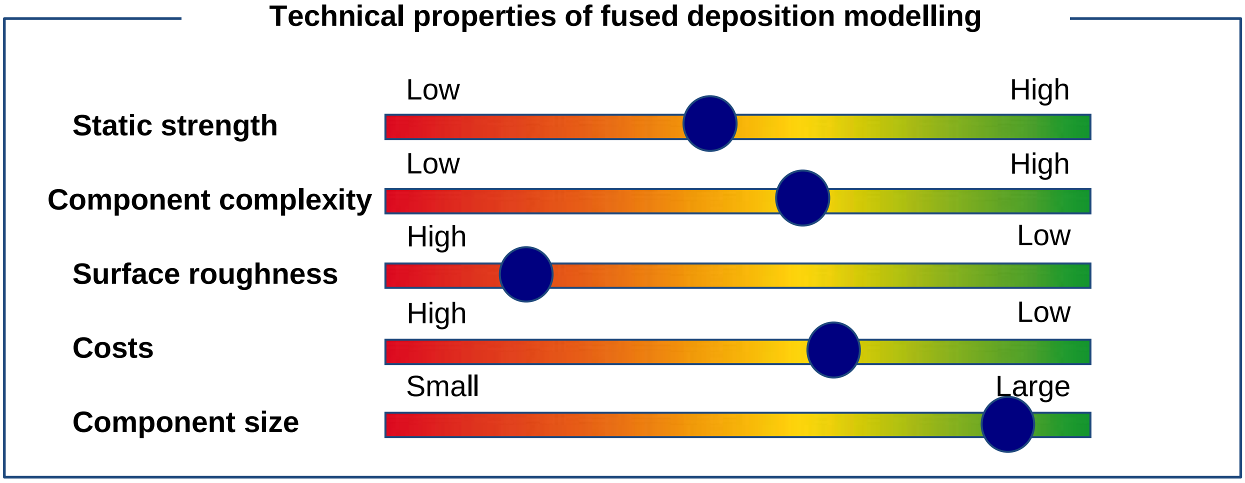
[37] Cf. sources on page 12 for a detailed process description of this AMP



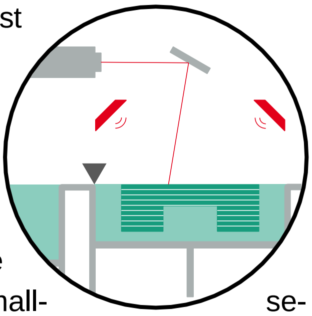
Advantages and disadvantages of fused deposition modelling

- High layer thickness allows for quick construction speed
- Scalable construction space allows for large components
- High material variety
- High-performance materials, e.g. flame-proof materials, can be used
- Low costs for small series and large components

- Low surface quality and requires post-processing work
- Anisotropic strength properties (low strength in direction of construction)
- Mechanical properties do not match those of injection moulding
- Support structures required for overhangs

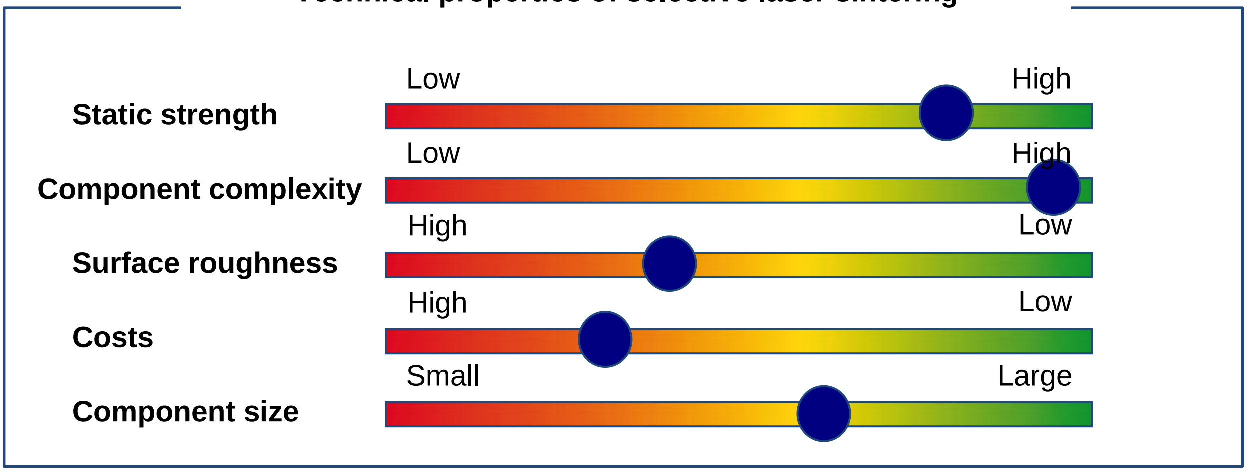
Figure 14: Overview of fused deposition modelling

Selective laser sintering (SLS)



The powder bed-based method of selective laser sintering is the most widely used additive manufacturing technology for plastics. Due to its good mechanical strength values, very high degree of design freedom and the possibility of using high-performance PA12, SLS is suitable for myriad applications. However, more widespread dissemination of the technology is made difficult by the limited selection of materials (PA12, PA11) and the higher costs per unit in large series compared with injection moulding. The method is used in small-series production, e.g. for consumer goods such as glasses. Boeing is also using SLS to manufacture complex ventilation channel structures in one step within short lead times. Thanks to its high degree of flexibility, selective laser sintering is also a popular method for the manufacture of spare parts and in prototyping in all sectors.[38]

Technical properties of selective laser sintering



Advantages and disadvantages of selective laser sintering

- Very high component complexity
- No support structures required
- Good strength properties
- Hardly any anisotropy

- Limited selection of materials (only PA11, PA12 & TPU available, PA6 in development)
- Brittle material
- High plant costs
- Post-processing work required for improving surface quality
- Component warpage possible

Figure 15: Overview of selective laser sintering

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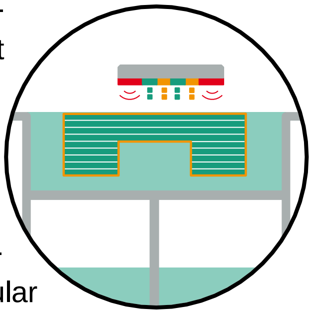
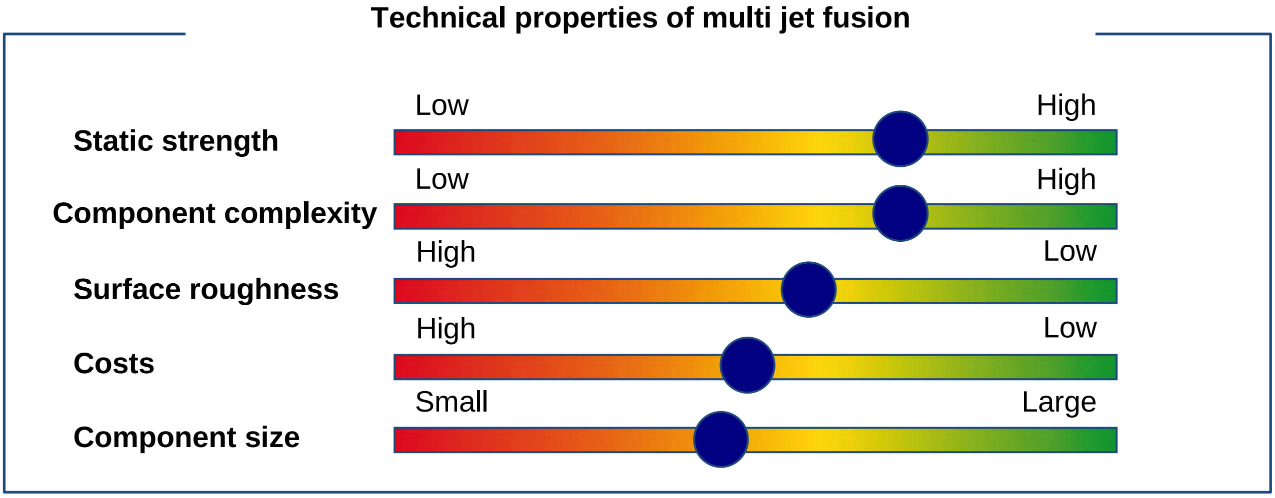
[38] Cf. sources on page 12 for a detailed process description of this AMP

Multi jet fusion (MJF)



The novel multi jet fusion method, which builds on the binder principle, is rising up the ranks in plastic-based additive manufacturing. It is similar to selective laser sintering in terms of the component properties and materials that can be used (PA12, PA11). Its main advantage is that construction speeds are faster and component costs lower. The scalability of the process chain and the "Industry 4.0" capabilities of the method make it suitable for customised production in large quantities. The target group for this process in particular includes sectors with series applications and customisation capabilities, such as the consumer goods sector and the automotive industry.[39]



Advantages and disadvantages of multi jet fusion

- High complexity possible, in particular in filigree components
- No support structures required
- Good mechanical properties achievable
- Faster than SLS
- Process scalable for series production
- Potential for adjusting material properties during process

- Limited selection of materials: only PA12 and PA11 can be used
- Warpage in particular in thick-walled structures
- Slight anisotropy
- Only one supplier (Hewlett Packard) available
- Peripheral equipment required
- Data security (cloud connection to HP)

Figure 16: Overview of multi jet fusion

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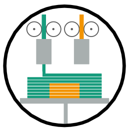
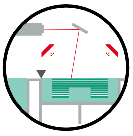
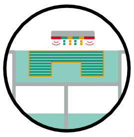
[39] Cf. sources on page 1 for a detailed process description of this AMP

Table 6: Comparison of plastic-based additive manufacturing technologies

Technology	Fused deposition modelling (FDM)	Selective laser sintering (SLS)	Multi jet fusion (MJF)
			
Static strength	O	+	+
Component complexity	O	++	+
Surface roughness	-	O	O
Costs	+	O/-	O
Component size	++	O	O

++	Very good characteristics
+	Good characteristics
O	Average characteristics
-	Bad characteristics
--	Very bad characteristics

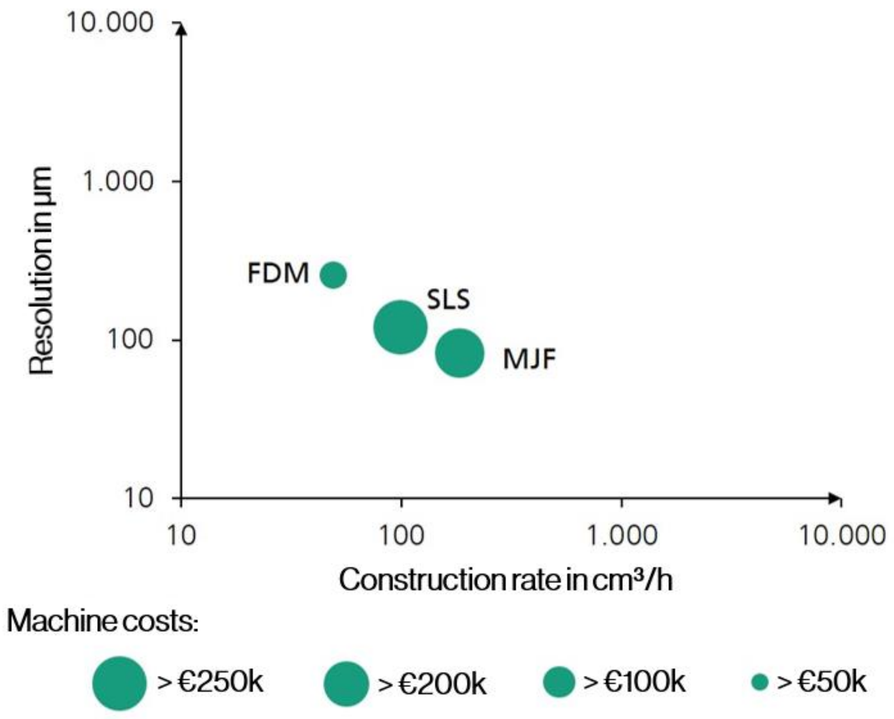


Figure 17: Construction rates, resolution and investment costs of additive manufacturing processes (plastic)

Conclusion

Additive manufacturing techniques involve a broad range of processes that can produce a wide variety of components from myriad materials. Each technology has applications in which they excel. The most widely used and most mature metal-processing technology is laser beam melting, for which numerous series applications have already been tried and tested. Plastic-based additive manufacturing of individual products, small series and spare parts is also well established. The plastic-based methods of fused deposition modelling and selective laser sintering are already economical, industrially mature alternatives to injection moulding.

The laser-based directed energy deposition (DED) technology for repair work and coating applications is already state-of-the-art. On account of their higher productivity and spatial scalability, DED methods have future potential for the additive manufacture of large metal structures, which are prevalent in the maritime sector.

Furthermore, we can expect another innovative leap over the next 2 to 5 years thanks to the use of binder jetting (metal) and multi jet fusion (plastic). These binder-based processes are more scalable than other AMPs and may soon prove more cost-efficient than conventional manufacturing processes for large product quantities.

1.2 Potential applications of additive manufacturing in a maritime context

Before discussing the potential applications of additive manufacturing in the maritime sector, it would first be expedient to categorise the companies in the industry in order to establish a common starting point rather than delve into the intricacies of each individual company. These categories shall then be assigned theoretical application examples that may involve fields of application, specific components, systems or assemblies. These application examples will then be assessed with regard to their realisation potential based on the general capabilities of additive manufacturing in industrial application before being practically verified using individual examples in chapter 1.3.

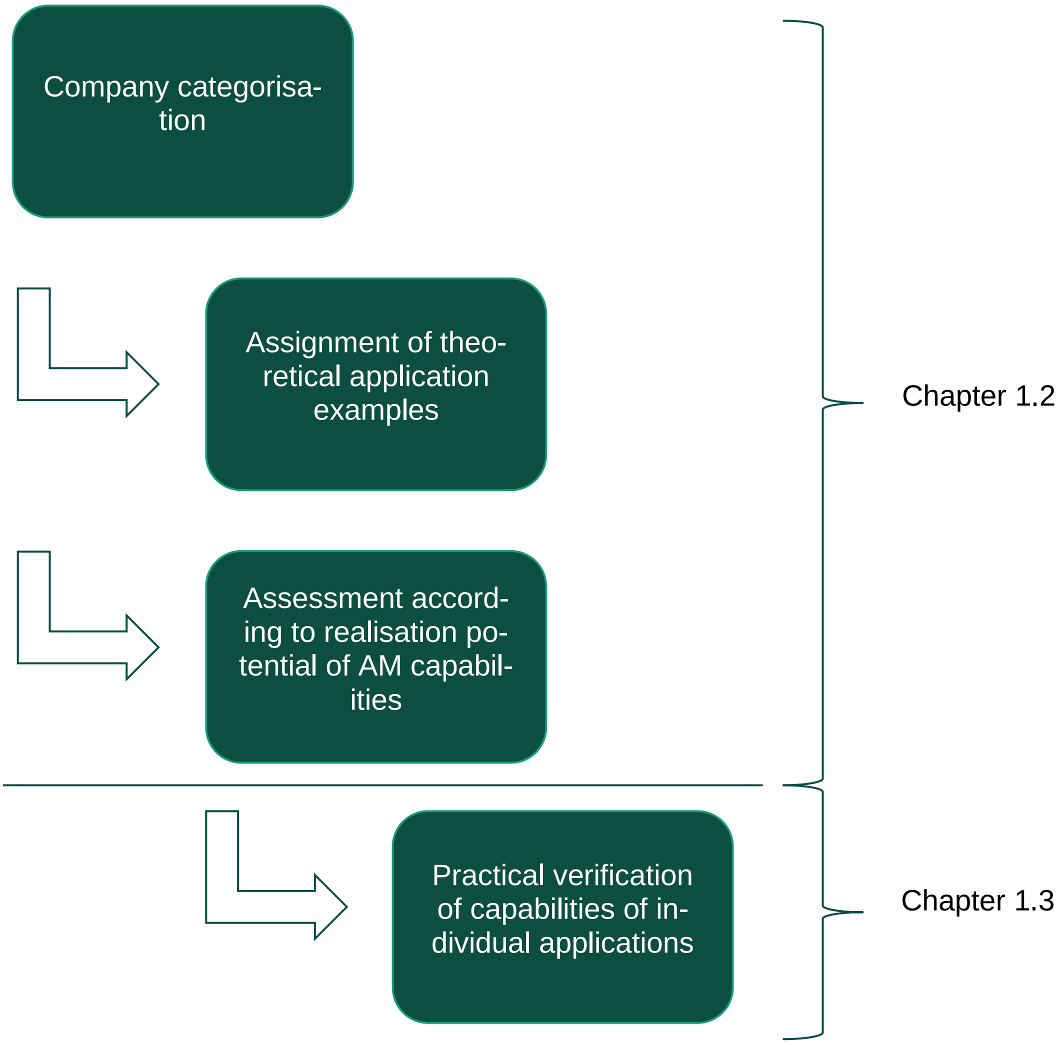


Figure 18: Approach for identifying potential applications of additive manufacturing in a maritime context

1.2.1 Categorisation of all companies in the maritime sector

The effects of additive manufacturing on the special disciplines of the companies operating in the maritime environment are as diverse as the disciplines themselves. Before assessing the various potential applications, the companies within the maritime sector shall first be categorised. This will ensure that companies which cover several subsections of the entire value chain can be assigned to each potential field from Table 7.

Table 7: Categorisation of companies in the maritime sector according to company focus

Company category	Company focus
Shipyards	• Construction, repair and maintenance of ships of all types ○ Boats ○ Cargo ships ○ Passenger ships ○ Leisure craft and yachts ○ Fishing vessels ○ Historic ships ○ Sports craft ○ Offshore service vessels ○ Special and small vessels ○ Warships ○ etc. • Yard-specific facilities and infrastructure ○ Dock facilities ○ Lifting equipment ○ etc. • Large structures for offshore use
Ship propulsion technology and power generation	• Manufacture, repair and maintenance of parts or entire systems in the fields of ○ Engines ○ Transmissions ○ Turbines ○ Turbochargers ○ Shafts ○ Fuel systems ○ Power generators ○ Alternative drives ○ etc.
Manoeuvring and drive systems	• Manufacture, maintenance and repair of ○ Propellers ○ Steering gears ○ Stabilisers ○ Manoeuvring systems ○ etc.

Company category	Company focus
Ship operation facilities	• Companies focusing on the fields of ○ Air-conditioning systems ○ Exhaust gas cleaning ○ Ballast water management ○ Fresh water ○ Recycling ○ Ship kitchens ○ Electrical engineering and electronics ○ Heat exchangers ○ Cooling ○ etc.
Ship chandlers	• Non-manufacturing companies focusing on distribution, wholesale and logistics in the fields of ○ Ship equipment ○ Spare parts ○ etc.
Marine technology	• Construction, maintenance and repair of ○ Offshore technology of all types ○ Wind power ○ Drilling technology ○ Underwater technology ○ etc.
Harbour technology and marinas	• Companies focusing on fields such as ○ Transshipment and transportation systems ○ Quay facilities ○ etc.
Maritime services	• Companies such as ○ Engineering firms ○ Consultancy firms ○ Institutes and research facilities ○ Associations ○ Classification societies ○ etc.

The first category represents all types of **shipyards** involved in building new ships as well as repairing and maintaining existing ships in all fields. Operators and producers of special facilities for shipyard operations (e.g. docks, lifting equipment, etc.) are also included.

The category of **ship propulsion technology and power generation** groups together all companies with a focus on engines and associated systems, such as turbochargers, transmissions, generators, etc. Alternative drive types, e.g. LNG or hybrid drives, also fall under this category.

Building on this, but in a separate category to ship propulsion technology, are companies that deal with the manufacture, repair and maintenance of **manoeuvring and drive systems**. This includes ship propellers and associated components, stabilisers, steering gears, etc.

The category of **ship operation facilities** groups together all companies that manufacture components not used for driving or manoeuvring ships or for generating power and thrust.

This for example includes air-conditioning systems, heat exchangers, cooling systems, but also pumps, fresh water facilities and exhaust gas cleaning systems.

The category of **ship chandlers** covers companies with a focus on wholesale of components from the maritime sector. This includes distribution and logistics for spare parts and ship equipment.

The category of **marine technology** represents companies involved in the fields of offshore technology, wind power, drilling technology and underwater technology, e.g. submarines, pipelines, etc.

The field of **harbour technology and marinas** includes operators of transshipment and transportation systems in harbours, marinas, and quay and harbour facilities. Firms operating close to ports, e.g. oil and gas refineries, bunkering companies, etc., can also be included here.

The category of **maritime services** groups together all service providers that do not fall within the aforementioned categories. This for example includes engineering firms, consultancy firms, institutes, research facilities and associations.

1.2.2 Assignment of theoretical application examples and assessment according to realisation potential of additive manufacturing capabilities

Now that the companies involved in the maritime sector have been categorised, the capabilities of additive manufacturing shall be explored. Table 8 shows a first selection of application examples in the respective categories and assigns AM capabilities to these application examples.

Table 8: Correlation of application examples according to category and additive manufacturing capabilities

Evaluation system
■ = High realisation potential
▨ = Medium realisation potential
□ = No realisation potential

		Capabilities of additive manufacturing in industrial application								
Category	**Application example**	Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Time reduction
All categories	Prototypes	■	■	▨	▨	□	■	■	□	■
	Spare parts and maintenance	□	□	□	□	■	■	▨	□	■
Shipyards	Mould-making	■	▨	□	□	□	▨	■	▨	■
	Superstructures	■	□	■	□	□	□	□	□	□
	Sports and racing craft	■	□	■	▨	□	□	■	□	□
Ship propulsion technology and power generation	Engines	■	□	▨	■	□	□	□	■	□
	Transmissions	■	□	▨	■	□	□	□	■	□
	Turbochargers	■	□	▨	■	□	□	□	■	□
Manoeuvring and drive systems	Drivetrains	■	□	□	▨	□	□	▨	■	□
	Stabilisers	■	▨	□	▨	□	□	▨	■	□
	Ship propellers	■	▨	□	□	■	□	▨	■	□
Ship operation facilities	Oil-water sparators	■	□	□	■	■	□	□	■	□
	Exhaust technology	■	□	□	■	■	□	□	■	□
	Pump technology	■	□	□	■	■	□	□	■	□
	Heat exchangers	■	□	□	■	■	□	▨	■	□
	Hydraulic systems	■	□	□	■	■	□	▨	■	□
	Filter technology	■	□	□	■	■	□	□	■	□
Ship equipment	Yacht accessories	■	■	■	■	□	□	■	■	□
Marine technology	Drilling technology	■	□	□	■	■	▨	□	■	□
	Underwater vessels	■	▨	■	▨	□	▨	□	■	□
	Offshore technology	■	▨	■	□	□	▨	□	□	□
Harbour technology	Customised components	■	■	□	□	□	■	▨	▨	■
Maritime services	Design services	■	■	■	■	■	▨	□	□	□

As some possible applications of additive manufacturing could apply to all categories listed in Table 8, a row that encompasses all categories has been inserted for prototypes, spare parts and maintenance, in order to emphasise these further.

All categories

Evaluation system
■ = High realisation potential
▨ = Medium realisation potential
□ = No realisation potential

		Capabilities of additive manufacturing in industrial application								
Category	**Application example**	Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Time reduction
All categories	Prototypes	■	■	▨	▨	□	■	■	□	■
	Spare parts and maintenance	□	□	□	□	■	■	▨	□	■

In the case of prototyping, the potential of AM lies in particular in constructional freedom and freedom of design. Additive manufacturing can be used, for example, to produce precise, filigree prototypes that very closely resemble the original component. They can be used as display material for customers who want a detailed picture of the product beforehand, which thus allows for freedom of design. Additionally, initial variants can be produced for comparison purposes relatively cheaply and quickly, thus fulfilling the positive aspects of cost reduction, customised production and time reduction.

Another cross-category capability of additive manufacturing can be realised in spare parts manufacture. Because AM makes it possible to manufacture spare parts as and when they are needed, storage space and the associated costs can be saved, which would likely appeal most to ship chandlers. It is also possible to manufacture spare parts that are no longer available on the market, meaning that whole systems do not have to be replaced due to missing parts.

The field of spare parts manufacture also includes the repair and maintenance of defective large structures using laser deposition welding. For example, instead of having to replace whole worn turbine blades, the worn regions can be repaired. This technology therefore harbours potential for ship components such as ship propellers and shafts, as time, money and material can be saved.

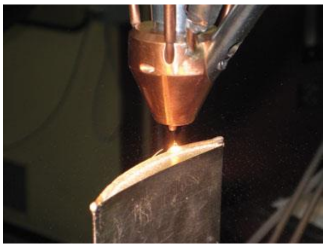


Figure 19: Laser deposition welding of a turbine blade[40]

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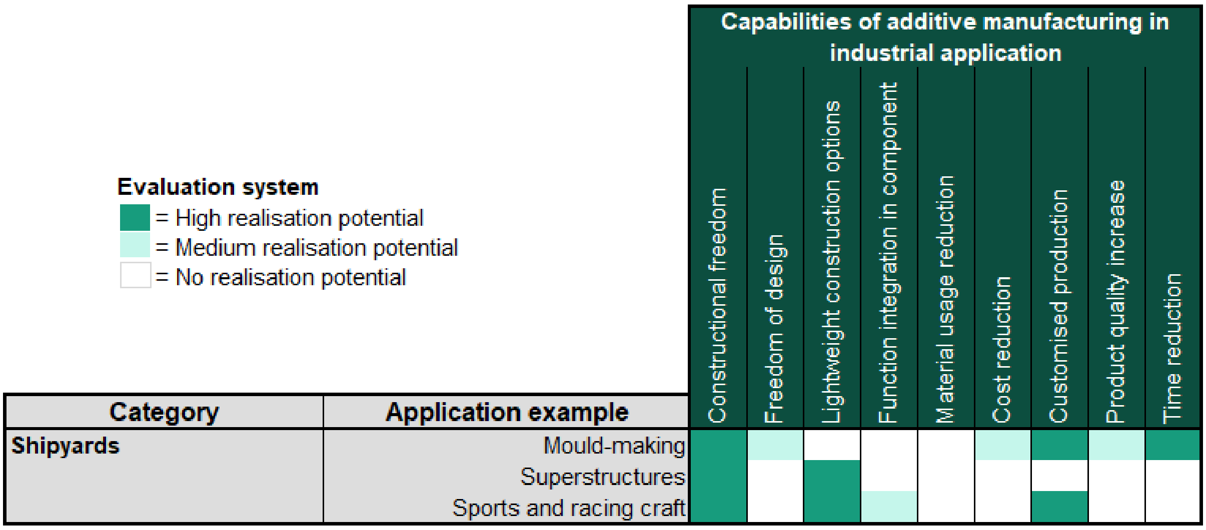
[40] [Indu 19] – Industrial Laser Solutions For Manufacturing, 2019

Shipyards



Evaluation system
🟩 = High realisation potential
▨ = Medium realisation potential
☐ = No realisation potential

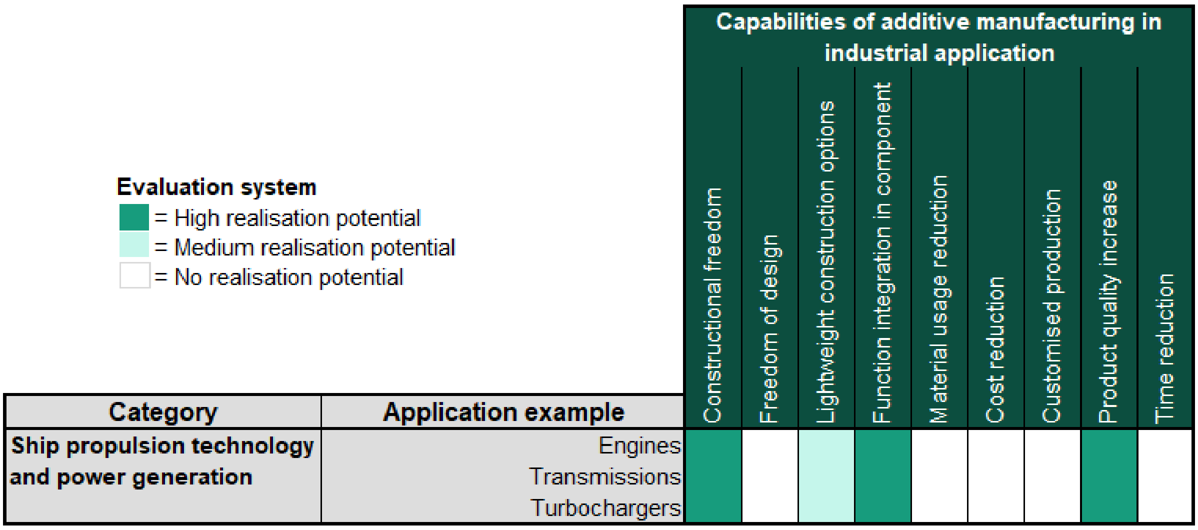
Category	Application example	Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Time reduction
		Capabilities of additive manufacturing in industrial application								
Shipyards	Mould-making	🟩	▨	☐	☐	☐	▨	🟩	▨	🟩
	Superstructures	🟩	☐	🟩	☐	☐	☐	☐	☐	☐
	Sports and racing craft	🟩	☐	🟩	▨	☐	☐	🟩	☐	☐

In the case of shipyards, the capabilities of additive manufacturing technologies must also be distinguished depending on whether a shipyard focuses more on building new ships or repair work. The possibility of additively manufacturing spare parts has already been discussed above and can also be applied to the field of shipyard infrastructure. However, when it comes to building new vessels, the steel or aluminium structure of ships currently does not offer any economically viable starting points for additive manufacturing of construction elements. The costs of large, printed, solid metal structures are still too high due to the unsatisfactory construction rates of the available methods.

However, when it comes to smaller boats, there is much promising potential to be tapped in the field of mould-making. There have already been efforts to additively manufacture entire hulls from plastic or hull moulds for sports yachts, instead of producing them with great manual effort and at vast expense. The boat builder Livrea put AM to the test in 2018 and managed to additively manufacture segments of a boat hull. This paves the way for ever more variant variety, as hull shapes can be produced more cheaply and with shorter life cycles. As a result, the capabilities with highest realisation potential in this category can be expected to be constructional freedom, customised production and time reduction.

Layered construction is also ideal for making lightweight structures. This method is currently used primarily in aviation applications, but it also harbours potential for shipbuilding, as the new construction possibilities offered by this method can be used to make superstructures and upper deck structures lighter so that more cabins can be provided on cruise liners, for example. It can also be applied to sports and racing craft, as they can be further optimised and ships and boats adapted to the corresponding requirements can be produced.

Ship propulsion technology and power generation



Evaluation system
🟩 = High realisation potential
▨ = Medium realisation potential
☐ = No realisation potential

		Capabilities of additive manufacturing in industrial application								
Category	**Application example**	Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Time reduction
Ship propulsion technology and power generation	Engines Transmissions Turbochargers	🟩	☐	▨	🟩	☐	☐	☐	🟩	☐

The greatest potential in the category of ship propulsion technology and generators is offered by the engine and the associated turbocharger. In addition to repair applications using laser deposition welding for large engine pistons, it is also conceivable to combine and print components such as the injection nozzle. The field of special engines, which involves small production runs, is also ripe for additive manufacturing technology. Because applications in this category involve lengthy exposure to high temperatures and forces, the requirements for reliability and service life are particularly stringent. Performance can be enhanced by means of novel construction options or by integrating functions into a single component, for example by combining several function carriers of an assembly into one component.

Figure 20: AM-manufactured jet injection nozzles[41]

The turbocharger also harbours potential in the engine system. It, too, operates in a system characterised by high temperatures and performance requirements. This makes it possible to use the constructional freedom offered by additive manufacturing as a starting point for rethinking the design with regard to function integration, flow optimisation and thus performance enhancement. An example of this is the printed variable turbocharger from Königs-

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[41] [Engi 19] – EngineeringSpot, 2019

egg. The boost pressure is adjusted and optimised depending on the rotational speed of the engine. All components were printed directly, meaning that no assembly was required. In addition to lightweight construction and function integration, other capabilities could also be exploited thanks to the combination of a shorter development cycle and the geometric freedom required for the design.

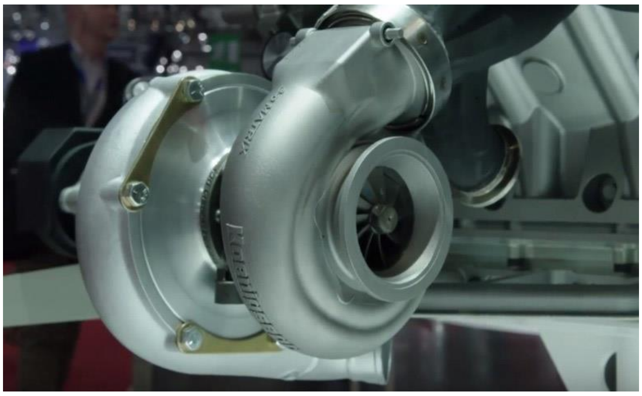

Figure 21: Additively manufactured turbocharger by Königsegg[42]

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[42] [Turb 19] – Turbo Dynamics: Quality without Compromise, 2019

Manoeuvring and drive systems

Evaluation system
■ = High realisation potential
▒ = Medium realisation potential
☐ = No realisation potential

Category	Application example	Capabilities of additive manufacturing in industrial application								
		Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Time reduction
Manoeuvring and drive systems	Drivetrains	■	☐	☐	▒	☐	☐	▒	■	☐
	Stabilisers	■	▒	☐	▒	☐	☐	▒	■	☐
	Ship propellers	■	▒	☐	☐	■	☐	▒	■	☐

Thanks to the high degree of constructional freedom provided by additive manufacturing, parts of the drivetrain can also be optimised and assemblies combined to improve performance. Integrated dampers for the drivetrain that are tailored exactly to the requirements of the ship in question are conceivable here. So, too, are optimised moulds for stabilisers modelled on structures from nature. Similar approaches have already been applied to wings of aircraft.

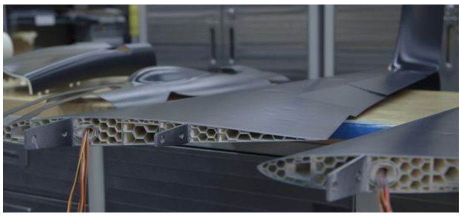

Figure 22: Honeycomb structure of an optimised wing manufactured using AM[43]

Another potential component is the ship propeller. Here there is also plenty of scope for optimising performance and minimising the use of material. In 2017, the first additively manufactured ship propeller was created in a collaborative effort between Rotterdam Additive Manufacturing Lab and Autodesk, then approved and finally presented to the public at the Hannover Messe.

Figure 23: Additively manufactured ship propeller – WAAMpeller[44]

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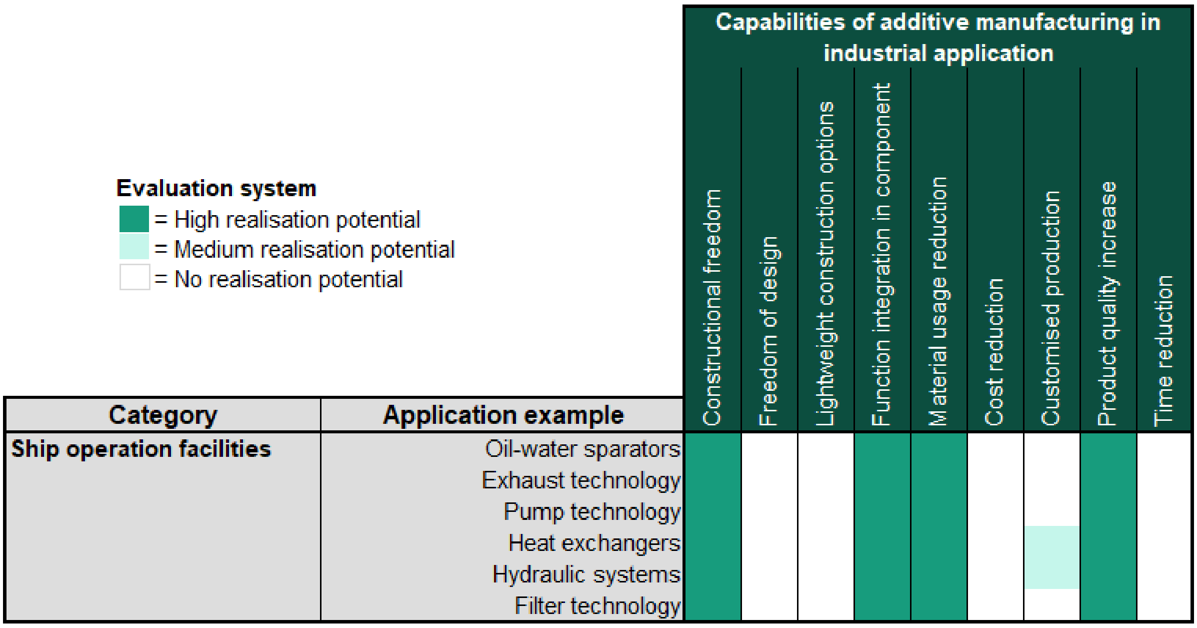
[43] [Form 19] – Form+Werkzeug, 2019

[44] [Raml 19] – Rotterdam Additive Manufacturing Fieldlab, 2019

Ship operation facilities

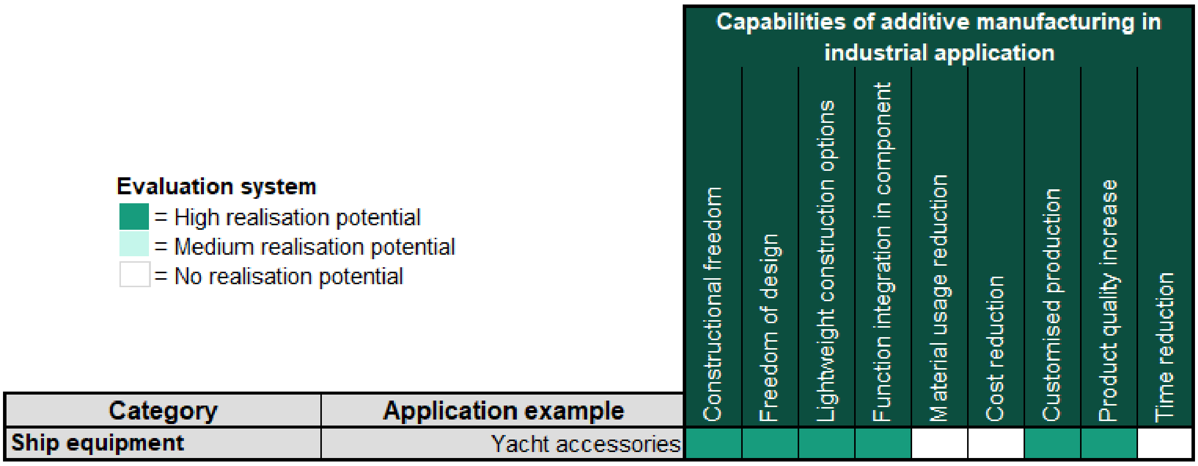


Evaluation system
🟩 = High realisation potential
▨ = Medium realisation potential
☐ = No realisation potential

Category	Application example	Capabilities of additive manufacturing in industrial application								
		Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Time reduction
Ship operation facilities	Oil-water sparators	🟩			🟩	🟩			🟩	
	Exhaust technology	🟩			🟩	🟩			🟩	
	Pump technology	🟩			🟩	🟩			🟩	
	Heat exchangers	🟩			🟩	🟩		▨	🟩	
	Hydraulic systems	🟩			🟩	🟩		▨	🟩	
	Filter technology	🟩			🟩	🟩			🟩	

Another area with application potential in additive manufacturing is that of ship operation facilities. Complex components such as oil-water separators offer potential when it comes to merging assemblies. Furthermore, additive manufacturing can be used for new projects in exhaust technology, for example, to optimise component function. In the case of heat exchangers, there is scope for designing component structures by means of simulation in such a way that optimal transfer is ensured. The first examples of this are already being used in other industries, e.g. in car manufacture.

Ship equipment

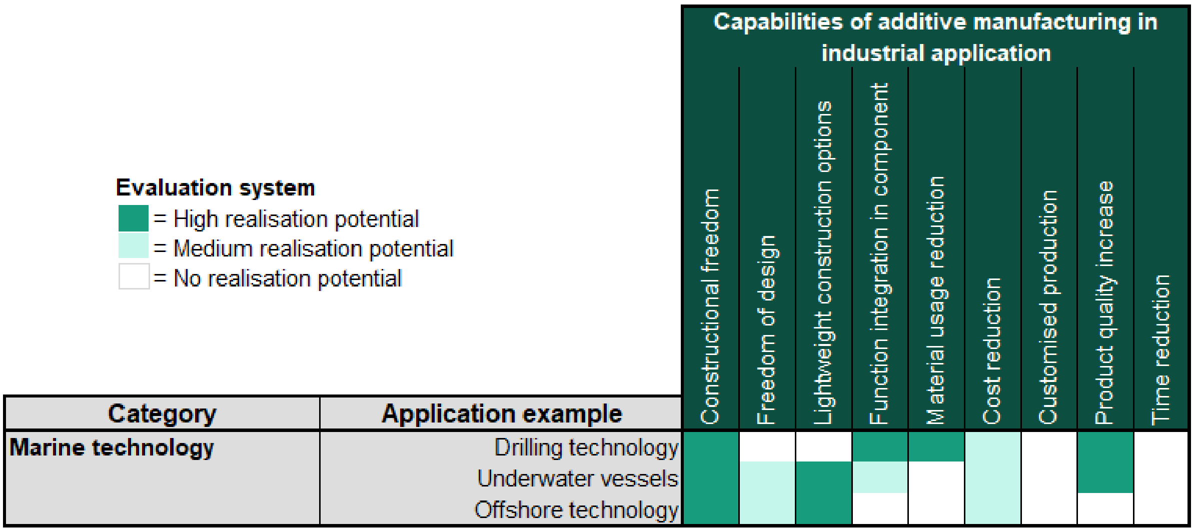


Evaluation system
🟩 = High realisation potential
▨ = Medium realisation potential
☐ = No realisation potential

Category	Application example	Capabilities of additive manufacturing in industrial application								
		Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Time reduction
Ship equipment	Yacht accessories	🟩	🟩	🟩	🟩			🟩	🟩	

For ship chandlers, i.e. in this case predominantly wholesalers and utility companies, additive manufacturing offers the possibility of expanding their product range to additively manufactured components. Customised products that may also boost performance thanks to practical experience from the industry can also be made relatively cheaply thanks to AM. Additive spare parts manufacture is also especially promising for this category, as already explained under “All categories”, since in spite of increasing variant variety, higher utility company availability can be expected.

Marine technology



Evaluation system
■ = High realisation potential
▒ = Medium realisation potential
□ = No realisation potential

		Capabilities of additive manufacturing in industrial application								
Category	**Application example**	Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Time reduction
Marine technology	Drilling technology	■	□	□	■	■	▒	□	■	□
	Underwater vessels	■	▒	■	▒	□	▒	□	■	□
	Offshore technology	■	▒	■	□	□	▒	□	□	□

In the realm of marine technology, application examples can already be found in the fields of drilling technology, underwater vessels and offshore technology.

In drilling technology, materials that have to be especially resistant to abrasion but that also offer the possibility of designing components such that many functions can be provided within a small space are frequently used. Since constructional freedom makes it possible to achieve precisely this function integration, this aspect has high realisation potential. Furthermore, the components no longer require laborious machining work, but rather can be made to closely match the desired final shape. An efficient use of materials, along with an increase in product quality thanks to optimised component design, is also possible. GE Oil & Gas is already tapping this potential in order to additively produce control valves.

With regard to underwater vessels, there is also great potential when it comes to constructional freedom, since function integration can be used to free up more space on-board, where space is limited. In addition, there is potential to make structures more lightweight, thus improving the manoeuvrability of underwater vessels.

Harbour technology and marinas

Evaluation system
🟩 = High realisation potential
▨ = Medium realisation potential
☐ = No realisation potential

		Capabilities of additive manufacturing in industrial application								
Category	**Application example**	Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Time reduction
Harbour technology	Customised components	🟩	🟩	☐	☐	☐	🟩	▨	▨	🟩

In the fields of harbour technology and maritime services, the potential applications of additive manufacturing include not only spare parts manufacture, but also and in particular new projects. These include custom-made products in the port sector that differ from standard components produced in large quantities.

Maritime services

Evaluation system
🟩 = High realisation potential
▨ = Medium realisation potential
☐ = No realisation potential

		Capabilities of additive manufacturing in industrial application								
Category	**Application example**	Constructional freedom	Freedom of design	Lightweight construction options	Function integration in component	Material usage reduction	Cost reduction	Customised production	Product quality increase	Time reduction
Maritime services	Design services	🟩	🟩	🟩	🟩	🟩	▨	☐	☐	☐

Prototypes used by design service providers or port planners, for example, to create a preliminary haptic component in consideration of costs can be produced individually and cost-effectively with additive manufacturing. In addition to prototyping, these design service providers will also increasingly have to grapple with new tools for free-formed surfaces, etc., which will open up new possibilities in terms of component shapes, designs, lightweight construction, function integration and material reduction and thus alter the way they construct things.

1.2.3 Conclusion

Based on the technology overview in chapter 1.1.2 and the application possibilities in chapter 1.1.1, the following recommendations for action can be derived for the maritime industry:

- Find ways to save costs immediately and in the future in plastic-based small-series and spare parts manufacture.

- Consider transitioning to additive mould and tool manufacture in the near future.

- Identify repair applications using DED methods.

- Identify complex metal components in products with high price tolerance, e.g. yachts.

- Evaluate the potential of metal spare parts manufacture now. In doing so, bear in mind that implementation can take from one to three years.

- Additively manufactured components can improve products and reduce costs in the medium-term, in particular in the case of ship aggregates. Identify components this could be applied to now, as implementation time ranges from one to three years.

- Applications involving large structures of several cubic metres (cf. Gefertec[45]) offer very high future potential for the maritime sector, as in the long run it will be possible to manufacture them using directed energy deposition methods. Identify these applications today. Sector- and application-specific materials and process controls may have to be developed.

- It is difficult to estimate when the binder jetting method will be able to be used for series production. The development of this technology should be monitored closely due to its disruptive potential.

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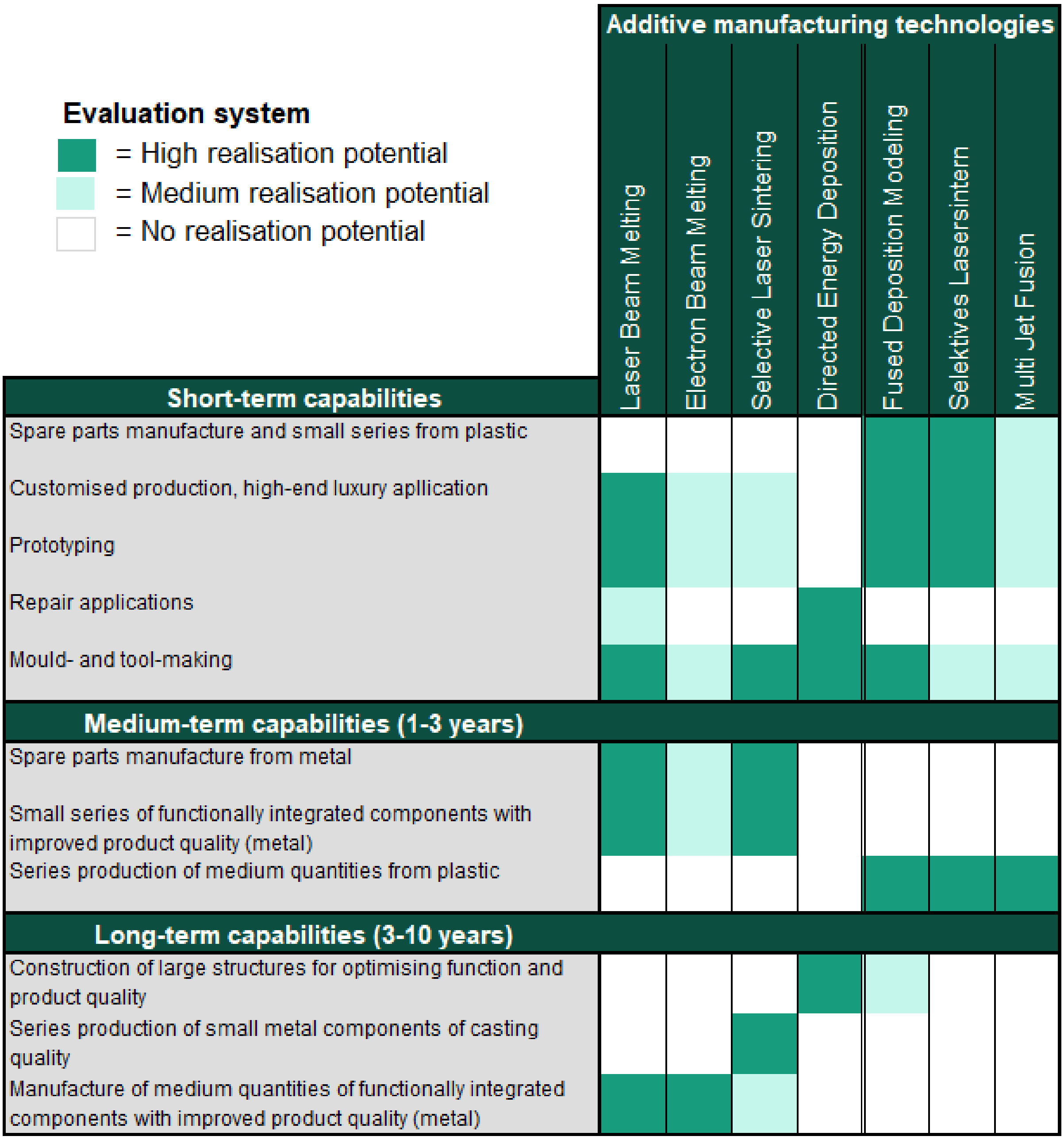
[45] [Gefe 19] – Gefertec: 3D Metal Printer für die industrielle Fertigung, 2019

Companies will have to decide specifically which capabilities and technologies to use and which recommendations to follow. Table 9 is intended as a tool for choosing suitable technologies and potential applications.

Table 9: Recommended AM technology choices in the short-, medium- and long-term



Evaluation system

■ = High realisation potential
▨ = Medium realisation potential
□ = No realisation potential

	Additive manufacturing technologies						
	Laser Beam Melting	Electron Beam Melting	Selective Laser Sintering	Directed Energy Deposition	Fused Deposition Modeling	Selektives Lasersintern	Multi Jet Fusion
Short-term capabilities							
Spare parts manufacture and small series from plastic	□	□	□	□	■	■	▨
Customised production, high-end luxury apllication	■	▨	▨	□	■	■	▨
Prototyping	■	▨	▨	□	■	■	▨
Repair applications	▨	□	□	■	□	□	□
Mould- and tool-making	■	▨	■	■	■	▨	▨
Medium-term capabilities (1-3 years)							
Spare parts manufacture from metal	■	▨	■	□	□	□	□
Small series of functionally integrated components with improved product quality (metal)	■	▨	■	□	□	□	□
Series production of medium quantities from plastic	□	□	□	□	■	■	■
Long-term capabilities (3-10 years)							
Construction of large structures for optimising function and product quality	□	□	□	■	▨	□	□
Series production of small metal components of casting quality	□	□	■	□	□	□	□
Manufacture of medium quantities of functionally integrated components with improved product quality (metal)	■	■	▨	□	□	□	□

1.3 Applying the AM capabilities to companies in the maritime industry

This chapter will demonstrate the potential of the AM capabilities theoretically analysed in chapter 1.2 for the maritime sector using practical analyses of components made by companies in the maritime industry.

1.3.1 Component analysis using the example of the Hamburg Port Authority

The Hamburg Port Authority (HPA) is the owner of the majority of harbour plots in the Hanseatic city of Hamburg and manages them with the help of roughly 1,800 employees. A key task of the HPA is to keep port operations going. In this regard, the so-called Technical Division Maintenance & Operation (TDMO) is entrusted with developing and maintaining the associated infrastructure. As a technical service provider, it ensures proper functioning of the 72-square-kilometre port infrastructure network on a daily basis. The port infrastructure comprises water-based infrastructure, such as quay walls, locks, ferry docks and pontoons, and also land-based infrastructure, such as roads, bridges and railway lines. These water- and land-based structures are generally unique features that often have to last for several decades. The TDMO therefore faces the challenge of having to provide a thoroughly comprehensive and diverse range of spare parts round the clock in order to ensure that port operations run smoothly.

Companies involved in the maritime sector were categorised in chapter 1.2.1. The HPA belongs to the category “Harbour technology and marinas”. For this category, the potential of AM for spare parts manufacture was analysed in particular. Furthermore, AM can be used in this company category to make customised components in a more economical manner than with CM. These two capabilities will now be demonstrated based on four selected application scenarios of the HPA:

Rocking ball bearing

A rocking ball bearing serves as a flexible connection element between a ferry dock pontoon and the associated passenger stairs. The ball of the rocking bearing has a diameter of just under 150 mm and has traditionally been turned from solid stainless steel, as is the associated socket. On account of wear, approximately 5 to 10 of these rocking ball bearings have to be replaced every year. In light of the material, precision, size and strength requirements of this component, LBM is the most suitable AM method for substituting machining production (cf. chapter 1.1.2).

Figure 24: Rocking ball bearing (ball on left and socket on right)[46]

By using additive manufacturing, production costs can be reduced by approximately 10 %. However, the main advantage of switching to AM is that the extra freedom of design at the same cost would create added value when it comes to manually installing the component in its final position on the pontoon. This is because making the component more lightweight by means of hollow inner structures (based on strength simulation) or switching from stainless steel to titanium would reduce the weight of the component by up to 25 %, which would greatly simplify the task of the person who has to install the bulky rocker bearing.

Bearing seal

Roughly 40 to 60 bearing seals have to be replaced every year due to wear. They are used to seal a wide variety of bearing shells in barrages, locks and tiltable bridges and vary in size depending on their intended use. The bearing rings are currently turned from polyethylene by HPA's in-house tool-making department, since in the vast majority of cases they are not standard seals that can be acquired from suppliers.

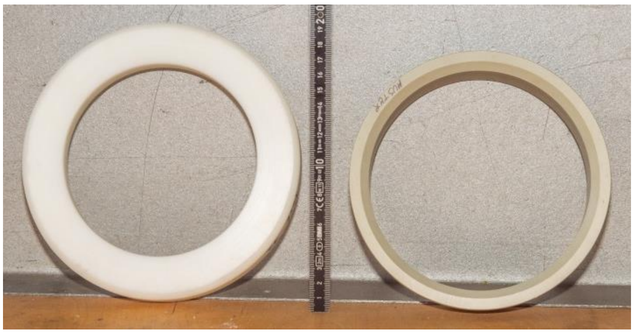


Figure 25: Bearing seal[47]

In light of the strength, size and precision requirements of this component, the SLS method is the natural choice for this application (cf. chapter 1.1.2). However, as things stand, polyethylene cannot be worked using the SLS method, which is why it should be checked in each individual case whether the polyethylene can be substituted for a plastic that is compatible with the process, such as PA12 or TPU, in view of the wear requirements. In this case, the AM capability of cost-effective small-series production comes into play. All that needs to be

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[46] Hamburg Port Authority

[47] Hamburg Port Authority

adjusted in the design process are the characteristic parameters, such as the inner and outer diameter. The corresponding digital data model can then be automatically manufactured by the SLS machine as needed. Conventionally, this would involve NC programming specific to the seal or manual machining. The AM process also allows for greater material efficiency compared with the large volume of swarf produced during conventional turning. It would be possible to reduce the provisioning costs for bearing seals by up to 40 % by switching from CM to AM (if the AM plant is running at full capacity).

Housings and covers

Collision-induced damage to covers and housings of motors of all kinds (e.g. the ventilation hood for protecting the ventilation propeller) has hitherto required the entire motor to be replaced, as covers and housings of this kind cannot be acquired specifically as spare parts. These housings generally have organic free-form surfaces that are very hard to dimension and manufacture in small quantities by conventional means, since they are cast mass products.

Figure 26: Electric motor (ventilation hood on right hand edge of the picture)[48]

Through the combined use of 3D scanning and AM technology, this would be simplified greatly. Using 3D scanning, a digital data model could be created from the original housing in a matter of minutes (if applicable with the approval of the manufacturer), and this model could then be used to manufacture the housing with minor design modifications by means of AM. Therefore, thanks to AM, the company would no longer need to invest in a new motor. Optionally, the additively manufactured replacement housing could also be functionally optimised, for example by substituting plastic for metal in order to increase the strength of the component.

Decoupling spring

In addition to spare parts, HPA’s internal tool-making department also manufactures specialist engineering products such as measuring torpedoes for sounding and measuring services. The manufacturing restrictions of CMPs can hamper the feasibility of such specialist engineering projects. One component of the measuring torpedo is the so-called decoupling spring, which has a narrow connection web just 1 mm across. This poses a challenge for the conventional milling method. With AM, however, shapes of almost any desired complexity can be produced at constant costs, as in the case of this decoupling spring (cf. chapter 1.1.1).

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[48] Hamburg Port Authority

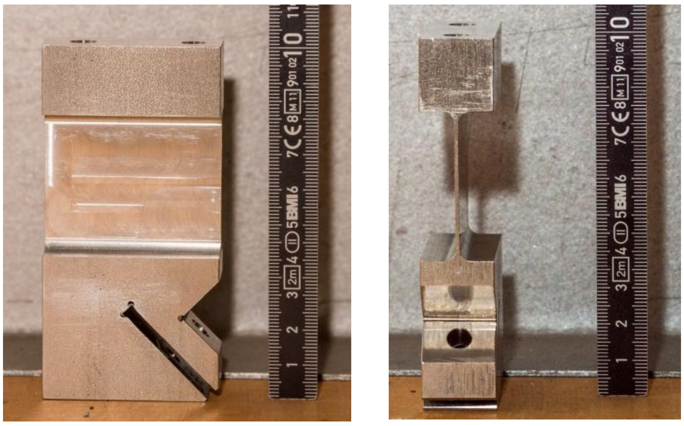

Figure 27: Decoupling spring[49]

Furthermore, switching from CM to AM makes it possible to bypass the laborious process of assembling components with tolerances in the range of 0.1 mm by manufacturing these components as a complete unit. In light of the material, precision, size and strength requirements of this component, LBM is the most suitable AM method for substituting machining production (cf. chapter 1.1.2). The measuring torpedo can be functionally optimised in this way at a marginally lower cost.

1.3.2 Component analysis using the example of German Naval Yards

The shipyard group German Naval Yards employees roughly 1,000 staff in Germany and builds ships at a total of three locations in Schleswig-Holstein. The company, founded in 2009, focuses in particular on the construction and repair of naval ships and mega yachts. At the headquarters of the corporation, German Naval Yards Kiel GmbH, which grew out of the surface-ship construction company HDW (Howaldtswerke-Deutsche Werft), predominantly plans and manufactures complex and highly integrated frigates and corvettes. Lindenau Werft in Kiel also belongs to the group, as does Nobiskrug Werft in Rendsburg.

Unfortunately, the structure of the ships themselves provide little scope for AM technology both in terms of the construction of new ships and in terms of repair work on existing ships. The relatively slow construction rates of additive manufacturing plants, combined with the generally very large construction volumes of the structural elements of the ships, prevent any economically viable application of AM. However, the situation looks different when it comes to shipyard infrastructure. As with the aforementioned scenario for the Hamburg Port Authority, there is often a need for spare parts for shipyard facilities on account of their long service life and duration of use. Because storage space is seldom provided for these components, fast manufacturing solutions are sometimes required. Although these components are often large, the higher costs of additive manufacturing are justified by the quicker availability of the spare parts, which helps to ensure operational readiness of the infrastructure, e.g. crane and dock facilities, and to put it back into operation as quickly as possible. If downtime of the in-

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[49] Hamburg Port Authority

frastructure systems can be reduced by using additively manufactured components, added value that is reflected in the constancy of production or the associated operational processes is created by means of the technology.

Rail tongs

In 2016, rail tongs for the 900-tonne gantry crane of German Naval Yards in Kiel had to be completely overhauled. The rail tongs are used to prevent horizontal movements of the gantry bridge of the crane outside the locked position during lifting or lowering of a load.

Figure 28: 900-tonne gantry crane (left); rail tongs (centre and right)[50]

In this specific case, additive manufacturing could have been used to replace individual components of the rail tongs, such that a potential application of the alternative manufacturing method investigated in this study could hypothetically have been attested for this and similar situations. However, the usefulness of the technology essentially depends on the geometry of the component. In other words, a simple broken bolt (as shown in Figure 28) can always be reproduced faster and more cheaply with conventional methods (i.e. by means of turning). But if a component has free-form surfaces or greater geometric complexity, then the amount of manufacturing effort required increases with conventional technologies, and additive manufacturing becomes comparatively more attractive. Consequently, cast and forged parts are destined to be replaced by AM spare parts, especially if the casting moulds or dies for the original components are no longer available.

Seepage water pump

Another potential application of AM in this context is the seepage water pump shown in Figure 29. It is used in dock seepage water channels when stationary pumps fail. Pumps of this kind are not off-the-shelf products. Depending on the size of the pump, lead times can be several weeks or even months. If a fault occurs with these pumps, additive manufacturing offers the possibility of repairing the pump instead of having to replace the whole component and waiting for its replacement to arrive.

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[50] German Naval Yards Kiel GmbH

Figure 29: Seepage water pump (left); claw coupling (centre); component dimensions (right)[51]

Damaged cast parts of the pump housing or the claw coupling of the pump could be additively manufactured if it is decided that repair work is required. With dimensions smaller than 250 mm, the claw coupling could be printed with a standard system using the powder bed method (LBM). One thing to consider, however, is that CAD models that may have to be generated for example using 3D scanning methods (as described in chapter 1.3.1) are required for additively manufacturing the components.

1.3.3 Component analysis using the example of Becker Marine Systems

Becker Marine Systems GmbH from Hamburg is the world-leading provider of manoeuvring and energy-saving systems for maritime application. The company was founded in 1946 by Willi Becker and currently has around 250 employees. The huge success of the company is based on many pioneering innovations, in particular the invention of the flap rudder. Nearly all types of ship, such as supertankers, container ships, ferries, cruise ships and luxury yachts, are equipped with Becker rudder systems.

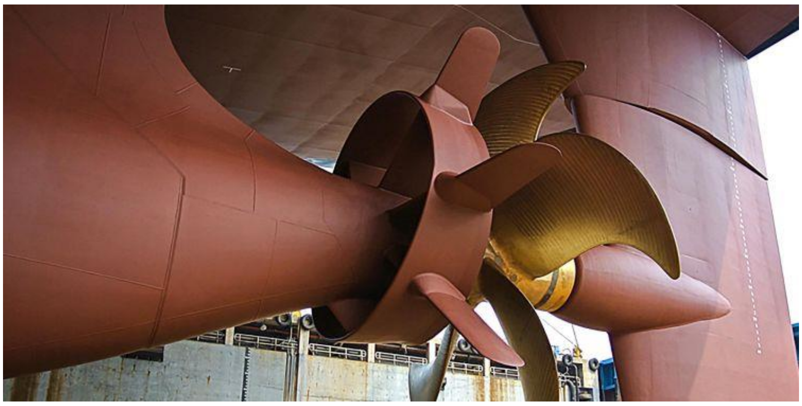

Figure 30: Becker Mewis Duct® Twisted[52]

In 2009, Becker Marine Systems rolled out a new type of nozzle (Becker Mewis Duct®) that can cut fuel consumption in large, slow-moving ships by an average of 6 %, and then three years later they unveiled a version (Becker Mewis Duct® Twisted) for faster ships (cf. Figure

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[51] German Naval Yards Kiel GmbH

[52] Becker Marine Systems GmbH

30). The Mewis nozzle is installed in front of the ship propeller (cf. Figure 31) and generates pre-swirl in the flow, which improves the effectiveness of the propulsion, thus increasing energy efficiency and reducing carbon dioxide emissions. Other products can also be used to cut down on greenhouse gas emissions, for example the floating power supply platform (LNG Hybrid Barge) for cruise ships in the port as well as a compact battery system for maritime use.

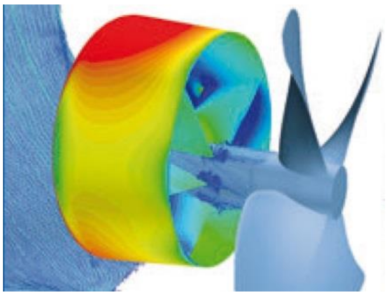

Figure 31: Improving the flow through the ship propeller using the Mewis nozzle[53]

As a particularly progressive company, Becker Marine Systems is also conducting research on substituting steel for fibre composite materials and has for some years also been exploring ways of using additive manufacturing technologies, e.g. for lightweight construction projects.

Becker Mewis Duct®

The Mewis nozzle is fundamentally very well suited for AM methods due to its shape. In the case of conventional manufacture, however, the free-form surfaces of the nozzle require extensive milling operations and therefore necessitate a large amount of programming work and material consumption. However, the idea of printing a Mewis nozzle entirely from metal cannot be made reality for cost reasons. Instead, they came up with the plan of applying for a research project together with the Fraunhofer IAPT and constructing individual components – specifically the fin tips – of the Mewis nozzle from plastic using 3D printing technology. Using plastic instead of metal for additively manufacturing the parts is significantly cheaper and also reduces weight. Moreover, the strength requirements of the fin tips can substantially be met with the use of plastic as well.

The proposal was approved (funded by the Hamburg Investment and Development Bank) and the project was launched in February 2018. The aim is to find a printable material that meets all requirements in order to adapt the printing process to large structures and to optimise the design of the fin tips. Since AM technology is largely free of manufacturing restrictions, the geometry of the fin tips can be individually tailored such that the best possible flow through the ship propeller is achieved.

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[53] Becker Marine Systems GmbH

The Mewis Duct® Twisted version, in particular, stands to benefit from the geometric freedom offered by the new AM method, as the fin tips can easily be twisted to a greater extent. In order to exploit this advantage fully, an interface for securely connecting the plastic components to the metal base structure of the Mewis nozzle must first be developed as one of the key project tasks (cf. Figure 32).

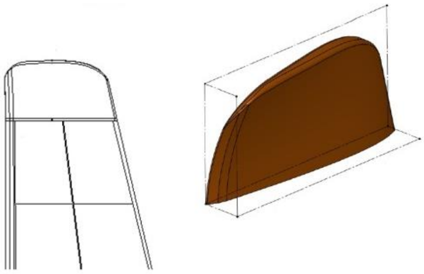

Figure 32: Mewis nozzle fin tip[54]

Aside from improving the efficiency and further saving energy during ship operation, Becker Marine Systems also strives to reduce weight and production costs by way of this research project, with a view to further promoting Mewis nozzles as an original piece for a variety of ships and as a retrofitted piece for existing fleets. The cooperation partners are expecting a full answer to the question of whether the ambitious goals of the project are achievable at the start of 2021.

1.3.4 Component analysis using the example of Gebr. Potthast Kunststoffspritzguss

Gebr. Potthast Kunststoffspritzguss GmbH & Co. KG is an SME with 35 employees based in Dänischenhagen, Rendsburg-Eckernförde. The company history started way back in 1945 with the manufacture of fountain pens, and today they make plastics components using 16 injection moulding machines. Their expertise spans the entire production chain from development to design to manufacture and installation of components. They work with a whole range of plastics, from PP to PEEK, in small as well as large production runs. The two-component injection moulding process is also part of their portfolio, as is the insert method (injecting material around inserts, e.g. made of metal) and individual plastic dyeing.

Tool- and mould-making forms the second branch of the company’s activities. Thanks to their experience in plastics processing, Gebr. Potthast has the expertise required for creating the tools and moulds needed for the injection moulding process. Gebr. Potthast therefore develops and manufactures customised tool solutions that are optimally tailored to the work process and the component to be produced.

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[54] Becker Marine Systems GmbH

Main housing of automatic inflation system for life jackets

Within the maritime sector, Gebr. Potthast has taken on the role of supplying plastics parts for ship equipment. One example of this is the main housing of the automatic inflation system for life jackets (see Figure 33). They make 20,000 such housings every year using the injection moulding process.

Figure 33: Main housing of automatic inflation system for life jackets[55]

Although this housing is relevant to the present analysis and provides scope for the use of AM technologies, the aim is not to print the housing itself from plastics material. The series size of 20,000 units per year would clearly benefit most from the injection moulding method, but the advantages of additive manufacturing can be drawn on for the production of injection moulding tools. The highly complex plastic housing requires injection moulding tools (see Figure 34) that are developed, built, tested and improved over several iteration steps.

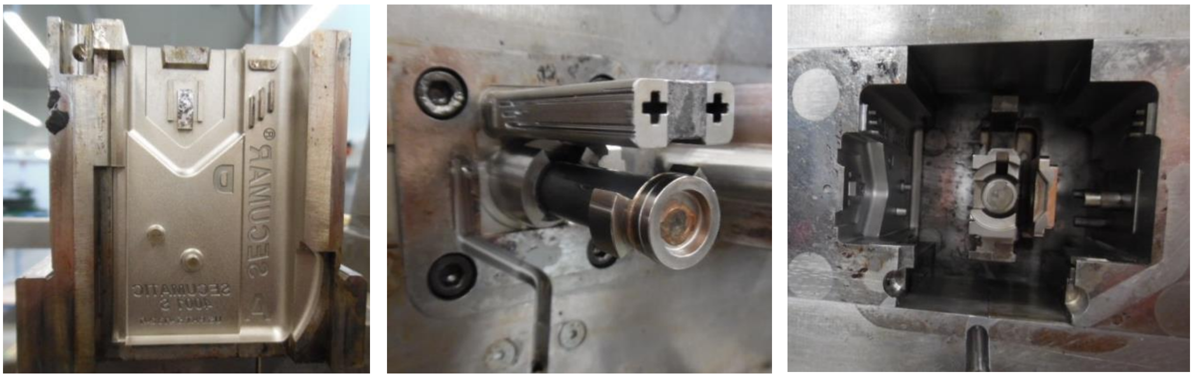

Figure 34: Injection moulding tools for the main housing of the automatic inflation system[56]

The core of the tool (cf. Figure 34: middle image), in particular, poses a significant challenge. It is rotatably mounted so that an undercut can be made in the injection-moulded part, and it must meet high strength requirements. However, the main problem is that of keeping the core at the right temperature, which is why special materials such as copper beryllium or iron-cobalt-nickel alloys are used instead of steel, as they are better at conducting heat, however they are also less strong than steel.

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[55] Gebr. Potthast Kunststoffspritzguss GmbH & Co. KG

[56] Gebr. Potthast Kunststoffspritzguss GmbH & Co. KG

But by applying additive manufacturing and the associated constructional freedom, cooling structures that are close to the surface and thus highly effective can be incorporated into the core in order to achieve targeted temperature management with the aid of a liquid coolant. Quicker cooling of the tool translates into earlier ejection of the injection-moulded component and thus shorter cycle times. The new injection moulding tool could be additively manufactured from metal (e.g. steel or titanium) using the LBM method, and the likely higher production costs for the tool could be amortised by the productivity gain in the injection moulding process and also by the higher component quality as a result of the homogeneous distribution of wall temperatures.

1.3.5 Component analysis using the example of develogic subsea systems

develogic GmbH from Hamburg was founded in 2000 and is an internationally oriented SME that specialises in projects in the field of marine technology. The high-tech company develops and manufactures components for underwater applications, such as oceanographic surveys and offshore raw material extraction. The product portfolio of develogic includes customer-specific end-to-end solutions for data collection, transmission and evaluation in the maritime sector. A typical example of this is underwater acoustic communication systems. Due to the environment in which they are used, the components are subject to stringent requirements in terms of temperature, pressure and seawater resistance, which is reflected in the equally stringent standards of quality for the materials and processes used in the production of these components. develogic therefore has its own manufacturing process that includes not only assembly of electronic modules but also manufacture of mechanical components using modern CNC machining centres.

Numerous starting points have been identified for develogic in the search for potential components for AM methods. The customised manufacturing approach of the company generally involves small batch sizes, which could be made more cost-effective by AM processes. Furthermore, these components conventionally require a great deal of milling work. One possible AM application is the pod drive shown in Figure 35 for the Hamburg Shipbuilding Research Institute (HSVA), where it is to be tested.

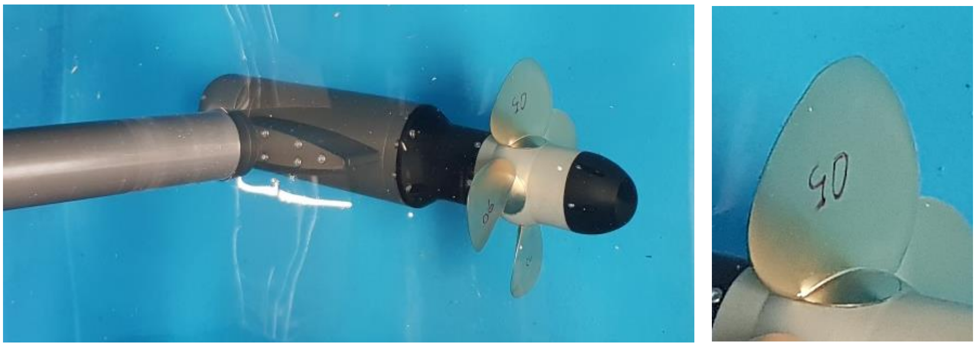

Figure 35: Pod drive unit (left); propeller blade of drive unit (right)[57]

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[57] develogic GmbH

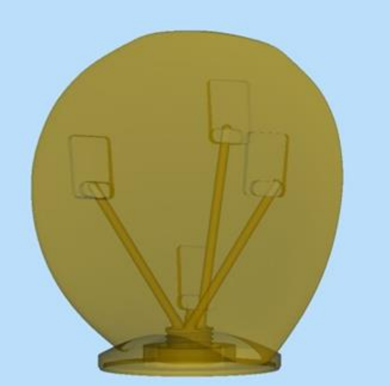
The drive unit consists of a housing and four propeller blades that are screwed to the housing. The theoretical alternative of casting individual components of the pod drive would not be appropriate due to the low unit quantities and high one-off costs for a casting mould. Therefore, a comparison between additive and subtractive (i.e. milling) production would be more useful.

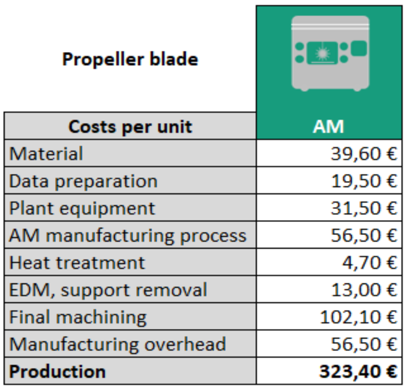
Propeller blade

Every propeller blade offers huge potential for additive manufacturing methods on account of their free-form surfaces. As the test drive is to be monitored metrologically during use, the propeller blades shown here have to be provided with pockets for receiving strain gauges as well as internal channels for feeding in the associated sensor cables (cf. Figure 36). These cut-outs in the component can be made with additive construction of the component, meaning that the subsequent machining steps that are normally required can be dispensed with. The propeller blade is currently milled from brass, and the costs of conventional milling manufacturing are €440 per unit. Titanium (Ti6Al-4V alloy), which comfortably meets the requirements in terms of both strength and corrosion resistance, is recommended for the additive production method in the powder bed.

The IAPT has developed a software tool for estimating the costs of AM components and applied it in this example. The analysis is carried out based on the CAD data of the component as well as other individual criteria specified by the user. Relevant constraints include batch size of the component and AM plant construction rate. The calculation incorporates not only the material and manufacturing costs for the 3D printing, but also the cost rates for data preparation and any required post-processing steps. In the case of the LBM method, these post-processing steps necessarily include separating the components from the construction platform (generally by wire EDM) and removing the support structures from the component. Recommended, optional post-processing steps include heat treatment and radiative surface finishing. Depending on the roughness or tolerance specifications, any functional surfaces on the component may also have to be reworked.

Table 10: AM calculation for the propeller blade (material: titanium; batch size: 4)





Propeller blade	
Costs per unit	**AM**
Material	39,60 €
Data preparation	19,50 €
Plant equipment	31,50 €
AM manufacturing process	56,50 €
Heat treatment	4,70 €
EDM, support removal	13,00 €
Final machining	102,10 €
Manufacturing overhead	56,50 €
Production	**323,40 €**

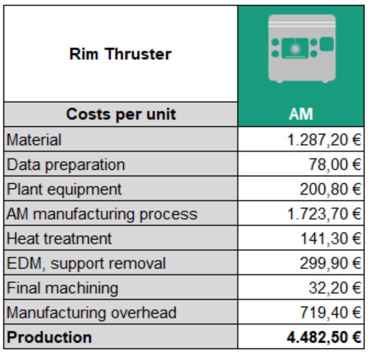
Figure 36: Propeller blade with internal channels[58]

With a total of four propeller blades required for a pod drive unit, the calculation tool estimates the production costs to be €323.40 per unit (cf. Table 10). The optional heat treatment and final machining work are already included in this calculation. Compared with the previously used conventional method, cost savings of 26.5 % can be achieved with AM.

Rim thruster

The situation is similar for the rim thruster shown in Figure 37. The rim thruster is the rotor from a thrust unit for a stabilised drop-off and pick-up system for installing data recording devices on the sea floor. With the help of the drive unit, the drop-off and pick-up system can position itself underwater even in the trickiest flow conditions. This system is currently still in development and will be milled from aluminium in the conventional manner for the trial. The milling time alone takes 28 hours. Then, the component must be hard-anodised in order to increase its abrasion and wear resistance. In other words, a thick, hard coating is applied to the aluminium. This method is very laborious and is therefore not intended as the final solution. The cost of conventional manufacture, including material and coating, is approx. €5,200.

Table 11: AM calculation for the rim thruster (material: titanium; batch size: 1)



Rim Thruster	
Costs per unit	**AM**
Material	1.287,20 €
Data preparation	78,00 €
Plant equipment	200,80 €
AM manufacturing process	1.723,70 €
Heat treatment	141,30 €
EDM, support removal	299,90 €
Final machining	32,20 €
Manufacturing overhead	719,40 €
Production	**4.482,50 €**

Figure 37: Rim thruster[59]

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[58] develogic GmbH

[59] develogic GmbH

With a diameter of approximately 300 mm, the rim thruster can be produced on a medium-sized machine using the AM powder bed process. The crucial advantages would be that, firstly, construction is material-efficient – i.e. no material is unnecessarily removed – and, secondly, titanium can be used, as it is a material that is sufficiently hard and corrosion-resistant even without an additional coating. For the additive manufacture of the rim thruster, the calculation of the IAPT gives the cost items listed individually in Table 11 and a total production cost of €4,482.50 per unit. This is assuming that only one component is manufactured. In this application scenario, the cost advantage of AM over CM can be estimated at 13.8 %.

Support for a piezoceramic half-shell

develogic manufactures the piezoelectric acoustic transducer shown in Figure 38 for underwater communication. This transducer contains an annular aluminium carrier (also shown in the figure) for a piezoceramic half-shell. With conventional machining work included, the cost of production for the carrier is approx. €170 per unit.

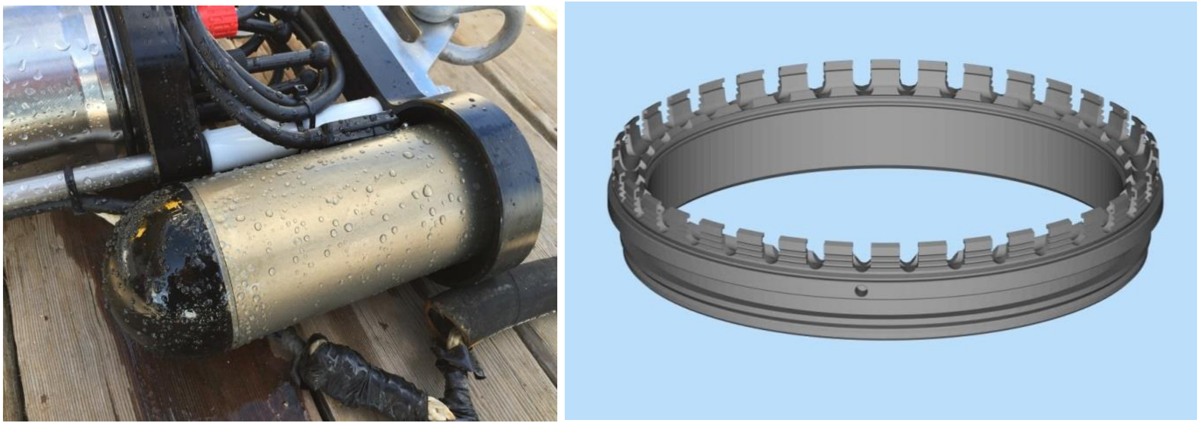

Figure 38: Acoustic transducer for underwater use (left); support for piezoceramics (right)[60]

The piezo carrier also has AM potential, because the milling operations for producing the numerous cut-outs in the component could be omitted if a different manufacturing method were chosen. Admittedly, however, the calculation by the IAPT software tool shows that the production costs for additive manufacturing in this case amount to €213.80, which is roughly 25 % higher than for the conventional variant (cf. Table 12). But this calculation applies to the manufacture of just one component. If the batch size changes, the order-related costs (e.g. data preparation costs) are spread over a larger number of components. This reduces the costs per unit, meaning that a new comparison of additive and conventional manufacturing should be carried out based on batch size.

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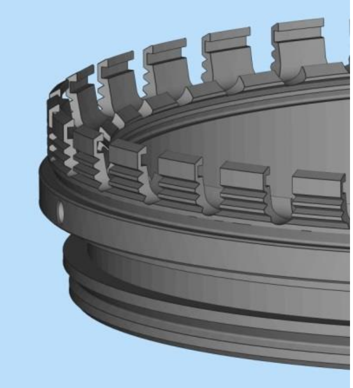
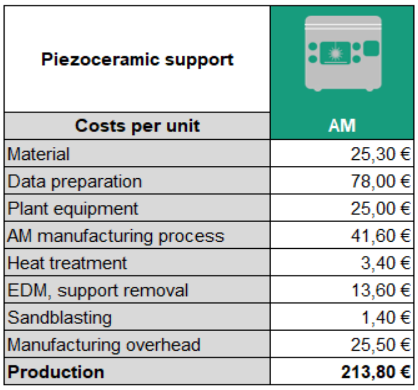
[60] develogic GmbH

Table 12: AM calculation for the piezoceramic support (titanium; batch size: 1)





Piezoceramic support	
Costs per unit	**AM**
Material	25,30 €
Data preparation	78,00 €
Plant equipment	25,00 €
AM manufacturing process	41,60 €
Heat treatment	3,40 €
EDM, support removal	13,60 €
Sandblasting	1,40 €
Manufacturing overhead	25,50 €
Production	**213,80 €**

Figure 39: Support for piezoceramics (magnified)[61]

The two application examples of the propeller blades and rim thruster provide both qualitative and quantitative (IAPT calculation) proof of the advantages of additive manufacturing for a company from the field of marine technology. The high demands placed on the components in terms of the material and the geometric complexity justify the technically and economically sensible use of AM technology for new components.

1.3.6 Component analysis using the example of Reintjes Power Train Solutions

Reintjes GmbH, headquartered in Hamelin, falls within the “Ship propulsion technology” category for the purpose of this study. The medium-sized enterprise with roughly 400 employees specialises in the manufacture of marine transmissions that range in power from 250 to 30,000 kW and that are used for working and special vessels and in particular for fast ferries. Transmissions for gas and steam turbines in the power plant sector have also been part of the product portfolio since 2011. The following Figure 40 shows a selection of various marine transmissions that weigh up to 62 tonnes depending on their power class and that are therefore very large.

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[61] develogic GmbH

Figure 40: Transmission sizes for various types of ship[62]

The housing parts of the transmissions are overwhelmingly manufactured using the casting method. Although production involves very small batch sizes (i.e. more or less single-part manufacture), AM methods are not a viable alternative to casting on account of the size of the transmissions.

Housing parts of auxiliary units

Nevertheless, the housings of auxiliary units, e.g. hydraulic pumps which are flanged to the transmission housing, are significantly smaller and would certainly be printable using the powder bed method. This method is economically feasible if the lead time for the original cast piece is relatively long and if a suitable spare part is urgently required. Figure 41 shows an example of a small cast housing made of aluminium, the maximum length of which is just 440 mm.

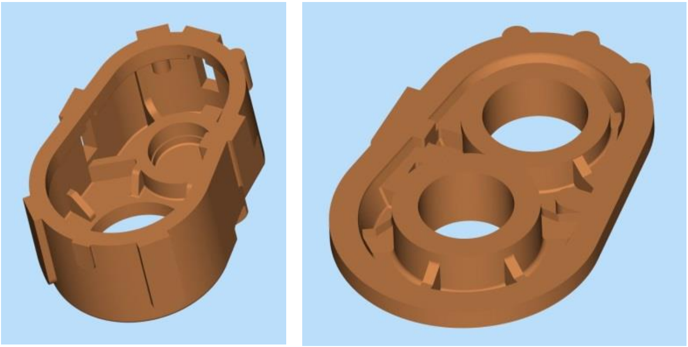

Figure 41: Housing parts for an auxiliary unit[63]

There is further potential for AM in repair applications. Since Reintjes GmbH also offers global servicing for their transmissions, the company is interested in solutions that guarantee quick and easy restoration of a ship’s operability in the event of transmission failure.

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[62] Reintjes GmbH

[63] Reintjes GmbH

Repair of bearing seats and sealing surfaces

If a large housing cast part becomes damaged, e.g. in the region of a bearing seat or a sealing surface, a repair solution would be preferable if this saves effort. In view of the high expected costs of a new part, it would therefore be conceivable to use the LMD method to restore the damaged component to its original condition by means of powder deposition. This measure would be particularly advantageous if the transmission did not have to be removed, but this would require a transportable device for carrying out the LMD process including any required post-processing work on-board the ship.

Figure 42: Damaged pinion shaft (left and centre); surface after repair (right)[64]

This form of repair work is typical in large and therefore expensive transmission shafts. Figure 42 shows the damage caused by wear on the surface of a pinion shaft in the region of the bearing and sealing ring seat. Because the pinion (gearwheel) is inseparably connected to the shaft, the component is of high value, which justifies repair work. The worn regions on the component surface can be filled using the additive method, and then the dimensions of the shaft have to be reduced to the nominal diameter by means of grinding. For this purpose, it is essential for the shaft to be removed from the transmission, as the circularity of the shaft can only be ensured if it is machined on a precise machine tool.

Repair of gearwheels

The gearwheels in ship and power plant transmissions are also subject to wear. With production costs running up to €200,000 per gearwheel, it is worth repairing these large components as a matter of principle (cf. Figure 43). Using AM, it is theoretically possible to mend damaged teeth, but the problem is that of replicating the exact shape of the teeth such that a uniform contact pattern is restored on all tooth flanks after the repair work. Furthermore, the required hardness of the teeth presents a challenge. The entire gearwheel is generally case-hardened. If a tooth is repaired by means of powder deposition, for example, it will lack the required hardness. This means that a suitable material and a means for locally hardening the material (potentially using a laser) would have to be found in order for all teeth to have the same mechanical properties post-repair. AM potential therefore does exist, but in the case of gearwheel repair there is room for technological improvement.

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[64] Reintjes GmbH

Figure 43: Gearwheel with a large diameter

1.3.7 Conclusion of the component analyses

The component analyses carried out for six companies demonstrate that there is wide-ranging application potential for AM technologies in the maritime industry as well. Each of the companies belongs to a different category, so that various technical and commercial interests could be represented in the analysis. As a result, the AM capabilities are also very diverse.

Most of the companies investigated stand to benefit from 3D-printed spare parts. Hamburg Port Authority, German Naval Yards Kiel and Reintjes could reduce lead times if spare parts were made available earlier thanks to AM. These additively manufactured components would generally substitute cast parts, as these can often involve very long lead times, especially if the required casting moulds are not to hand.

If damaged components are too large for an additively manufactured copy, then an AM-based repair solution could be used. The LMD method is especially suitable for increasing the service life of components. Although the component dimensions common in the maritime sector are often an obstacle to the use of AM, they actually work in its favour when it comes to repair applications, as large-scale repair is only really worthwhile for large and expensive components.

Nevertheless, some large components can be produced by means of AM if they are made of plastic (or can be made of plastic). As shown by the example of Becker Marine Systems, AM can improve the performance of the component in question, resulting in optimised flow and/or energy savings. And because material-efficient lightweight structures can be produced, ecological aspects can also be taken into consideration, thus making a substantial contribution to “Green Shipping”.

The field of marine technology offers AM potential that can be directly exploited. Based on a preliminary calculation for the component examples for develogic, additive manufacturing offers cost advantages that can be achieved without having to re-design the components. This means that by optimising components further, e.g. reducing the volume, AM costs can be cut further and the benefits become even more pronounced. The reasons for the above-average suitability of AM for high-tech maritime applications are the high standards set for the components and their comparatively small dimensions.

Tool-making is another area with very high potential for the application of additive manufacturing processes, as this technology and the concomitant constructional freedom offered thereby can be utilised to achieve a decisive functional improvement for injection-moulded tools by providing these tools with internal and near-surface cooling structures. This AM application is not necessarily maritime, but it can serve to benefit the maritime sector by supplying high-quality injection-moulded parts, as in the case of Gebr. Potthast.

Finally, it should be noted at this point that the selection of typically maritime companies investigated here was made in close consultation with the MCN and in consideration of its members. The discussion of AM capabilities in this study should not be interpreted as exhaustive.

2 Identifying AM service providers in Germany along the AM process chain

In this chapter, the focus will be shifted from AM users to AM service providers. This chapter will provide an indication of who companies can turn to for implementing their potential AM applications. The companies based in the catchment area of the Maritimes Cluster Norddeutschland e. V. (MCN) (Lower Saxony, Bremen, Hamburg, Schleswig-Holstein, Mecklenburg-West Pomerania) are indicated by green highlighting in Table 13.

Additive manufacturing is characterised by a unique process chain that is split into three sections: **pre-processing, in-process and post-processing**. The AM service providers will be classified based on these supercategories in order to provide an overview of where the specific strengths of these AM service providers lie.

Table 13 shows a list of AM service providers in Germany. Only companies that offer services relating to AM as one of their core competencies are included in the list. The majority of the companies listed operate as toll manufacturers on the AM market. They therefore provide AMPs and manufacture components to order for their clients (cf. category “In-process” in Table 13). Moreover, there are companies which offer services upstream (pre-processing) or downstream (post-processing) of the actual additive manufacturing process. Apart from that, German plant manufacturers relevant for industrial applications are listed in the table.

The supercategory of pre-processing is divided into a further three categories. Firstly, a **3D scan** can be performed in order to create a digital data model from a physical component. This data model can then be modified and additively manufactured. The category **design & simulation** involves designing a component using CAD software in consideration of the design restrictions typical for AM. This category additionally includes simulation procedures for designing topologically optimised or bionically inspired components, for example. The next step is **data preparation**. Here, the digital data model is subjected to AM-specific manufacturing preparation involving support structures or component orientation. The simulation of the manufacturing process is also counted into this category.

The second supercategory of in-process relates to the **plastic-based (FDM, SLS, BJ) and the metal-based (LBM, EBM, BJ, DED) AMPs** set out in chapter 1.1.2. The **construction materials** are also included in this category and these are subdivided into plastic (filament, powder) and metal (wire, powder).

Post-processing encompasses the post-processing steps carried out on the component following AM. These include **heat treatment**, e.g. hardening or curing, **surface finishing**, e.g. electropolishing, and **post-machining**, e.g. milling.

Following on from the post-processing steps are quality assurance measures on the additively manufactured component. **Quality assurance** comes in a wide variety of forms, from in-process monitoring to optical measurement systems to non-destructive testing of the mechanical component properties. These measures are amalgamated under the umbrella term “quality assurance” for the sake of simplicity.

Other services are also offered. These include target group-oriented training for imparting AM-specific skills, advice for identifying components suitable for AM and strategic guidance on how to grow a business segment in the field of AM, for example.

The companies are classified according to their AM competencies based on the categories explained above. In the classification, a distinction is made between “Product” (blue), “Service” (red) and “Product & service” (beige). If, for example, a toll manufacturer is manufacturing a metal component by means of LBM technology on behalf of a client, this is indicated as “Service” (red) in the table. However, a company that develops and sells LBM plants is marked as “Product” (blue) in the LBM category. In some cases, there are companies that offer both services and products (beige). An example of this may be a software developer that sells software for additively designing a product, but they also offer design services in parallel.

Approximately one quarter of the AM toll manufacturers identified in Germany (just under 40) are headquartered in the catchment area of the MCN. Rolf Lenk Werkzeug- und Maschinenbau GmbH is an AM toll manufacturer that is already a member of the MCN. The mechanical engineering firm based in Ahrensburg near Hamburg offers contract manufacturing of metal components by means of LBM and DED (WAAM). The company also covers the upstream and downstream steps of the AM process chain with complementary services (cf. Table 13).

One of the twelve AM industrial plant manufacturers in Germany is based within the catchment area of the MCN. This plant manufacturer, SLM Solutions Group AG, produces LBM plants at the company headquarters in Lübeck.

Taken together, the companies within the catchment area of the MCN cover almost the entire AM process chain. In the category of pre-processing, 3D scans, design and simulation, and data preparation are entirely carried out by AM toll manufacturers and other service providers – such as engineering firms and development service providers – from Northern Germany. Furthermore, almost all industrially used AM technologies for processing metals and plastics are available within the catchment area of the MCN. Only the more recent technologies of binder jetting and multi jet fusion are not currently available, but even in the rest of Germany there are very few companies that offer them.

When it comes to post-processing, such as heat treatment, surface finishing and post-machining, these are not AM-specific services, but rather processes that are well established in conventional manufacturing. For this reason, it should be assumed that there are many more post-processing service providers in Northern Germany than those listed in the table.

Due to the novelty and unconventionality of AM as a production technology, AM is currently the subject of research and development. The majority of German universities and higher education institutions with a focus on engineering are getting to grips with the process of additive manufacturing. AM is also being taught at these universities.[65] However, only in a very small number of cases is AM a central topic of research and teaching. The Institute for Materials Science and Welding Technology (IWS) of the Hamburg University of Applied Sciences and the Hemholtz-Zentrum Geesthacht Centre for Materials and Coastal Research are the

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[65] [Mars 16] – Marschall: Personal für die additive Fertigung. 2016

two research-oriented members of the MCN with AM competencies. There are also research institutes that have built up AM competencies as their main focus. Laser Zentrum Hannover and the Bremen Institute for Applied Beam Technology are both examples of this in the catchment area of the MCN, and they are researching laser-based AMPs (e.g. LBM and DED). Additionally, the Fraunhofer IFAM in Bremen has acquired competencies in powder bed-based AMPs (e.g. LBM). The German Aerospace Centre is also researching the use of AMPs within the scope of aerospace applications. The Fraunhofer IAPT is the research institute in the catchment of the MCN that is explicitly dealing with the industrial application of additive manufacturing. The institute covers the entire AM process chain with its research activities, from component design to comprehensive in-house plant technology to quality assurance. The institute also offers an extensive training portfolio as well as consultation on the successful implementation of AM in a company. In general, it is possible for industrial companies and research institutes to cooperate with one another within the scope of research projects and thus to make a contribution to the further development and entrenchment of AM.

It should be noted that Table 13 is the result of research and interviews with experts. The list should therefore not be interpreted as exhaustive and merely serves as a guide for identifying AM service providers in Germany.

Table 13: Classifying AM service providers in Germany along the AM process chain (1/ 4)

AM toll manufacturer

🟩 Catchment area of Maritime Cluster Northern Germany e. V.

🟦 Product

🟥 Service

🟫 Service & product

			Pre Processing			In-Process									Post-Processing			Quality assurance	Other services		
						Material		Plant engineering													
Postcode	Company		3D scan	Design & simulation	Data preparation	Polymer	Metal	LBM (Laser Beam Melting)	EBM (Electron Beam Melting)	BJ (Binder Jetting)	DED (Directed Energy Deposition	FDM (Fused Depostion Modeling)	SLS (Selective Laser Sintering)	MJF (Multi Jet Fusion)	Heat treatment	Surface finishing	Post-machining	Quality assurance	Training	Component identification	Strategy consulting
65203	3D ACTIVATION GmbH		🟥	🟥	🟥							🟥	🟥								
07745	3Faktur GmbH		🟥	🟥	🟥									🟥							
65326	Beta LAYOUT GmbH												🟥								
21339	Bionic Production AG	🟩	🟥	🟥	🟥			🟥					🟥		🟥	🟥	🟥	🟥	🟥	🟥	🟥
65830	C.F.K. CNC-Fertigungstechnik Kriftel GmbH				🟥			🟥								🟥	🟥				
89160	CNC-Technik Mack GmbH & Co. KG			🟥	🟥			🟥									🟥	🟥			
04229	Dick & Dick Laser- & Systemtechnik GmbH			🟥	🟥							🟥	🟥	🟥							
79541	Fabb-It UG		🟥	🟥	🟥			🟥		🟥		🟥	🟥								
92331	FIT GmbH				🟥			🟥	🟥	🟥	🟥		🟥		🟥	🟥	🟥				🟥
35216	FKM Sintertechnik GmbH				🟥			🟥					🟥			🟥	🟥	🟥			
79318	Franken Guss GmbH & Co. KG							🟥													
20457	Gall & Seitz Systems GmbH	🟩			🟥						🟥						🟥				
42477	GKN Sinter Metals Engineering GmbH			🟥	🟥					🟥					🟥			🟥			
75443	Hasenauer & Hesser GmbH		🟥	🟥	🟥								🟫			🟫				🟥	
25421	Hoedtke GmbH & Co. KG	🟩			🟥			🟥			🟥	🟥				🟥	🟥				
72072	Jomatik GmbH		🟥	🟥	🟥								🟥			🟥	🟥				
63110	Kegelmann Technik GmbH			🟥	🟥			🟥					🟥			🟥	🟥	🟥			
54578	KerCon GmbH & Co. KG		🟥	🟥	🟥			🟥					🟥								
33649	Krause DiMaTec GmbH	🟩		🟥	🟥			🟥				🟥	🟥			🟥	🟥		🟥	🟥	🟥
56651	LIGHTWAY GmbH & Co. KG		🟥	🟥	🟥			🟥								🟥	🟥	🟥			

Table 13: Classifying AM service providers in Germany along the AM process chain (2/ 4)

AM toll manufacturer

🟩 Catchment area of Maritime Cluster Northern Germany e. V.

🟦 Product

🟥 Service

Service & product

		Pre Processing			In-Process										Post-Processing				Other services		
					Material		Plant engineering														
Postcode	Company	3D scan	Design & simulation	Data preparation	Polymer	Metal	LBM (Laser Beam Melting)	EBM (Electron Beam Melting)	BJ (Binder Jetting)	DED (Directed Energy Deposition	FDM (Fused Depostion Modeling)	SLS (Selective Laser Sintering)	MJF (Multi Jet Fusion)	Heat treatment	Surface finishing	Post-machining	Quality assurance	Training	Component identification	Strategy consulting
🟩 25436	🟩 Loll Feinmechanik GmbH		🟥	🟥			🟥									🟥				
91166	MBFZ toolcraft GmbH	🟥	🟥	🟥			🟥							🟥	🟥	🟥	🟥			
🟩 21079	🟩 MCB Additive Manufacturing GmbH	🟥	🟥	🟥							🟥	🟥			🟥	🟥	🟥			
39179	Oerlikon AM Europe GmbH			🟥		🟦	🟥	🟥				🟥		🟥	🟥	🟥	🟥			
86757	Ohnhäuser GmbH						🟥													
56412	PK Prototyping		🟥	🟥								🟥	🟥							
🟩 32825	🟩 PROTIQ GmbH	🟥	🟥	🟥			🟥				🟥	🟥	🟥		🟥					
85622	Proto Labs GmbH						🟥					🟥	🟥							
🟩 21129	🟩 Quast Praezisionstechnik GmbH		🟥	🟥			🟥				🟥	🟥		🟥		🟥	🟥			
04229	Rapidobject GmbH	🟥	🟥	🟥			🟥				🟥	🟥			🟥	🟥	🟥			
73249	Rioprinto UG		🟥	🟥							🟥	🟥								
96215	Robert Hofmann GmbH		🟥	🟥			🟥								🟥					
🟩 22926	🟩 Rolf Lenk Werkzeug- u. Maschinenbau GmbH	🟥		🟥			🟥			🟥				🟥	🟥	🟥	🟥			
76327	Rosswag GmbH		🟥	🟥			🟥							🟥	🟥	🟥	🟥			
55545	Schneider Prototyping GmbH										🟥	🟥								
98529	Speedpart GmbH	🟥					🟥				🟥	🟥								
16761	trinckle 3D GmbH		🟦								🟥	🟥								
82152	Trindo Digitalmanufaktur GmbH		🟥	🟥			🟥		🟥			🟥	🟥		🟥					
71229	VISIOTECH GmbH	🟥	🟥	🟥							🟥	🟥			🟥					

Table 13: Classifying AM service providers in Germany along the AM process chain (3/ 4)

Other AM service providers

🟩 Catchment area of Maritime Cluster Northern Germany e. V.

🟦 Product

🟥 Service

🟨 Service & product

Postcode	Category	Company	Pre Processing			In-Process									Post-Processing				Other services		
						Material		Plant engineering													
			3D scan	Design & simulation	Data preparation	Polymer	Metal	LBM (Laser Beam Melting)	EBM (Electron Beam Melting)	BJ (Binder Jetting)	DED (Directed Energy Deposition)	FDM (Fused Depostion Modeling)	SLS (Selective Laser Sintering)	MJF (Multi Jet Fusion)	Heat treatment	Surface finishing	Post-machining	**Quality assurance**	Training	Component identification	Strategy consulting
🟩 21107	Engineering firm	FEM-Composites		🟥																	
🟩 24226	Engineering firm	S.M.I.L.E.-FEM GmbH	🟥	🟥																	
38889	Engineering firm	JUREC Juergen Reinemuth Consulting		🟥															🟥	🟥	🟥
🟩 21129	Management consultancy	AM Power		🟥															🟥	🟥	🟥
🟩 20354	Development service provid	H & H GmbH	🟥	🟥	🟥			🟥				🟥	🟥			🟥	🟥	🟥			
84513	Development service provid	FORMRISE GmbH		🟥	🟥								🟥						🟥	🟥	🟥
57368	Development service provid	LMD GmbH Co. KG aA		🟥	🟥								🟥								🟥
🟩 20459	Development service provid	CompriseTec GmbH		🟥	🟥							🟥								🟥	
82024	Development service provid	APWORKS GmbH		🟥	🟥															🟥	
83233	Development service provid	JELL GmbH & Co. KG		🟥	🟥			🟥													
🟩 28359	Software developer	Materialise GmbH	🟥	🟨	🟨			🟥				🟥	🟥	🟥						🟥	
🟩 21079	Software developer	simufact engineering gmbh		🟦																	
10625	Software developer	3YOURMIND GmbH																		🟨	🟥
80333	Technology group	Siemens AG		🟦	🟦												🟦			🟥	🟥
80686	Technical inspection organisatior	TÜV SÜD AG																🟥			
🟩 28865	Mechanical engineering firn	Nabertherm GmbH													🟦						
40237	Raw material supplier	SMS group GmbH		🟥	🟥		🟦	🟥													
40549	Raw material supplier	voestalpine AM Center GmbH					🟦														
06733	Raw material supplier	TLS Technik GmbH & Co.					🟦														
80339	Raw material supplier	H.C. Starck GmbH					🟦														
41189	Raw material supplier	Erasteel GmbH					🟦														
40880	Raw material supplier	Praxair Surface Technologies GmbH					🟦														
81829	Raw material supplier	Poligrat GmbH														🟥	🟥				
🟩 28359	Dental company	BEGO GmbH & Co. KG			🟦	🟦							🟦								
🟩 38122	Optical measuring technolo	GOM GmbH	🟦															🟦			
🟩 22525	Quality assurance	GMA Werkstoffprüfung GmbH																🟥			

Table 13: Classifying AM service providers in Germany along the AM process chain (4/ 4)

AM plant manufacturer

🟩 Catchment area of Maritime Cluster Northern Germany e. V.

🟦 Product

🟥 Service

🟫 Service & product

Postcode	Company	Pre Processing			In-Process									Post-Processing			Quality assurance	Other services		
					Material		Plant engineering													
		3D scan	Design & simulation	Data preparation	Polymer	Metal	LBM (Laser Beam Melting)	EBM (Electron Beam Melting)	BJ (Binder Jetting)	DED (Directed Energy Deposition)	FDM (Fused Depostion Modeling)	SLS (Selective Laser Sintering)	MJF (Multi Jet Fusion)	Heat treatment	Surface finishing	Post-machining		Training	Component identification	Strategy consulting
72290	ARBURG GmbH&Co.KG				🟦						🟦									
10961	BigRep GmbH		🟥		🟦						🟦									
96215	Concept Laser			🟦		🟦	🟦													
33689	DMG Mori AG						🟦			🟦						🟦		🟥	🟥	🟥
82152	EOS GmbH			🟦	🟦	🟦	🟫					🟦						🟥	🟥	🟥
86368	ExOne GmbH	🟥	🟥	🟥					🟫											
12681	Gefertec GmbH					🟦				🟫										
64807	O.R. Laser GmbH						🟦			🟦										
73614	Oskar FRECH GmbH						🟦													
72124	Renishaw GmbH			🟦		🟦	🟦													
23560 🟩	SLM Solutions Group AG			🟦		🟦	🟫													🟥
71254	TRUMPF GmbH + Co. KG					🟦	🟦			🟦										

3 Implementing additive manufacturing in SMEs

This chapter will consider the implementation of additive manufacturing in industrial companies, with a focus on SMEs. As a first step, chapter 3.1 will discuss the challenges of implementing AM in existing conventional manufacturing processes. Then, in chapter 3.2, two best practice examples will be used to show how AM can be implemented successfully in an SME in spite of the previously mentioned challenges.

3.1 Obstacles to AM implementation

Chapter 1.2 discussed the capabilities of AM technologies with regard to product and process improvement in the maritime sector in particular. As it stands, individual companies seeking to implement AM are confronted with a variety of obstacles that slow down this process. Interviews with experts with a background in industrial AM were conducted in order to examine these obstacles more closely. The content of the interviews was then sorted thematically and assigned to various categories.

The introduction of AM largely depends on the components that need to be manufactured. This component-oriented thinking has the result that, firstly, a suitable business case is identified before implementation can begin. This approach differs from conventional technologies. The interplay between know-how, technological, economic and regulatory obstacles – as portrayed in Figure 44 – makes identifying a suitable component difficult. In the following, these four categories shall be examined one-by-one in greater detail.

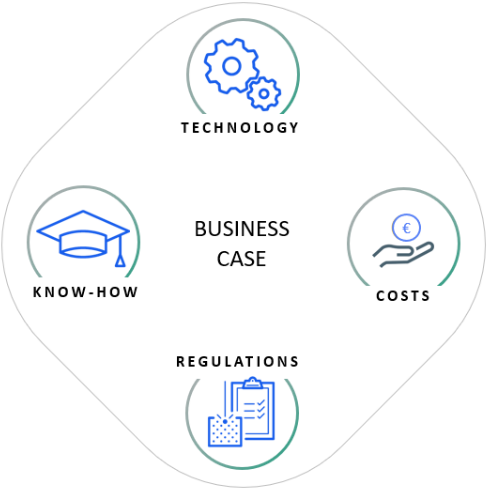

Figure 44: Categories of obstacles to AM implementation

3.1.1 Know-how

The basis for technological implementation is the knowledge of this technology, including all underlying conditions such as regulatory requirements. Here a distinction can be made between basic knowledge and specialist knowledge. Basic knowledge should be understood to mean general knowledge about various additive manufacturing processes, the associated component properties and a basic knowledge of design. The basics are vital for novices so that they can build up the technological understanding required for identifying suitable components. The process of choosing a technology is made harder by the complexity of the various manufacturing technologies (for metals: LBM, EBM, DED, BJ), which all have different characteristics (cf. chapter 1.2.1).

Setting up an AM process chain is a complicated and application-specific process. Therefore, application-specific knowledge must be developed so that process steps such as suitable post-processing measures can be optimally tailored to the application in question. Furthermore, interdependencies can crop up anywhere along the process chain, and these also have to be taken into consideration. Therefore, specialist knowledge of each process step is essential for mastering the entire process chain. This includes knowledge of the legal guidelines with regard to IT rights, plagiarism and copyright.

Knowledge of design is of particular importance, as different construction principles apply in additive manufacturing than in CM. As a general rule, it is advisable to build up knowledge of the capabilities of AM and the basic construction guidelines throughout the entire design and development process. This then makes it possible to identify applications for additive manufacturing as early as during product development and allows the benefits of the design to flow into the construction of the components.

Another challenge for the construction is that competencies in simulation, design and manufacturing preparation are needed during the design process of the additive manufacturing, which necessitates additional qualifications.

Specialists can apply their knowledge of post-processing and quality assurance during production. Because many different disciplines come together here, this knowledge generally cannot be provided by just one person. There are several ways to build knowledge within a company:

a) Knowledge can be built by the company itself.

b) Specialists can be brought in to expand company knowledge. However, there is a lack of qualified AM staff on the job market.

c) External advisers and training programmes can also be used.

As it stands, many designers are inadequately trained. Furthermore, the demand for AM plant operators currently exceeds supply. This is due, inter alia, to the fact that AM was only very recently incorporated as a compulsory element into the corresponding education programmes. It is possible to take AM courses at some universities, including TU Hamburg.

Moreover, AM technology is currently suffering from acceptance problems. This acceptance can be increased by improving knowledge of the field. Through the trust and experience of individual employees, AM acceptance can be passed on to other employees and the company as a whole. In order for implementation to be successful, this trust in the technology must be built up across the entire supply chain and across all disciplines, including with the client or OEMs.

3.1.2 Technology

Current technology also creates obstacles for the implementation of AM. The basis of additive manufacturing is the material used. The standard range of tools available at many companies does not go far enough. Specific tools therefore have to be developed. However, there are already many suppliers who specialise in the development of materials for additive processes.

Construction space is another limitation on component size, depending on the method used. In addition, the orientation within the construction space must be considered, in particular for functional surfaces of the component. The various AM processes are also at different stages of development. For instance, the challenges associated with the thermal process, such as residual stress, may have to be examined more closely. Furthermore, the reproducibility of the process is yet to be homogenised across the board. In addition, the various AM plants differ from one another. In general, many development standards have not yet been definitively established. This is made difficult by the fact that the individual process parameters are hard to reconcile with one another.

When implementing AM, the low surface quality – for example with the EBM or DED method – is a factor to consider. Generally, the need for post-processing work in the form of support structure removal, heat treatment, hot isostatic pressing and surface finishing all involve additional effort. Most service providers therefore offer the entire process chain, including the subsequent post-processing steps (cf. chapter 2).

A mature, automated, online quality assurance system is not currently available. Sensor systems and data evaluation systems are currently being developed for this purpose. To date, no uniform test methodology has been established. As such, it is often necessary to test all additively manufactured components fully.

Safety risks must also be taken into consideration when implementing AM in manufacturing. The powder materials pose a risk, and therefore the entire powder handling process including powder storage and disposal has to be monitored. Furthermore, laser safety officers need to be appointed if lasers are used.

3.1.3 Regulations

There is still some uncertainty when it comes to rules and regulations. Some standards have already been defined for individual sectors such as aerospace by institutions such as the Institute for Innovation and Technology (VDI) or the German Institute for Standardisation (DIN) in order to set some kind of benchmark and provide some clarity. The standards from other industries are partially transferable and serve as a template for developing other standards in other industries.

Approval and certification also differ depending on the industry. For example, the decision as to whether a component or the AM process is qualified differs from industry to industry. In the maritime sector, approval is carried out by the classification society DNV GL, for example. Process certification is also required by OEMs. For example, the entire process chain may have to be certified, as is the case in the automotive industry, for example.

There is a great deal of uncertainty among companies with regard to the legal aspects of contracts, secrecy and liability along the entire process chain. This relates to legal guidelines such as IT rights and plagiarism protection as well as to compatibility with copyright law in the event of changes and modifications to components. Manufacturers and users must be aware of these provisions. Finally, when it comes to CAD data exchange, the procedure is similar for AM technology as for other technologies, for example milling, and therefore any uncertainty can generally be attributed to a lack of experience, trust and acceptance.

3.1.4 Costs

Implementing AM can incur substantial costs in some cases, and particularly for SMEs. The costs differ for one-off expenses such as investment costs and approval costs and for ongoing expenses such as manufacturing costs and the costs of quality management, which are incurred during operation. Due to the complexity of the process chain, the AM cost structure is also complex.

One-off costs are incurred during implementation of AM and during knowledge acquisition – regardless of whether this is through training, consultancy, own experience or recruitment of specialists (see “Know-how” section). If a company decides to make rather than buy a product (make-or-buy decision), then investment costs will be incurred for the plant technology as well as for the follow-up steps and peripheral equipment. Commissioning an AM plant takes time – depending on the technology and the provider – which presents itself as another cost factor. Approval is yet another expense that may be required in a particular sector for OEM qualification.

Production also generates costs. The costs of materials vary significantly for both metals and plastics. Depending on the method used, the material costs play a minor role during implementation of additive manufacturing. The construction rates and productivity are comparatively low in comparison to conventional manufacturing, which results in long process and lead times. Moreover, the entire manufacturing process involves manual effort, since process steps such as post-processing work are still not fully automated.

As part of the quality assurance process, a test using accompanying manufacturing samples is still carried out today, which comes with corresponding testing costs. The test rate can be reduced as experience increases and confidence in the technology improves. Furthermore, in-process monitoring methods are also in development. The high uncertainty with regard to testing can partially be explained by lack of knowledge. System investment costs may also give rise to high hourly machine costs, depending on capacity utilisation. Therefore, sufficiently high system capacity utilisation must be ensured during implementation. Low capacity utilisation of the AM plant should be prevented by identifying suitable applications beforehand.

3.1.5 Business case

The business case emerges clearly as a central element of AM implementation. It is therefore advisable to firstly identify an application and to make a make-or-buy decision on this basis. Developing a suitable business case also makes it possible to account for what at first glance appear to be high production costs. The business case is generally based on significant product added value and an advantage in the life cycle costs (total cost of ownership) of the product. This may be a technical solution, an additional function or customisation. Adequate AM knowledge is required in order to be able to assess such advantages. Therefore, money must firstly be invested in knowledge in order to be able to identify a business case. Decisions such as the selection of a method must be made in advance in order to carry out a comprehensive total cost of ownership calculation. All of the aforementioned challenges associated with the implementation of additive manufacturing show the complexity of the task of drawing up a business case. However, as technology continues to evolve, there is a good chance that the cost structure will improve. The dynamics of the market and the complexity of the technology mean that no fixed implementation strategy is possible for AM. A dynamic business case and agile implementation strategy based on individual applications often result in success. In principle, a company can outsource AM manufacturing to external service providers to start with in order to gain first experiences and reduce investment risks.

3.1.6 Conclusion

The discussion above reveals just how complex AM implementation is, involving several factors including know-how, technology, costs and regulations that have to be taken into consideration in the individual business case.

It is often expedient to start with identifying pilot applications and thus gain initial insights into all four aspects. Furthermore, initial applications and successes will increase user trust in the process and dispel any doubts about AM.

Thanks to the ever growing range of training options and the establishment of standards, the barriers to implementation created by lack of know-how are continuously being knocked down. From a technological point of view, there is a trend towards industrialisation and productivity is improving thanks to closed powder cycles, more lasers and larger construction spaces. The range of available materials is constantly increasing and the material costs are constantly decreasing. As a result, the costs of AM will decrease significantly in the medium term.

The first standards and guidelines for additive manufacturing have been set out and others are being devised. In some industries, such as aerospace and medical technology, the production of components by means of AM has already been approved. By and large, the course for successful implementation of additive manufacturing has been set. Furthermore, significant improvements with regard to the aforementioned implementation obstacles can be expected over the next one to five years.

3.2 Best practice examples for implementing AM in SMEs

This chapter will explain how an SME can successfully implement AM based on two concrete best practice examples. In both cases, a light will be shone on the progression from initial idea to full implementation of series additive manufacturing.

3.2.1 Implementing AM using the example of robomotion GmbH

robomotion GmbH, founded in 2003 and headquartered in Stuttgart, manufactures tailored and automated end-to-end solutions in the field of packaging and production logistics. With the help of over 20 employees, the company develops and builds automated handling systems for clients from the food and plastic industries as well as the pharmaceutical and packaging industries. One of the key challenges with ensuring a reliably functioning handling solution is the gripper technology, as without a firm grip on the product the entire packaging process grinds to a halt. Furthermore, the gripping systems are characterised by a high degree of product individualisation and must always be optimally tailored to the product to be gripped. These gripper requirements are at odds with the manufacturing-specific design restrictions of CM. Consequently, robomotion GmbH started evaluating the potential of AM way back in 2004. The following Table 14 shows a chronological sequence of the activities carried out by robomotion GmbH leading up to successful AM implementation.

Table 14: AM implementation timeline at robomotion GmbH

2003	robotomotion GmbH founded as a manufacturer of tailored and automated end-to-end solutions in the field of packaging and production logistics.
From 2004	Small stereolithography (SLA) desktop printer used to better understand AM technology and to evaluate the potential of AM for the company’s business areas with the help of AM experts from the Fraunhofer IPA as development service provider.
2005	First industrial project with the Fraunhofer IPA as AM development service provider launched to conceive and design additively manufacturable, functionally and weight-optimised grippers by means of SLA.
2006	robomotion GmbH presents the first prototypes of additively manufactured grippers at Automatica in Munich.
From 2006	AM used in product development to reduce costs and shorten provisioning time of prototypes and test grippers.
From 2007	Staff qualification in the field of design for AM to fully exploit AM potential as per the motto “learning by doing” in the absence of corresponding AM training programmes.
2008	Participation in a publicly funded BMBF (German Federal Ministry of Education and Research) research project to investigate material and strength properties of additively manufactured components, e.g. grippers.
2008	Due to the switch from SLA to SLS technology, new plastics could be used (e.g. PA12) and in this way other gripper optimisations (additive integration of pneumatic lines) could be achieved. SLS grippers still made by external service providers (see left-hand image in Figure 45).

2009	Methodology developed for parametrically designing grippers to be manufactured additively in consideration of the additive manufacturing restrictions within the scope of a Master's thesis.
From 2010	Additive gripper components manufactured on an industrial scale by a dedicated toll manufacturer specialising in AM in accordance with standards of quality, as the company's own SLS plant still could not be used to full capacity.
2009	Concept of additively manufacturing grippers implemented in series production within the scope of an automation project including a hybrid finger gripper, the fingers of which were additively manufactured by SLS. Finger grippers running in 3-shift operation (see middle image in Figure 45).
2010	Switch from hybrid gripper concept (conventional mechanics with additive gripper fingers) to a fully additive gripper concept (functionally integrated kinematics) without conventionally manufactured gripper components (see right-hand image in Figure 45).
2011	Introduction of quality assurance measures for additively manufactured gripper components in the form of continuous function tests, for example for functionally integrated film hinges.
2013	Purchase of components from external toll manufacturers supplemented by acquisition of an FDM industrial plant for in-house manufacture of prototypes and gripper components.
2014	Automation project involving over 300 additively manufactured individual parts.
2018	Internal investigation into material and strength properties of additively manufactured gripper components made of PA6 as an additional material option.

Figure 45: Additively manufactured gripper systems[66]

At the start of the implementation procedure, robomotion GmbH took the novel approach of cooperating with external development service providers, e.g. research institutes, in order to build up company expertise. In this way, their employees – who provided assistance in these bilateral development projects and state-funded research projects – were able to gradually acquire AM design and manufacturing process expertise over a period of 15 years. The company had no choice but to take the long-winded approach of building up their knowledge and skills on their own, as at the time there were no training programmes or consultancy ser-

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[66] robomotion GmbH

vices on offer. The AM design process was developed further at robomotion GmbH within the scope of student theses.

AM was initially used in product development to reduce costs and shorten the provisioning time of prototypes and test grippers. But as the expertise of the employees grew, AM was also used to manufacture grippers destined for clients from 2009. However, robomotion GmbH later focused on the development and design of novel gripper systems and outsourced additive production of AM grippers to toll manufacturers, as their own AM plant could not be used to full capacity.

The complexity of the additively manufactured grippers continuously increased over time. At the start, only individual gripper components were produced using the stereolithography method. But once the company switched to the SLS method, it became possible to additively manufacture not only rigid components but also elastic gripper systems with integrated functionalities thanks to the wider range of available materials. The importance of AM to the manufacture of grippers has grown continuously up to this day and, in 2014, a single automation project produced over 300 additively manufactured individual parts. Since then, robomotion GmbH has devised quality assurance measures for checking the service life requirements of AM components. In addition, new plastics for additively manufacturing grippers are being researched at the company in order to optimise the performance of the gripper systems into the future and to implement innovative gripper applications.

3.2.2 Implementing AM using the example of JELL GmbH & Co. KG

JELL GmbH & Co. KG was founded in 1987 as Gerhard Jell Werkzeugkonstrukteur. The company is headquartered in Bernau am Chiemsee and currently employees roughly 20 staff. The company initially focused on design services for tool-making and in particular mould-making.

The development and design of injection moulding tools is one of the core services offered by JELL. These injection moulding tools pose the challenge of conformal and homogeneous temperature control and cooling of the tools. Conventional manufacturing processes run up against their limits here. They restrict the freedom of design, and often temperature-control or cooling channels, for example, can only be drilled. But thanks to the freedom of design offered by AM over CM, the arrangement of these channels can be optimised. In this way, injection moulding cycle times can be reduced and the costs per unit of the injection-moulded parts can be lowered (cf. chapter 1.1.1). JELL recognised this potential in 2008 and immediately came up with idea of incorporating AM into the design of injection moulding tools in the future. Firstly, a decision was made for a suitable AM method. In light of the material, precision, size and strength requirements of the mould inserts, LBM emerged as the most suitable AM method for substituting CM (cf. chapter 1.1.2). In order to give the company’s own developers and designers more freedom of design, but also to familiarise them with the process restrictions of AM, JELL invested in an LBM plant in 2009. It was a starter plant from the lower price bracket that could only manufacture small components (construction space of 90x90x200mm).

During the following two years, the strategic focus still had not shifted to producing components with their own AM plant with a view to making a profit, but rather was on training employees in design and process understanding for AM and fostering acceptance of this new manufacturing technology within the company. The employees' first steps into AM technology were aided by the fact that new designs could be tested quickly on their own plant. Furthermore, by getting plenty of practice at using the in-house plant, the designers were able to acquire a deeper understanding of the metal-based AM process and the associated construction challenges. Around 2010, there were still no service providers who were offering training programmes or consultancy services for AM, which is why JELL developed its own internal training concept in order to qualify new employees in the field of AM in a systematic and time-efficient manner.

Figure 46: Injection moulding mould insert with additively manufactured cooling channels[67]

If injection moulding tools had to be additively manufactured for projects but their dimensions exceeded the maximum construction space of the company's LBM plant or the material was different to the standard stainless steel alloy used, JELL outsourced these manufacturing tasks to external toll manufacturers. With an ever growing number of projects in which AM components were being used, they had to continuously expand their LBM facilities. Today, they have a total of four LBM industrial plants for metal manufacture as well as one FDM plant for prototyping. By virtue of their ever growing AM production capacity, JELL has managed to reduce their dependence on AM toll manufacturers and can guarantee their clients consistent component quality. In order to be able to use their AM plants to full capacity at all times, JELL has also expanded its service portfolio. They no longer merely reach out to clients who want tools and moulds to be made. Rather, they can now apply their AM design and manufacturing knowledge to projects for clients from other metalworking industries, such as aerospace. After systematically building up AM competencies and a corresponding AM infrastructure, within the space of a few years JELL has been able to break into new markets representing various sectors and in which AM is in demand.

With their growing AM expertise, from 2013 JELL began to modify their LBM plants according to their own specifications regarding construction space heating, construction space volume and shielding gas flow in order to increase AM process stability and improve the quality of their additively manufactured components. In addition, they entered into collaborative partnerships with locally based research institutes in order to grow their AM technological maturity further. JELL also started to develop special AM metal alloys for clients and use them in their LBM plants.

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[67] JELL GmbH & Co. KG

In 2016, JELL finally married their knowledge of AM with their many years of experience in mould-making to create their very own product.

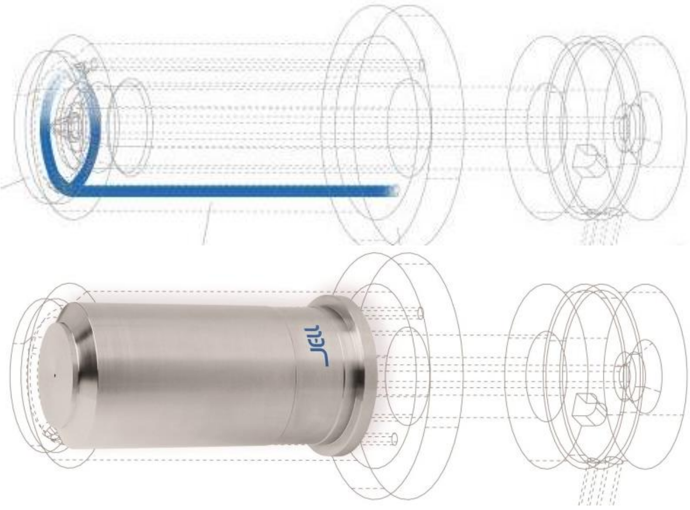

Figure 47: Antechamber bushing (bottom) and with course of cooling channel (top)[68]

The figure shows an antechamber bushing that thermally decouples the heating channel from the mould insert in an injection moulding machine. By additively integrating cooling channels into the antechamber bushing, the injection moulding process becomes more reliable. JELL now manufactures this bushing in series using their own LBM plants, along with other AM components used in a variety of sectors, which proves that AM can be successfully implemented in an SME.

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