AACHEN CENTER FOR ADDITIVE MANUFACTURING

Technical Drawings

Golden source to identify opportunities for 3D printing of spare and obsolete parts

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WERK 24

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Golden source to identify opportunities for 3D printing of spare and obsolete parts

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Institute for Digital Additive Production (DAP) of RWTH Aachen University

The institute for Digital Additive Production DAP was founded at RWTH Aachen University in August 2016 with the appointment of Prof. Johannes Henrich Schleifenbaum. In a strong network, more than 120 motivated and talented employees develop technological excellent solutions in the Additive Manufacturing (AM), product as well as production digitalization topic fields. In its basic and applied research, the chair pays particular attention to the economical as well as ecological impact of its work and the potential benefits for its partners. This way, it aims to sustainably strengthen and advance the developing and production industries. From production digitalization and networking to materials and manufacturing to post-processing and quality assurance: the chair's research activities are geared to preserve value creation and industrial production as an essential part of prosperity, put it on the AM track and, thus, contribute to a better tomorrow.
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W24 Service GmbH

Werk24 (W24 Service GmbH) is a Munich-based company specializing in using Artificial Intelligence and Machine Learning to process technical drawings automatically. By leveraging AI solutions, businesses can extract essential manufacturing information from various technical drawings, such as PDFs, JPGs, PNGs, and TIFs. The company's innovative technology can also convert drawings into machine-readable JSON files or Excel Sheets, leading to considerable improvement in data quality. These solutions allow manufacturers to automate the reading of technical drawings, freeing engineers to focus on innovation. The company processes 100 - 120,000 drawings monthly and offers a range of APIs to support the digital transformation of businesses across a wide range of use cases, such as automated feasibility check of incoming RFQs, the extraction of master data records, and the part selection for additive manufacturing.
https://de.werk24.io/

3D Printing of Spare Parts

In today's globalized economy, spare part supply chains are becoming increasingly complex, with parts sourced from all over the world. While this allows for greater efficiency and cost savings, it also means that disruptions in one part of the supply chain can have far-reaching economic consequences. The recent blockage of the Suez Canal by the "Ever Given" container ship is just one example of how unexpected events can cause widespread disruptions to supply chains [1]. Spare parts play a critical role in the efficient operation of various industries, from manufacturing and automotive to aerospace and healthcare. The availability of the right spare part at the right time is therefore crucial to avoid unwanted circumstances, such as production stops or aircrafts waiting in the hangar due to delayed maintenance. Besides the previous example, there are other reasons why spare parts become unavailable. Some of the common reasons include:

Obsolescence: Spare parts may become unavailable due to obsolescence, where the original manufacturer discontinues the production of the part, or the technology used to produce it becomes outdated. This can occur when newer versions or upgraded models are introduced, rendering older parts obsolete and difficult to source.

Supply chain disruptions: Supply chain disruptions such as natural disasters, geopolitical issues, or transportation disruptions, can disrupt the flow of spare parts from suppliers to end-users, causing delays or shortages in the availability of critical parts.

Lead times: Traditional manufacturing methods often require long lead times for producing and delivering spare parts, especially if they are sourced from distant suppliers or manufactured overseas.

Stock management challenges: Managing physical inventory of spare parts can be complex, time-consuming, and costly. Maintaining a large inventory of spare parts to cover potential demand can tie up capital, storage space, and resources. Inefficient inventory management practices can lead to excess inventory or stockouts, resulting in unavailability of spare parts when needed.

Cost considerations: Sourcing and stocking spare parts can be expensive, especially for low-volume or low-demand parts. The cost of production, storage, and logistics can add up, making it economically unviable to keep certain spare parts in stock, leading to unavailability when needed.

The above reasons can collectively contribute to spare parts unavailability, leading to challenges in maintenance, repair, and operation for industries that rely on them. However, Additive Manufacturing (AM) – often referred to as 3D printing – has the potential to address many of these challenges. The german national railway company Deutsch Bahn AG for instance has recently announced that they have 3D printed 100.000 spare parts thus far, stating that 3D printing helps them to reduce lead times, simplify their supply chain and decrease inventory costs [2]. Moreover, it reduces the dependency on their external spare part supply chain and helps to overcome supply shortfalls. These achievements can be traced back to the following perks 3D printing offers [3,4]:

Obsolescence: 3D printing is a toolless manufacturing technology with a broad freedom of design, that way it allows to produce a wide range of different products. In addition, it does not rely on economies of scale and production of small lot sizes is thus cost-efficient. This can overcome the challenge of obsolescence, as parts can be produced as needed, regardless of whether the original manufacturer has discontinued production.

Supply chain resilience: 3D printing can enhance supply chain resilience by reducing dependencies on external suppliers. Organizations can produce spare parts on-site or near-site, reducing the risk of supply chain disruptions, such as transportation disruptions or geopolitical issues, which can impact the availability of spare parts.

Reduced lead times: 3D printing can significantly reduce lead times for producing spare parts compared to traditional manufacturing methods. Parts can be printed locally or near-site, reducing the time and cost associated with transportation, and eliminating delays due to distant suppliers or overseas manufacturing.

Lower inventory costs: With 3D printing, organizations can potentially reduce the need for extensive physical inventory of spare parts, lowering inventory costs, and freeing up capital and storage space. Parts can be produced as needed, reducing the risk of excess inventory or stockouts, and optimizing inventory management practices.

Subsequently, by understanding the impact of 3D printing on spare parts management, organizations can unlock new opportunities for agility, cost savings, and operational efficiency in their supply chain. Finding the right starting point to transform the existing spare part sourcing strategy and to enhance it with the capabilities of 3D printing can be quite difficult. The journey of Deutsche Bahn AG with 3D printing of spare parts, for example, started with a very inconspicuous part, a coat hook in 2015 [5]. However, this and other success stories help to introduce systematic approaches to investigate the potential of 3D printing to a product portfolio and its respective supply chain.

Identifying Opportunities

The story of Deutsche Bahn AG has shown that 3D printing's benefits can be leveraged to establish a lean and efficient spare part production. However, 3D printing is not applicable to each and every part and for various reasons it can be challenging to identify the right opportunities. Especially for spare parts the following challenges apply [6,7]:

Large inventories: Many industries rely on a complex and big product portfolio stemming from product diversity, multi-variant products and the evolution of different product versions over time. While modern product lifecycle management (PLM) tools help to track which parts are assembled in which product, they do not contain information on which parts can be 3D printed. Therefore, screening inventories for 3D printable spare parts remains a manual and time-consuming task.

Missing data: Data is the basis to identify printable spare parts. However, collecting and maintaining databases up to date is often still a manual time-consuming process, leading to missing, incomplete or false data caused by the lack of time or human errors. Moreover, obsolete parts can be very old and thus might not be tracked at all or only limited data might be available.

Lack of knowledge: Companies or customers needing a spare part typically hold deep expertise in the operation of their products and production, but often lack knowledge about the capabilities of 3D printing. Judging the applicability of 3D printing to a specific component in terms of material and functional requirements can exceed their area of expertise a systematic approach can help to identify the right opportunities for 3D printing, and to overcome the above-mentioned challenges. Best practices regarding the general procedure, the usage of digital tools and establishing an automated reasoning process are explored in the following.

General Procedure

To determine if a spare part is suitable for 3D printing, technological and economical aspects need to be considered. Moreover, if technical feasibility does not automatically imply economical suitability and vice versa. In practice the following four-step approach – as shown in figure 1 – has been proven to systematically identify suitable parts.

1. Preselection: In order to reduce complexity and to focus on the relevant parts, a preselection is expedient. The preselection is individually depending on the company and can involve steps such as analyzing the business units, the exclusion of standard parts or certain materials. The aim is to define the scope and reduce the number of parts to be screened.

2. Economical assessment: In the economical assessment the costs of a part are determined for both manufacturing. Here, the cost accounting for the production but also for downstream processes such as assembly or logistics need to be considered to account for the total costs of a spare part replacement. The comparison of both process routes allows to evaluate the financial potential. In addition, effects such as shortened lead times can lead to cost benefits and must be priced in if, for example, a production stop can be avoided, or the operation of an asset can be continued. For instance, if reduction in the delivery time of a spare part can help, to bring an aircraft back in the air or a train back on the railway, higher costs in production of the spare part might be justified by a significant decrease of operational costs.

3. Technical assessment: Evaluating the printability of a component is based on an analysis of both functional and non-functional requirements. The latter is often related to legal aspects, e. g., guidelines. To assess the technical fit material and geometry play a major role. Questions such as “Does the part fit into the 3D printer?”, “Is the specific or an equivalent material processable?” or “Which 3D printing technology is most suited?” have to be answered.

4. Reasoning: In order to evaluate which spare parts can be printed and lead to a financial benefit, the result of the economical and the technical assessment need to be combined. Spanning a matrix having the technical rating on one axis and the economical rating on the other axis helps to generate an overall rating.

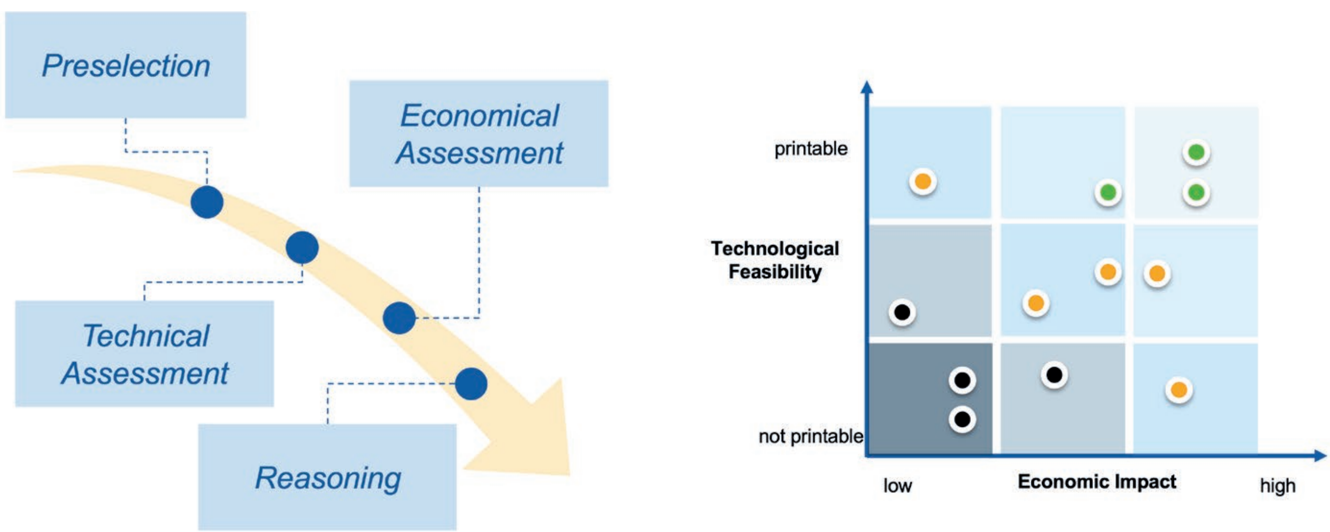

Figure 1: Systematic approach to identify parts suitable for AM

Digital Tools

> **"OCR only extracts the raw text – Werk24 puts it into context and adds the domain knowledge of a trained engineer."**
>
> Dr. Jochen Mattes, CEO of Werk24

Even though an investment of 12 billion euro into new trains by Deutsch Bahn AG, old trains from the 70ths and 80ths will keep operating to address the increasing number of passengers [8]. With the increasing age of the trains, the need for spare parts and maintenance increases. However, spare parts become obsolete over time and documentation, or 3D drawings might be missing. Therefore, digitalization plays a major role in the successful implementation of 3D printing at Deutsche Bahn AG [2].

In case of obsolescence, special or old parts, the data extraction from technical drawings is an essential process to determine if a spare part is suitable for 3D printing, as drawings are often the only technical data available. Screening and understanding technical drawings are thus crucial. However, it is a time-consuming task and subsequently digital tools might help to accelerate this process. Therefore, the machine building industry has been actively seeking technological solutions to automate this process. For a long time, the only viable option available has been utilizing Optical Character Recognition (OCR) technology that allows computers to recognize and extract text from images. However, it is widely acknowledged that the use of generic OCR solutions alone falls short in terms of understanding the complexity of technical drawings. OCR-based solutions exhibit a host of limitations in understanding intricate design details that technical drawings often entail. A deep understanding of elements and symbols and their context is needed which poses a non-trivial task as the following shows:

Understanding Meaning of Elements: Machines struggle to understand the meaning of text and group it correctly. OCR can only extract text, not interpret it. Technical drawings often contain features such as dimensions which can be presented as a nominal size with upper and lower deviations stacked on top of each other. OCR can only extract text from left to right and cannot distinguish between these different elements.

Understanding Special Symbols: Generic OCR solutions are not equipped to understand the meaning of special or mathematical symbols that are significant for showing part measures and tolerances, such as "Ø" or "±".

Understanding Graphic Elements: Detecting text in drawings surrounded by cluttered and intersected graphic elements, such as lines, symbols present a significant challenge for generic OCR solutions and may result in unreliable text extraction.

Understanding Multiple Orientations: Technical drawings often include text elements in various orientations, unlike articles where text typically faces a single direction. However, some OCR solutions may require a dominant orientation from the document, resulting in missed text elements.

The TechRead API developed by Werk24 utilizes machine learning models and AI algorithms. Its purpose is to understand common formats of measures, tolerances, GD&T, and title blocks, enabling an automated extraction process for data. As a result, it offers data extraction solutions for technical drawings without encountering the limitations associated with OCR. Artificial intelligence (AI) technology can comprehend the meaning of elements, special symbols, graphic elements, and multiple orientations in technical drawings. It understands them and engages in continuous learning throughout the process to improve the data quality. Through the application of AI technology, the technical drawings can be understood and standardized when they involve different languages or material standards (see figure 2).

Understanding Multiple Languages: The language of technical drawings can be altered based on the company's location. AI technology can read and understand different languages and extract the exact data in diverse business scenarios.

Understanding Multiple Material Standards: Technical drawing standards allow for multiple representations of the same material. For example, the material name "ALU SHEET 5754 (AG3) CONDITION H111 NT A50541" written in the technical drawing is equivalent to "EN AW5754 H111" in another technical drawing, both representing aluminum sheet. AI technology can understand that the materials are the same in the data extraction process.

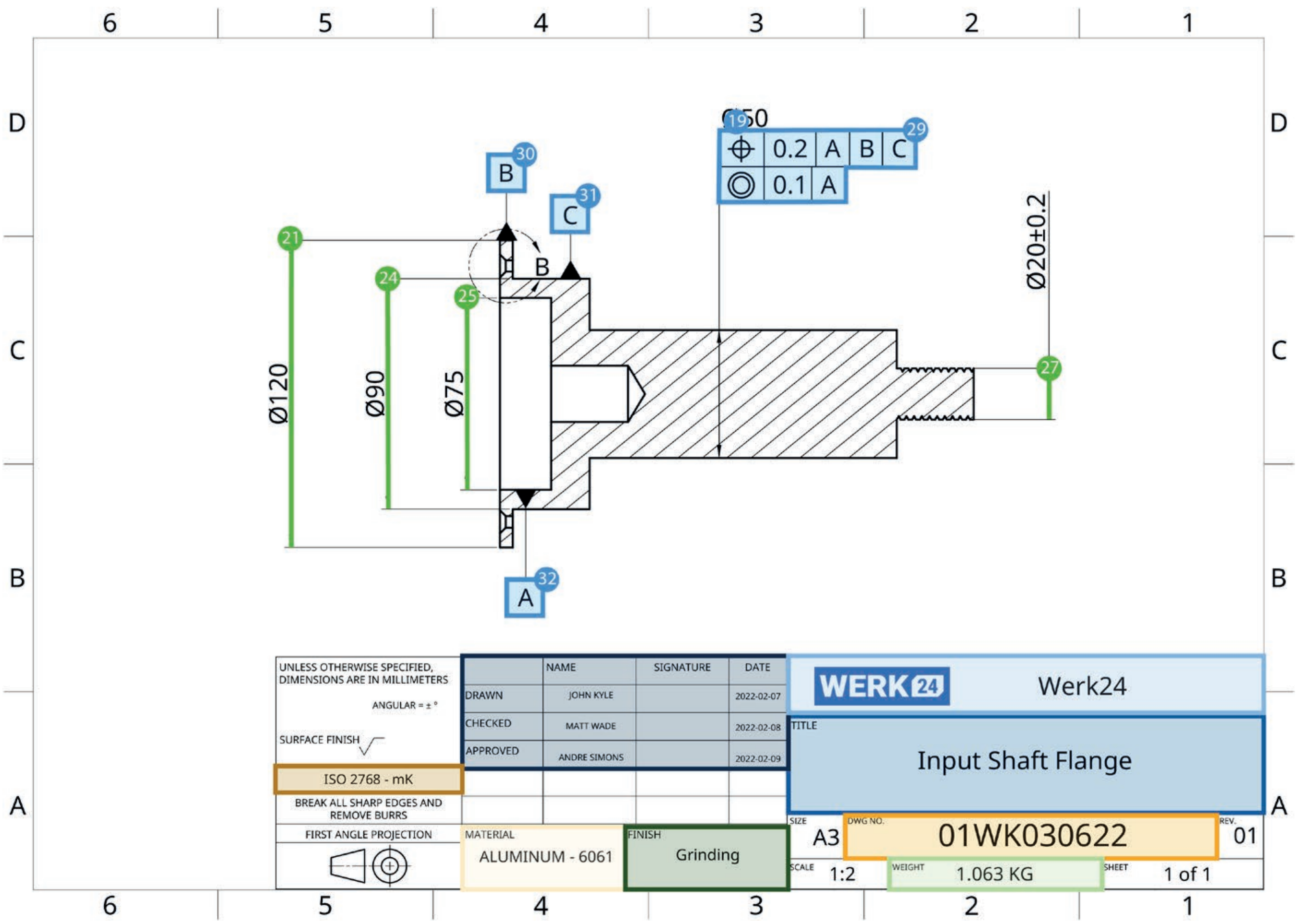

Figure 2: Transformation by the TechRead API

Semi-Automated Reasoning

The above-mentioned general procedure in four steps is a proven framework to identify the right opportunities for 3D printing spare parts. Facing the challenges of missing data and extensive inventories, however, including digital tools in that procedure to reduce the screening effort can significantly speed up the process and improve the quality of the result. Combining computational intelligence and human expertise – as shown in figure 3 – in a funneled process allows filtering large portfolios efficiently. Preselection as a first iteration and technical assessment can be done in an automated way. For instance, relying on AI technology, technical drawings can be analyzed, and parts that would be feasible for manufacturing using 3D printing can be identified. Part identification for 3D printing needs an in-depth analysis of the manufacturing constraints that limit the part's manufacturability. Manufacturing constraints can be identified partially from the 3D CAD models and the rest from 2D technical drawings. Even though the manufacturing industry is moving towards digitization, technical drawings still exist for many parts. For instance, spare parts for assemblies designed decades ago are occasionally required. 3D models are not available for such spare parts; all that exists are old drawings stored in archives. With the help of AI, e. g., in the form of Werk24's data extraction technology, these old drawings can be examined, and product manufacturing information can be extracted within seconds. Part Manufacturing Information (PMI) such as bounding box, dimensions, tolerances, surface roughness, or geometric dimensioning and tolerancing are extracted from 2D technical drawings.

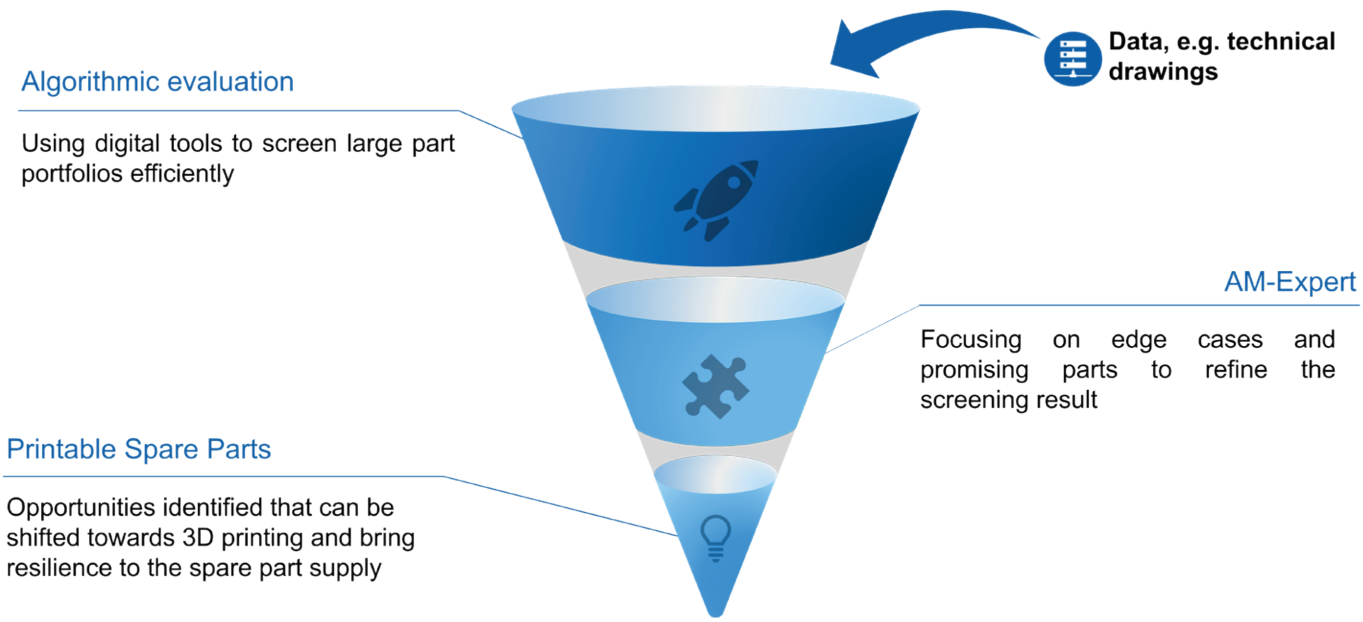

Figure 3: Semi-automated identification funnel

In the case study "Part Identification for Additive Manufacturing using Technical 2D-Drawings" of the Institute Digital Additive Production DAP and Werk24 such an automated and iterative process is investigated. This case study proposes a framework to allow end-users to identify a part for additive manufacturing using 2D technical drawings of the part. The PMI is extracted with Werk24's data extraction technology. Subsequently, a multilevel decision model is presented that automates the part identification process. The decision model generates an extensive report on the part's suitability for manufacturing using 3D printing machines in a database collected for the research. An exemplary report can be seen in figure 4. In addition to part drawings, the part identification process is also extendable to assembly drawings. Assemblies could be redesigned based on suggestions from the extracted data, thereby reducing the complexity of the conventional assembly process by producing the assembly as a single part, which is one of the significant advantages of Additive Manufacturing.

Afterward, experts can focus on the pre-filtered parts and use the information provided by the tools. In a second iteration, an in-depth assessment of the technological feasibility and financial viability can be conducted by AM-Experts. In these assessments, for example, part requirements are not only matched with the right 3D printing technology but with an entire process chain including postprocessing technologies to examine the total cost and ensure that the applications requirements can be met. Transforming the results in a matrix spanning the technical and economic dimensions of the different parts can be used for reasoning which parts are suitable. Finally, printable spare parts remain, which can be stored in a digital warehouse and printed on-demand.

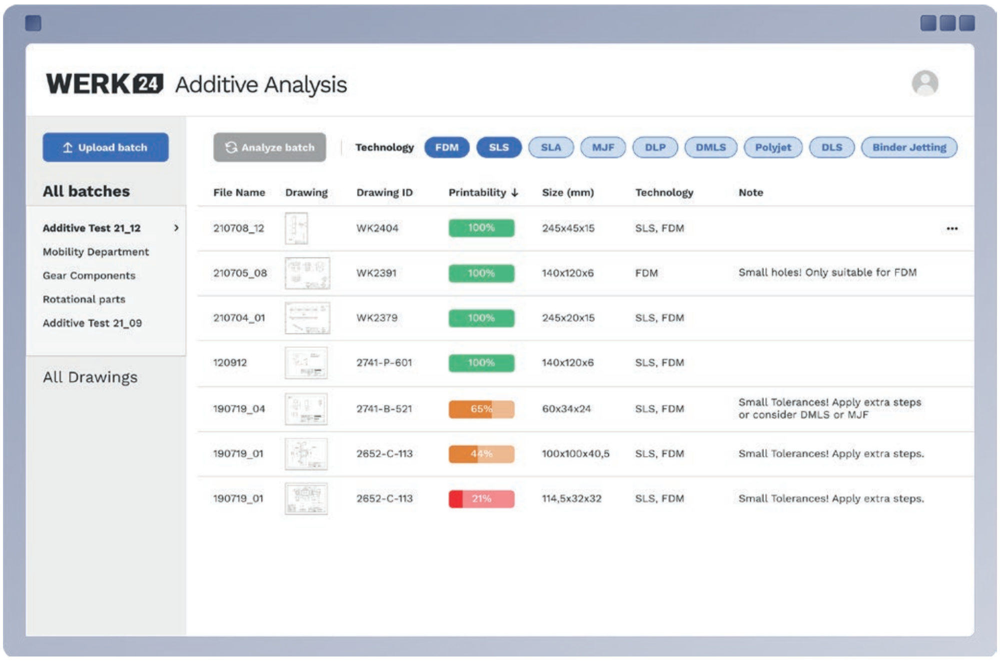

Figure 4: Exemplary report of the automated screening of technical drawings


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Towards resilient Spare Part Supply

Recognizing the undeniable competitive advantage of spare parts availability, exploring the utilization of 3D printing for spare part production can greatly enhance the resilience of the supply chain. It is crucial to identify suitable use cases and integrate the sourcing process into a digital workflow to fully leverage the benefits of 3D printing. By understanding the challenges associated with spare part supply as well as the identification process and transferring it into a holistic strategy, the potential of 3D printing can be harnessed effectively. Such a holistic concept starts with the identification of suitable parts, but requires further steps to implement an on-demand spare part production. To this end, respecting the following learnings - as depicted in figure 5 – is expedient:

Systematic identification process: To get the most out of 3D printing for spare part supply, it is important to identify the right applications in an efficient manner while not missing out opportunities. Systematic approaches such as the above-mentioned four-step approach can help to do so.

Using digital tools for opportunity identification: Digital tools such as AI technologies to analyze technical drawings can help to speed up the identification process significantly, especially in the case of large product portfolios. Indicating potential use cases and sorting out parts that are not printable, these tools prepare an efficient identification process and allow concentrating on value adding opportunities. Moreover, they can help to establish a continuous identification process and to increase the number of suitable parts over time, thus increasing the impact of 3D printing on resilience.

Cooperating with AM experts: Besides digital tools, AM experts can help to identify the right use cases and are helpful to refine first screening results. In addition, after an initial screening edge cases have to be analyzed in more detail to prove technical or financial feasibility. Transferring the identified opportunities can be speedup as well by the help of AM experts, for instance by providing best practices, giving insights on certification or connecting to specialized manufacturing hubs.

Establishing an ecosystem: Having identified spare parts at hand the next step is to establish an efficient and flexible sourcing strategy. Own manufacturing capacities if available can be a good starting point, but due to the variability of spare parts regarding material, size, demand and their point of use, it is expedient to build a widespread production network. Secondly, distributing and managing spare parts for flexible on-demand production requires digital management tools such as digital warehousing and smart order management. Collaborating in an ecosystem that provides access to AM experts, software vendors and service providers helps to build up a holistic concept for sourcing and managing of 3D printed spare parts.

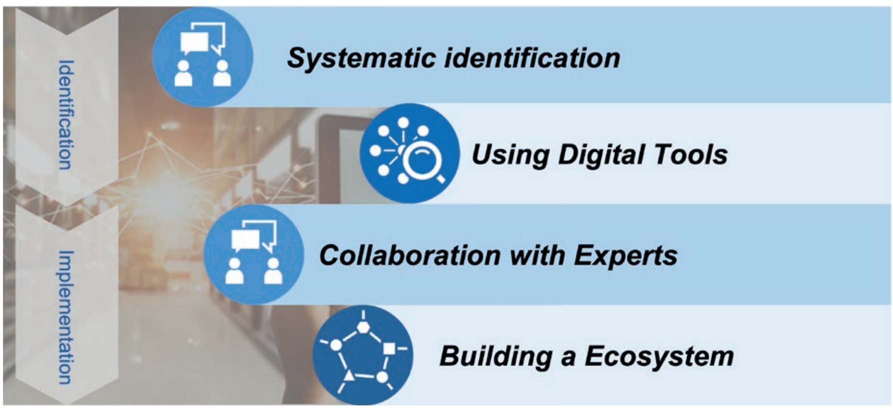

Figure 5: Key learnings to identify and implement an additive spare part supply

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