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AMAze DIMECC PROJECT ADDITIVE MANUFACTURING POST-PROCESSING AUTOMATION

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FAME ECOSYSTEM White Paper

Business Enablers for Post-processing Automation

AMAze Project
2025

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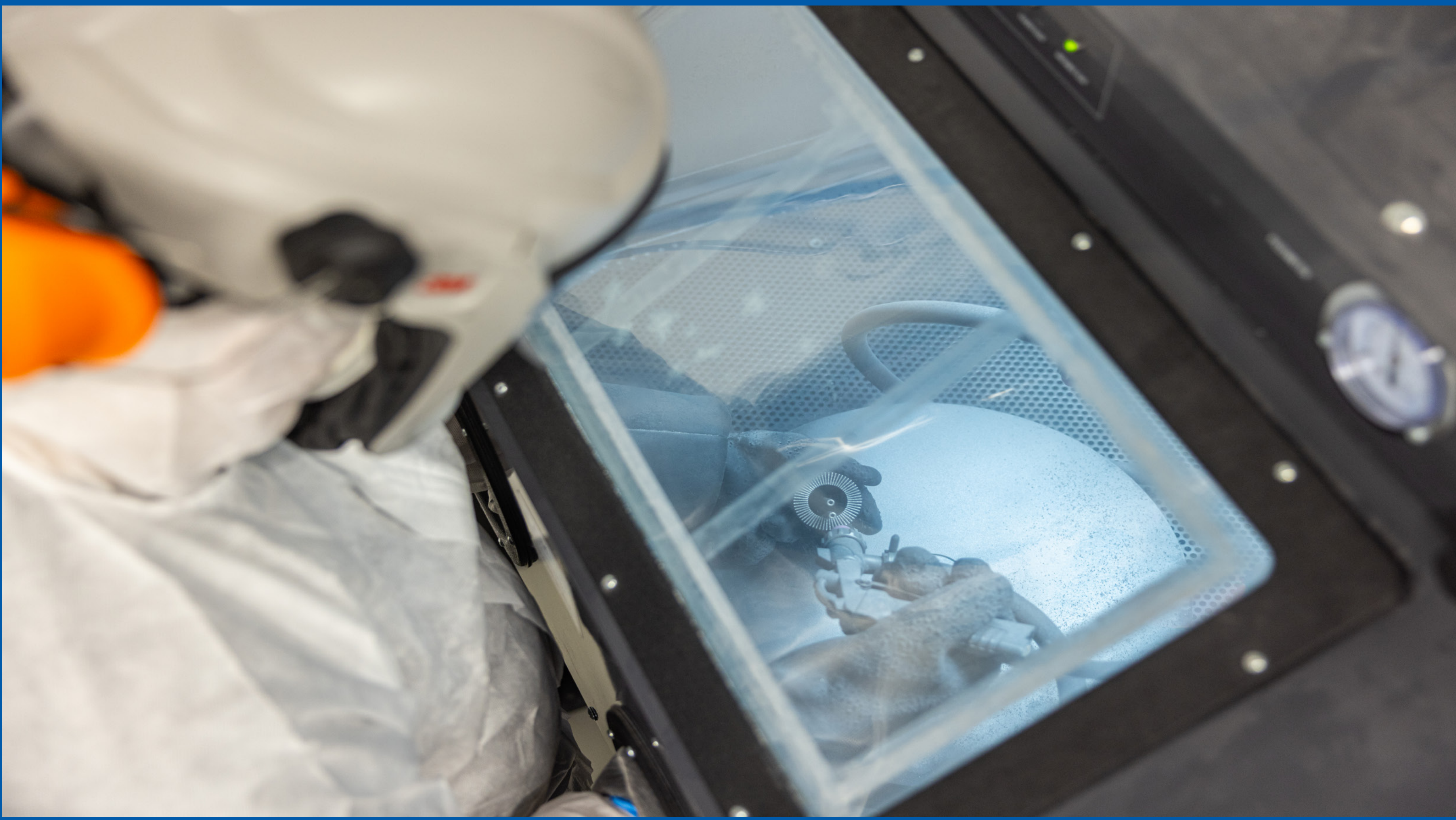

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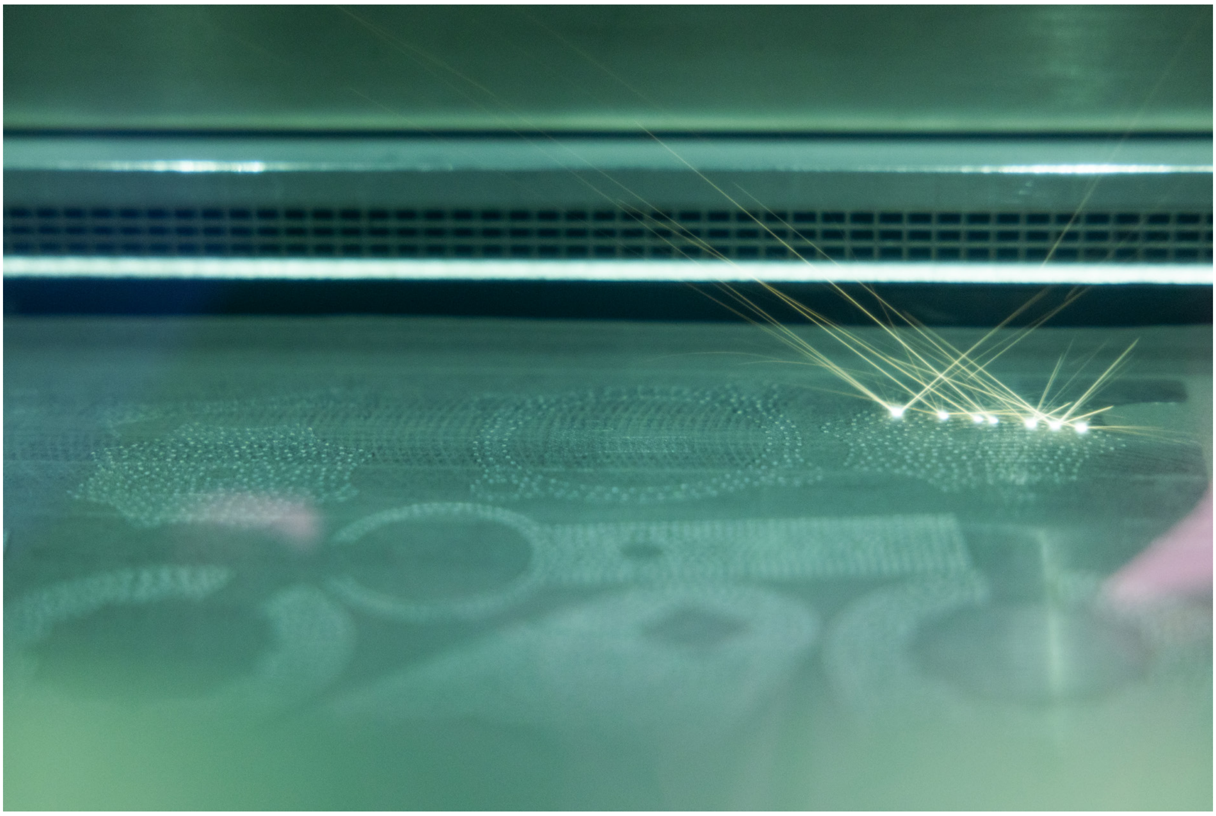
1. Introduction

The additive manufacturing (AM) market is rapidly growing internationally from its current $16.8 billion industry with a 21% percent annual growth rate to $44 billion by 2027 (3Dnatives, 2023). This is not surprising. Benefits of AM in comparison to conventional manufacturing technologies like machining or forming include but are not limited to lower cost of entry, savings on materials & energy and prototyping costs, faster and cheaper small production runs, and improvements in part reliability [1]. The growing interest of the manufacturing industry will increase the use of AM in a manner that more and more companies will envision using it for small batch or mass production, especially in high-mix, low-volume and high-mix, high-volume manufacturing.



AMAze consortium is focusing on post-processing of powder-based AM technologies.

1. Introduction

A bottleneck currently inhibiting this is costly and complex post-processing. The additively manufactured parts do not always meet customer requirements due to geometric flaws, poor surface quality, and additionally, even issues with mechanical properties [2]. For this purpose, various post-processing technologies are needed after printing. Unfortunately, the post-processing of AM takes more than 50% of the human work resources required for AM [3]. Overall, the post processing in AM creates significant challenges for production control since routings and processing requirements vary a lot between AM shops [4].

The AM post-processing is drastically dependent on several topics such as material and selected printer [5, 6]. AMAze consortium is focusing on post-processing of powder-based AM technologies such as selective laser melting (metals) and selective laser sintering (polymers). The core of AMAze project is to find solutions regarding proper selection of post-processing automation strategies, cleaning of the parts, automated quality assurance and different solutions that would make AM parts more traceable and sustainable.

The challenges of the AM post processing are limiting the growing investments of the AM hardware in industry. It is reasonable to assume that in the near future there will be a demand for automated and semi-automated post processing solutions. This could mean more business opportunities for the Finnish industry in post processing AM software (SW) and hardware (HW) sectors.

1.1. About AMAze

Towards opening new markets and create competitive edge for Finnish companies through Additive Manufacturing Post processes Automation and cost reduction (AMAze) is a Business Finland funded Co-Innovation project lead by DIMECC. Throughout the project, Tampere University of Applied Sciences (TAMK), Fastems Oy, Valmet Oy, 3D Formtech Oy, Materflow Oy, and Advian Oy provide research-based solutions and innovative business approaches to overcome largest bottlenecks in the post-processing of additively manufactured parts and components.

1.2. Problems & AMAze solutions

AMAze is producing solutions to the following post-processing problems:

CAPACITY

Post Process Technologies state in their 2022 yearly report [1] that AM post-processing remains a time-consuming step (up to 50% of the manual work) that needs to be more automated with emphasis on quality.

AMAze solution: Methods to elevate the capacity by providing tools to select post-processing automation strategies suitable for industry needs.

1. Introduction

PART QUALITY

Quality is typically checked manually, based on human visual detection of errors and defects. This makes it difficult to perform systematic quality assurance for large quantities or high mix parts. The industry is expecting service providers to commercialize functional and validated solutions for quality assurance [7].

AMAze solution: Intelligent machine vision systems accurate enough to detect even minor issues in surface quality and geometrical defects.

COST REDUCTION

38% of companies using AM need reduction of costs before using AM more [8]. Post-processing has significant costs, if done manually (i.e., labor intensive, not scalable, and unsustainable in mass production) [3].

AMAze solution: Proof-of-concept for a multi stage de-powdering to achieve higher levels of cleanliness and minimize manual work.

TRACEABILITY

Traceability affects the optimization of the production chain by simplifying it [9]. Companies are capturing production-related AM information through separate digital tools, software solutions, sheets, paper forms, etc. and typically there is no centralized system that provides all information regarding use of resources or traceability of printed parts [7]. Some companies may have confidential contracts in disposal of metal powder waste, but overall, powder-based AM continues to create a lot of it.

AMAze solution An open access architecture to track down data throughout the post-processing phases. AMAze also targets its research activities on traceability regarding AM sustainability, e.g., powder waste and inability to reuse it.

SAFETY

Safety is very important when it comes to handling new R&D materials [10]. The market needs to drive the development of new AM materials with special mechanical or electrical characteristics. People working closely with powder-based materials need to be safe and secure from any potential risks and long-term health problems while the material is being tested.

AMAze solution: Automation framework that minimizes direct human interaction with powder-based materials.

The current white paper provides insights on the post processing market potential by focusing on solving issues identified above through end-to-end automation, de-powdering and sustainability.

2. Automation Advancements

2.1. Market position of post processing solutions

In 2019, only 3.1% of the AM business revenue came from the post processing technologies [3, 11]. This creates an excellent starting point towards entering the markets with solutions aimed at facilitating post-processing. To put the markets in the context of AMAze project it must be noted that roughly 37% of the companies using AM are using powder bed fusion (PBF) [3]. According to the PPT yearly survey [3], PBF users have more challenges in post processing than the users of other printing technologies. In addition, more than half of the respondents of the PPT survey intend to improve health, safety and environment conditions of AM operations. A common characteristic motivating adapting automated solutions is simple: productivity and efficiency. Automating labor-intensive tasks can also increase the shortage of the available workforce. Simultaneously, the cost is typically reduced at least on the long term [12], which is often desirable for companies. The market demand and simplified metrics to demonstrate it for the industry is, therefore, real.
Based on industry surveys (e.g., 3, 11) the following post-processing pain points are identified by the PBF companies:
- De-powdering
- Safety
- Time to finish parts
- Consistency of the finished parts
- Waste management

To gain detailed information on existing solutions and to find gaps for new business, AMAze consortium used this information and performed a set of targeted queries on the patent landscape for AM post process automation. Overall, the results showed clearly that the mass of the patents are patented in the United States, China or Germany. Further, only a handful of patents focused on automating several steps of the post processing. De-powdering solutions were by far the most popular category of recent patents, illustrating the challenges industry currently faces with cleaning of AM parts. For this purpose, the rest of the chapter first positions process specific (e.g., de-powdering) solutions with end-to-end automation illustrating commercial potential for the latter and then proceeds to present an overview on the markets targeting to improve de-powdering of metal and polymer AM parts.

2.2. Opportunities for process specific vs. end-to-end automation

When looking at the automation of AM printing processes, two distinct levels can be observed. Traditionally both research and commercial initiatives and activities have been focused on phase-specific automation solutions such as automated solutions on de-powdering [13]. Only recently process level automation

2. Automation Advancements

has gained more attention [14, 15]. Process level automation focuses on combining phase-specific solutions into a comprehensive end-to-end automation system from the print build to packing and shipping steps, and therefore, when successful, would create for the AM industry significant benefits in tackling problems identified in the AMAze project (i.e., capacity, part quality, cost, traceability, and safety).

Unfortunately, both phase-specific automation solutions and process level automation innovations hold the same opportunities and face the same challenges that are typical to AM business in general. Automation of certain steps of post-processing could improve the productivity and quality of the production, but complexity and variability of the parts and materials hinders gaining all the potential benefits of the solutions [16]. Similarly, comprehensive end-to-end automation of the post-processing workflow would be a huge productivity leap. However, high variability in AM production technologies, production mix and volumes makes it extremely hard to levy the benefits of automation at full scale [17].

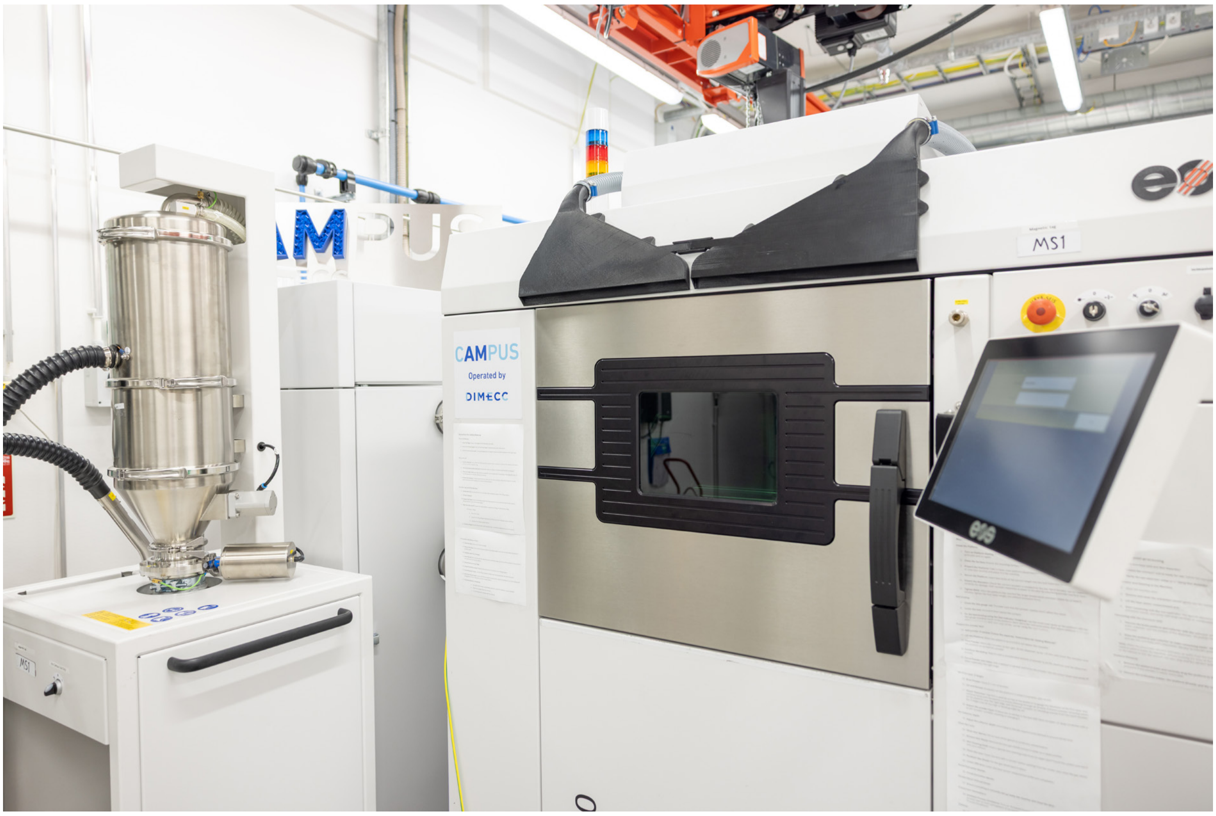
In small batch AM, consistent quality, delivery reliability and traceability are becoming more and more crucial [18]. Generally, automation of manual processes improves all the mentioned metrics. Additive Manufacturing is not an outlier. Latest advances in technologies like machine learning, machine vision and AI are removing the barriers on automating complex processes in high mix – low volume manufacturing environments. Solutions like adaptive pattern recognition, imaging and autonomous tooling path planning are all directly usable in AM post-processing tasks.

End-to-end automation is also a key enabler for Industry 4.0 and 5.0 initiatives. Automated processes are better controlled than manual ones. They can both produce and utilize data far more efficiently than manual processes. Traceability and sustainability reporting requirements are becoming competitive even in component manufacturing, and managing such data is hardly efficient in manual production environments. AMAze project is taking a bold step on this area with its simulation approach. While current research on AM production simulation focuses on traditional workflow optimization and operations management [19]. AMAze project is building a novel post-processing simulation model that integrates the data layer to the simulation. The goal for this challenging task is to develop a generic simulated post-processing “sandbox”, where different process attributes and data sources can be easily built, combined and analyzed.

Based on the above, following business oppotunities for comprehensive **end-to-end automation** can be recognized:

- Support for selecting end-to-end automation strategies (e.g., simulations)
- Tailored services and hardware combina-

2. Automation Advancements



In small batch AM, consistent quality, delivery reliability and traceability are becoming more and more crucial.

tions for end-to-end automation matching the exact needs of the company
- Smart services for consistent quality
- All automation solutions (hardware and software) covering several steps of post processing
- Solutions to support traceability of AM parts

2. Automation Advancements

2.3. De-powdering solutions

The core of the interest in de-powdering for PBF applications lies in powder contamination and work safety issues when an operator handles loose powder [3]. The main pain points of powder removal and de-powdering are length of time to finish parts and consistency of the parts [3].

Precision cleaning and de-powdering of metal AM parts offer multiple benefits for the companies [20]. De-powdering means the process of removing excess powder from AM part. Effective de-powdering mitigates the risks posed by trapped residual powder including but not limited to mechanical weakness and abrasive wear therefore, being a large component of product quality and performance.

However, de-powdering is far from simple process, automating it is challenging for the industry for industry. Kowen [21] has identified the key functions of a metal AM powder removal system. These include vibration to dislodge powder; rotation of the build plate; inter gas capability (to process reactive metal powders); programmability and automation; compressed air or gas; and access to large parts (e.g., crane loading).

Even a short benchmarking of existing technologies shows that in the world of metal AM the focus is on simple geometries, de-caking, and most simple methods such as combination of air flow or blast, and vibration. Table 1 compares four solutions from identified market leaders or interesting startups in the area.

The main pain points of powder removal and de-powdering are length of time to finish parts and consistency of the parts.

2. Automation Advancements

Table 1: De-powdering methods, programmable features, access to data, and degree of automation of metal AM de-powdering solutions.

	Volkmann DPS Metal 1	Addiblast Mars03	Lukon SFM-AT800-S	PRES-X
Methods	Nozzles (compressed air or inert gas), Frequency modulated vibrators	Rotary table; Pneumatic knocker; Blow off nozzles on swivel arm; Electro vibrator; Inert gas	Targeted vibration and automated programable endless rotation along two axes	Continuous vibration; Running cycles that clean narrow channels with a diameter of 1 to 20 mm using rotations up to 180°
Programmable features	Unknown	Customization of settings	SPR Pathfinder® software	De-powdering cycles that adjust the orientation and rotation of the cradle
Data interface	Integratable to Volkmann PowTReX supporting OPC/UA	Integrated smart measurement analytics system (e.g., humidity and inert gas consumption)	OPC/UA support	Unknown
Automated features	Unpacking and de-powdering without human intervention. Automated loading possible.	Cleaning is automated but allows manual work	Vibration and rotation. Allows robot loading	Fully automated system; Analyses the path and characteristics of the channels or cavities
Motorized movement	Yes	Yes	Yes	Yes
Closed system	Yes	Yes	Yes	Unknown

Metal is much more commonly used in AM than polymers or other materials and creates greater safety hazards for operators. It is not surprising that there is a skew towards available commercial solutions for metal de-powdering in comparison to polymers. This is also evident in the publicly available details of the polymer de-powdering solutions as well as their features. Table 2 illustrates solutions for polymer de-powdering.

2. Automation Advancements

Table 2: De-powdering methods, programmable features, access to data, and degree of automation of polymer AM de-powdering solutions.

	Solukon SFP770	Sprengler VibroBLAST Air	AMT DP/SB MAX	Dye Mansion Powershot C
Methods	Automatic blasting with glass beads and ionized air	Sand / shot blasting and vibration, three-dimensional vector to rotate object	Three moving blast nozzles, ionization	Two blasting and two air nozzles, rotatory basket
Programmable features	E.g., swivel angle, beam intensity and distance, and basket rotation	Unknown	Adjustable settings	All features are programmable
Automated features	Unpacking and cleaning	Surface blasting, rotation	Tumble belt, blasting	Cleaning processes, loading

Business potential of the solutions lies in both hardware (i.e., automated de-powdering machines) and services (i.e., providing specialized services for cleaning complex parts or precision cleaning or validating the success of cleaning). Following examples highlight potential business revenues for Finnish companies in this area.

PLASTIC AND POLYMER PARTS:

Most of the commercial solutions' available focus on metal AM, leaving room for companies developing solutions for de-powdering and precision cleaning of plastic AM parts.

PRECISION CLEANING:

Precision cleaning is crucial for maintaining the functionality and safety of metal and plastic AM parts [22, 23]. Most existing solutions focus on de-powdering even though several applications (e.g., medical, aerospace) require precision cleaning resulting in an additively manufactured part that that meets the most stringent cleanliness standards. Such industries require high levels of cleanliness to ensure optimal performance. The precision cleaning market is expanding, driven by stringent regulatory standards and the need for contamination-free products.

CLEANING OF COMPLEX PARTS:

Additive manufacturing often produces parts with intricate geometries that are challenging to clean using traditional methods such as blasting and vibration cannot reach, e.g., narrow cavities [24]. Advanced cleaning solutions

2. Automation Advancements

Figure 1.

that can handle complex internal and external structures are essential. Businesses that develop and provide innovative solutions for complex parts can tap into markets such as aerospace, healthcare, and electronics, where precision and reliability are critical.

AUTOMATION CHALLENGE:

De-powdering methods that are easy to automate (e.g., blasting) are not suitable for precision cleaning or complex geometries. Businesses should focus on validating methods to automate new solutions (e.g., path finding for precise cleaning or combination of several different methods).

AUTOMATED QUALITY CONTROL:

There is a need for systems providing real-time monitoring and data analysis and enabling early detection of powder residue and ensuring consistent quality after de-powdering. This can aid companies in maintaining the highest standards and constant quality of their parts.

3. Sustainability

The European Green Deal calls for more sustainable and energy-efficient industry, that thrives in the EU and global markets. Generally, sustainability of AM has been justified by the fact that parts are made only in demand with less material consumption and waste generation than conventional manufacturing. In addition, AM promotes circular economy by providing tools for broad thinking all 'R's, i.e., repair, refurbish, and remanufacturing but also in recycle and reduce by design [25]. A recent comparison on AM and conventional manufacturing (CM) revealed that AM reduces the overall environmental impact of metal parts of complex design, high value and low production volumes but CM shows better sustainability performance for simple parts in industrial applications [26].

In the EU regulatory framework digital product passport (DPP) is designed to close the gap between consumer demands for transparency and the current lack of reliable product data [27]. Battery DPP is at the head of DPP development which will gradually proceed to other consumer products and industries [28]. Benchmarking of 107 attributes in seven categories of battery DPP gives an outlook of how the EU's eco-design regulations will be implemented and what information is seen important to achieve the sustainability goals (Table 3). Forthcoming EU regulations expect most product categories to fall under the DPP regulation meaning that the specific features of AM and AM post processing should be evaluated against existing regulatory framework.

AM enables manufacturing of spare parts and repairment of products and can be an important technology in the 'circularity and resource efficiency' DPP category in different kinds of products. This also supports DPP objectives, namely, to provide new business opportunities to economic actors through circular value retention and optimization based on improved access to data (e.g. repair, servicing, remanufacturing, recycling, extended producer responsibility and product-as-a-service activities).

3. Sustainability

Table 3:

Name of the category (and subcategories, if any) in battery DPP	Number of attributes	Suggested applicability in AM compared to definition of attribute by battery consortium	Sustainability review
General product and manufacturer information (identification, general characteristics)	9	Identification of a product (e.g. model, serial number), a manufacturer and manufacturing details, an economic operator and general characteristics (e.g. use, weight and lifecycle status) should be included.	Lifecycle status (e.g. 'original', 'repurposed', 'reused', 'remanufactured', 'waste')
Compliance, labels & certifications (conformity, symbols)	6	All relevant declarations, test results and recycling instructions should be available and clearly communicated.	Carbon footprint declaration, waste handling and recycling
Product materials and composition (materials, substances)	11	Information of all materials, hazardous substances and chemicals, impact of substances on the environment, human health, safety should be included.	Substances used for AM post processing (surface treatment chemicals, paints and coatings)
Carbon footprint	7	Calculation of carbon footprint per service life and lifecycle stages as well as information about access to data should be included.	Availability of comparable carbon footprints of AM parts.
Supply chain due diligence	1 + 3 voluntary	Report on the supply chain due diligence policy, risk management plan, and summary of third-party verification should be included.	Voluntary reporting via DPP (e.g. EU taxonomy, sustainability).
Circularity and resource efficiency (design for circularity, safety requirements, recycled content, renewable content, End-of-Life information)	20	Definitions of attributes are not applicable to other products although category and subcategory titles are relevant to AM (battery DPP attributes focus on advancements of safe circularity of batteries)	Amount of recycled content in AM printing material (e.g. powder, polymers) would describe AM circularity.
Performance and durability (seven subcategories)	50	Definitions of attributes are not applicable to other products although category is relevant to AM (battery DPP focus on to ensure that the product is durable in their intended use).	AM quality measures (e.g. tensile testing, hardness, impact strength) would describe performance and durability.

3. Sustainability

To improve the sustainability of AM in mass production, post-processing and more specifically reuse of powder after de-powdering process is one of the key issues and target of AMAze. It has been recognised that postprocessing is one of the hidden aspects of AM which makes comparisons of material and waste reduction complicated [29]. Another key issue in AM sustainability is the improvement of energy efficiency [30]. Life cycle analysis (LCA) and carbon footprint are the key metrics in AM sustainability. Data is required not only to present the current situation but also to demonstrate the effects of developmental actions and piloting (in automation, in recyclability of powder) for traceability and sustainability metrics. The novelty in AMAze is to study possibility of using an open source FIWARE Industrial Internet of Things (IIoT) system to collect, analyze and visualize AM process and post process data. FIWARE-based solutions have been used to create digital threads of material passports [31] and data sharing for European Data Spaces [32].

In AMAze consortium, we envision that also sustainable AM and especially, sustainable AM post processing could open new markets for Finnish industry. Examples include but are not limited to:

Resource efficiency and Circularity. End-of-use applications for powder, recycling infrastructure (e.g., metal powder), and creating new polymer or metal powders for printing from used prints are all examples of means to lower CO2 emissions but currently options in markets are limited.

ICT. Forthcoming EU regulations require tools for advanced data management, collection and analytics. Forerunner companies can focus on services targeted to aid companies in complying with these regulations.

Life-cycle costing. Measuring CO2 emissions is often motivated by regulatory compliance and leaves out of the question of the cost of sustainability. AM production is complex, having great variability in terms of process requirements, materials etc. Services helping the companies to find balance between mandatory sustainability metrics and costs can be expected to become popular once environmental regulations take place.

Generative AI. Finally, complex data sets open new markets for advanced analytics and design tools. The recent developments in generative AI technologies could allow better AM post processing optimization, sustainable AM innovations, and supply chain management or traceability management for better sustainability. The generative AI markets are growing, but specific solutions targeted for AM and AM post processing are still rare as of writing this document.

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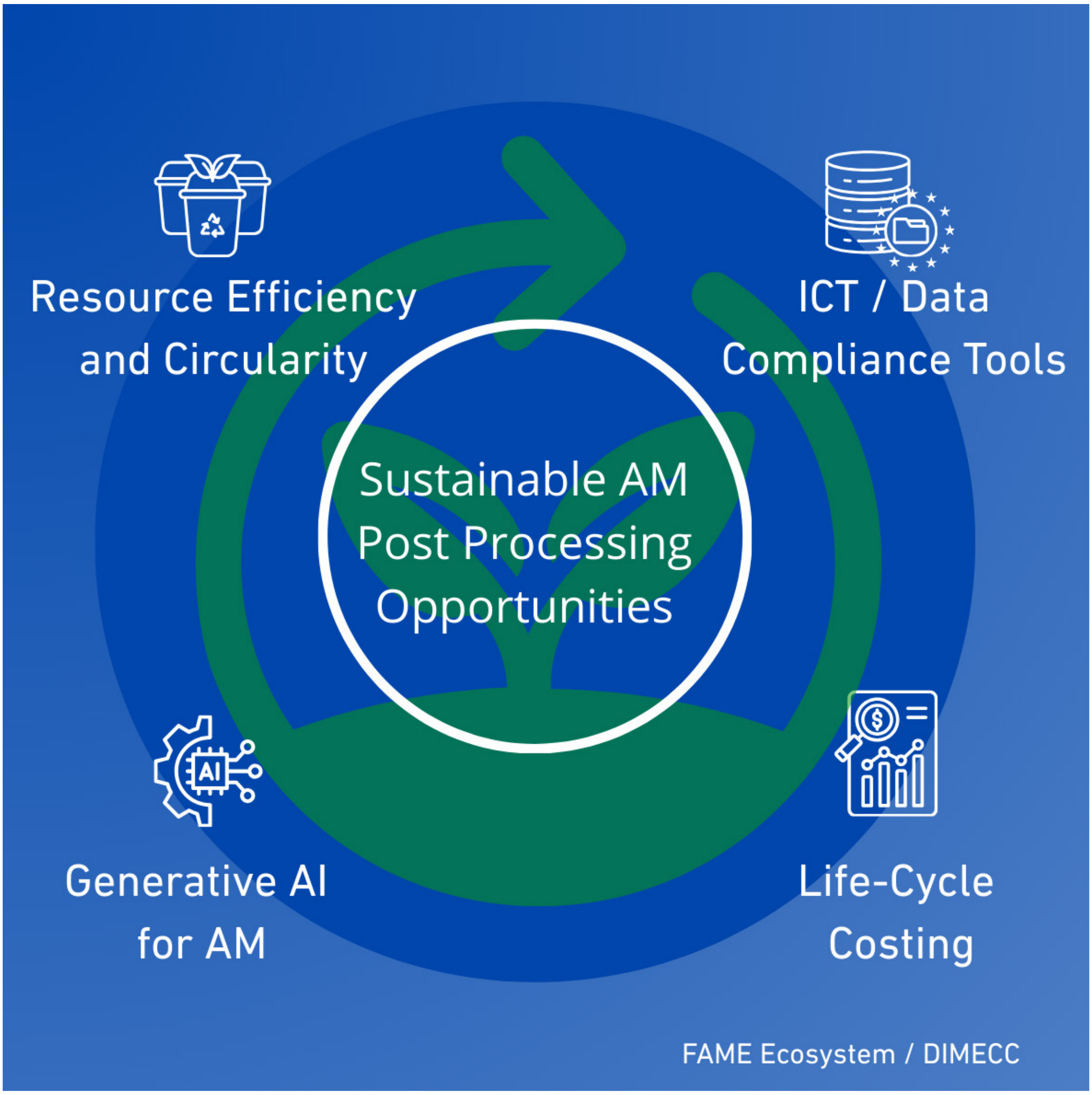

Figure 2.

4. Conclusions

AM post-process automation is an emerging business providing significant opportunities for Finnish industry. Post-processing automation in additive manufacturing (AM) presents a transformative business opportunity, especially as the industry scales toward mass production. The AMAze project highlights how automation can address key bottlenecks—capacity, quality, cost, traceability, and safety—through intelligent, end-to-end solutions.

Business potential lies in:

- End-to-end automation systems tailored to specific production needs, integrating machine vision, AI, and simulation tools.
- De-powdering innovations, especially for polymers and complex geometries, where current market solutions are limited.
- Precision cleaning services for high-regulation sectors like aerospace and healthcare.
- Sustainability-driven solutions, including powder reuse, lifecycle analytics, and compliance with EU digital product passport regulations.
- Data-driven platforms leveraging IIoT and generative AI for traceability, optimization, and regulatory reporting.

As AM adoption grows, companies offering scalable, intelligent, and sustainable post-processing solutions are well-positioned to lead in this evolving market.

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