Desk research

- *Insights from the literature review*

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Table of contents

Background

The background of this project is rooted in a complex problem. The fact is that SME's aren't gaining the expected value by investing in AM technology. Three main causes are behind this:

1. A lack of AM skill development
2. A lack of digital infrastructure
3. A lack of AM related services

To solve these complex problems, the Sustain3D project are going to develop solutions and new strategies that can help SME's create more value with AM technology. As a part of the desk research and the kick-off workshop in Herning, three definitions have been operationalized within the context of AM adaption by SME's. These definitions focus on AM related skill development, AM related services, the technological infrastructure, and sustainability.

The definition of **AM related services** is:

"Service within additive *manufacturing* (3DP) in the context of small and medium-sized enterprises (SMEs) refers to an ecosystem of services that focuses on specialized support that facilitates the adoption, optimization, and utilization of 3D printing technology" – (Søberg et. al 2018)

The definition of the **AM related technological infrastructure** is:

The definition of the technological infrastructure is: "In the context of additive manufacturing within a small or medium sized enterprise, "technological infrastructure" refers to the required hardware, software, and networking components required to support the entire workflow of 3D printing processes" - (Kristin et. al 2020 & Ruraldigital.eu 2023).

The definition of **AM related skill development** is:

"Learning skills for 3D printing is about understanding how to make digital models into physical things. This includes multidisciplinary – or soft - skills, which use expertise from different fields without combining them; interdisciplinary – or hard -skills, which blend knowledge from various fields to innovate. This involves CAD skills, which focus on using design software effectively for 3D printing, Knowledge about which materials to use and other specific engineering skills" – (Admire-project 2022)

The relationship between AM technology and sustainability is also being explored because the ability to create sustainable solutions and strategies is a core framework in this project.

Summary of key points

An extensive desk research was conducted as a key part of activity 1, as required in the projects' work plan. This literature overview presents existing research that is related to the adoption of AM technologies in relation to skill, infrastructure, services and sustainability. The next section presents a short summary of all the articles' main points and mitigating initiatives.

Article 1: *"The role of digital infrastructure for the industrialization of Design for additive manufacturing"* found that a low consideration of the digital infrastructure can negatively impact the Design for Additive Manufacturing (DfAM) process, leading to inefficiencies and ineffectiveness, particularly in early design iterations and in managing data for value-added activities. To mitigate these issues, it's important to concentrate on how Design for Additive Manufacturing (DfAM) interacts with the digital infrastructure of Small and Medium Enterprises (SMEs). This includes understanding the outputs produced by different methods and tools, and how these can be effectively utilized throughout the lifecycle of Additive Manufacturing (AM) technology. The research concludes that poor data and information processing can hinder industrialization, emphasizing the need for effective integration of data into DfAM and a greater focus on digital infrastructure in current DfAM methods (Hajali et. al 2022).

Article 2: *"10 of the biggest challenges in scaling additive manufacturing for production in 2020"* identifies key challenges in scaling additive manufacturing (AM) for SMEs, focusing on the need for appropriate digital infrastructure for managing 3D printing processes. It highlights that many companies rely on IT solutions designed for conventional manufacturing, which may not suit the unique demands of 3D printing. To mitigate this, the development of specialized workflow management software for 3D printing is emphasized. This software streamlines various stages of the process, enhancing efficiency and communication with suppliers. The conclusion underscores the importance of such software in integrating 3D printing into production, improving project traceability, and facilitating the incorporation of 3D printing into broader digital manufacturing systems. This advancement is crucial for optimizing operations and fostering industry innovation (AMFG 2023).

Article 3: *"Information flow analysis enabling the introduction of additive manufacturing for production"* explores the challenges of integrating Additive Manufacturing (AM) into traditional manufacturing processes, emphasizing the need for new design thinking and information flow management. It highlights that existing workflows and tacit knowledge can hinder AM's full potential and stresses the importance of integrating AM into existing digital infrastructure. The study suggests the need for decision support tools to aid in design and manufacturing trade-offs and points out AM's eco-friendly potential, despite challenges in integrating it with current Product Lifecycle Management (PLM) systems. The conclusion emphasizes systematic information gathering and recording as crucial for effective AM integration and comparison with traditional manufacturing methods. This approach is vital for optimizing operations and advancing industry innovation (Brahma et. al 2023).

Article 4: *"Design for sustainable additive manufacturing: A review"* emphasizes the urgent need for sustainable manufacturing practices in light of environmental concerns, highlighting Additive Manufacturing (AM) as a significant solution. It underscores AM's efficiency in lowering material waste, CO_2 emissions, and energy consumption, but also points out the challenges in maximizing these advantages. The study recommend the development of standard AM test samples for accurate data collection, the creation of a comprehensive life cycle information database, and the promotion of collaboration within the AM community. These initiatives are aimed at overcoming the challenges and optimizing the benefits of sustainable AM systems. In conclusion, the article stresses the importance of systematic information gathering and analysis for the effective integration and advancement of AM in comparison with traditional manufacturing methods. This approach is essential not only for optimizing operations but also for driving forward industry innovation and sustainability (Hegab et. al 2023).

Article 5: *"Additive manufacturing from the sustainability perspective: proposal for a self-assesment tool"* highlights the necessity of evaluating the long-term effects of AM processes and usage, emphasizing factors like resource efficiency, improved product lifecycle, and enhanced health and safety conditions for workers. However, the article also notes potential drawbacks, including high energy consumption in fusion methods, increased emissions affecting worker health, and limited data for life cycle assessment. A major mitigating initiative proposed is the operationalization of a checklist related to SDGs. This tool is intended for Small and Medium Enterprises (SMEs) to evaluate sustainability benefits and implications, aiding in informed decision-making for adopting new AM technologies. The conclusion of the study suggests that sustainable AM technologies can lead to more sustainable production operations if implemented strategically, impacting all life cycle phases positively. However, the article acknowledges a knowledge gap due to insufficient exploration of AM process issues, suggesting the need for more case studies to support this understanding in this field (Despeisse et. al 2019).

Article 6: "*Skill requirements of additive manufacturing - A textual analysis of job postings using Natural language processing*" examines the expanding market of Additive Manufacturing (AM) and the consequent need for a skilled workforce. It highlights the growth of AM with a Compound Annual Growth Rate of 23.3% and emphasizes the necessity for skills in design software, material properties, and manufacturing processes. Mitigating initiatives discussed include addressing the shortage of first-hand insights from operations managers and providing valuable information for training providers, job seekers, recruiters, and stakeholders to address the skill gap in the AM industry. The conclusion of the study showcases the effectiveness of NLP methodologies in identifying relevant skills for AM, including Word2vec, LSTM, and Named Entity Recognition (NER) with BERT. The study also suggests developing a dynamic data collection method and an online skills observatory platform for real-time tracking of job market trends and emerging skills in the AM industry. This would be valuable for monitoring the rapid technological evolution in AM and aiding various stakeholders in the job market (Chavez et. al 2023).

Article 7: *"Research and needs analysis on metal additive manufacturing"* delves into the growing economic and strategic importance of Additive Manufacturing (AM) in the UK and EU, highlighting a critical shortage of skilled professionals in the field. It emphasizes the need for specialized training to meet the demands of increasingly complex AM products and processes. To address these findings, the study underscores the importance of fostering stronger partnerships between academic institutions and the industrial sector. This collaboration is crucial in developing a workforce with the unique skills required for AM, a field known for its rapid advancement and distinctive production benefits, including efficiency, adaptability, and environmental sustainability. In conclusion, the report proposes the establishment of a specialized joint Master of Science program in Metal Additive Manufacturing. It highlights the need for a curriculum that closely integrates academic and industrial cooperation to fill the current gap in training offerings. The feedback also identifies specific aspects of the course structure that are essential for its success, noting a significant demand for a comprehensive, industrially relevant master's program in Metal AM, given the lack of such programs in Europe (Cruchley et. al 2018).

Article 8: *"The role of service providers in 3D print adoption"* examines the influence of service providers in the adoption of 3D printing (3DP) technologies in industrial manufacturing firms. The study recognizes a gap in research on the challenges these companies face during adoption and the disparity between expected and actual services received. Service providers are highlighted as key players in guiding customers through the adoption of 3DP. Their roles include selecting appropriate technology, keeping customers informed of advancements, and providing training opportunities. The study draws on previous research to emphasize the importance of monitoring technological developments and developing absorptive capacity in the face of new technologies. In conclusion, the article addresses the lack of focus on service providers in the Technology Acceptance Model (TAM) literature. This research offers insights into services needed at different adoption stages and suitable service delivery models, providing valuable information to both service providers and industrial users about potential challenges in adopting 3DP and strategies to navigate these challenges (Chaduri et. al 2019).

Literature review

In the context of additive manufacturing for small and medium-sized enterprises (SMEs), a systematic literature review was conducted. This analysis delves into the dynamics of implications, benefits, and actionable recommendations, emphasizing key areas such as skill development, technological infrastructure development, service improvement, and sustainability practices specific to SMEs. The following keywords was used in the desk researching process: *"Skill development for additive manufacturing", "Infrastructure for additive manufacturing", "Services development for additive manufacturing", "Sustainability for additive manufacturing".* Google Scholar was used as the primary search engine. A noticeable difficulty encountered was the scarcity of existing research that collectively examines the concepts of skills, services, and infrastructure as a single comprehensive study. Most research tend to concentrate on just one of these concepts separately. Therefore, further desk research is advised. The code generating the table below is included to ensure the reproducibility of the results presented in the literature review.

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l (2020)", "Chaudhuri et. al (2018)"),
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processing(NLP) method", "Survey and focus group interviews", "Explorative intervi
ew and case study"),
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"A design decision requires capturing information from various activity steps", "A
M technology is environmentally friendly", "A checklist to evaluate the sustainabi
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lf IT solutions", "Vital to collect information from the activity steps" ,"Lack of
data to acces the sustainability of AM" ,"AM processes can result in more sustaina
ble operations" ,"NLP is an effective method for skill extraction" ,"Lack of maste
r's level programs focusing exclusively on Metal AM" ,"Companies lack of resources
and training."))

# Watch table

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Table 1: Litterature review

Results from the litterature review

Desk research

Insights from the literature review

Article_ID	Author	Design	Results	Skill	Infrastructure	Services	Sustainability	Conclusions
A1	Hajali et. al (2022)	Industrial use Case and interviews	DfAM process was ineffective.	No	Yes	No	No	Low consideration of DfAM methods.
A2	AMFG (2023)	Expert interview and statements	A lack of digital infrastructure	No	Yes	No	No	Companies use off the shelf IT solutions
A3	Brahma et. al (2023)	Descriptive use business case	A design decision requires capturing information from various activity steps	No	Yes	No	No	Vital to collect information from the design activity steps
A4	Hegab et. al (2023)	A litterature review	AM technology is environmentally friendly	No	No	No	Yes	Lack of data to acces the sustainability of AM
A5	Despeisse et. al (2019)	Multiple case study	A checklist to evaluate the sustainability of adopting AM	No	No	No	Yes	AM processes can result in more sustainable operations
A6	Chavez et. al (2023)	Natural language processing(NLP) method	Design skills is the most requested skillset	Yes	No	No	No	NLP is an effective method for skill extraction
A7	Cruchley et. al (2020)	Survey and focus group interviews	Increased demand for AM specific skills	Yes	No	No	No	Lack of master's level programs focusing exclusively on Metal AM
A8	Chaudhuri et. al (2018)	Explorative interview and case study	Service providers must acknowledge customer concerns	No	No	Yes	No	Companies lack of resources and training.

Footnote: In no alphabetical order.

Sources: The table is produced with the GT package in R Studio.

Table 1: displays results from a literature review with eight entries. **Article_ID** is labeled A1 through A8. **Author** lists the author's name and the publication year, ranging from Hajali et al. (2022) to Chaudhuri et al. (2018). The **design column** describes various research approaches. The **results** column summarizes the main findings from each study, for example, the ineffectiveness of the DfAM process or the lack of digital **infrastructure**. The table also contains columns for **digital infrastructure, skills, services,** and **sustainability** indicate whether each study addressed these topics with a 'Yes' or 'No.' The last column **conclusions**, comments, provides additional insights such as the low consideration of DfAM methods or resource and training deficiencies. The next section presents the litterature analysis.

A1 - The role of digital infrastructure for the industrialisation of Design for additive manufacturing

Introduction

The focus of this study was to identify the role of the digital infrastructure in relation to design for additive manufacturing (Hajali et. al 2022: 1401). Their definition of the digital infrastructure is the information technology used toghether to proces all the data being generated, traced, and transfered during the DfAM proces steps (Alfaify et al. 2020).

Method

A systematic litterature review was conducted to identify research gaps. And a industrial use case was created to explore how the digital infrastructure has an impact on DfAM, and on the industrialisation in general. The use case period lasted for two months, and the case was based on a Swedish construction company that produces construction equipment. In the analysis phase six semi structured interviews was performed (Hajali et. al 2022: 1402).

Results

The case study made it clear that the digital infrastructure can have a negative effect, and therefore make the DfAM process both ineffective and inefficient. Ineffective meaning that results from the tools are poorly utilized. For example during the early iterations, interpretation of the fusion 360 requirements was inaccurate. This can severely limit the opportunities that AM technology can provide, such as the ability to gain value from light weight designs. And inefficient refers to time wasted on iterations during the design phase. Due to uncertainty in regards to where and how data from the design processes could be used or reused to in a valuable manner (Hajali et. al 2022: 1407).

Mitigating initiatives

Based of these insights from the study the recommendation is that DfAM need to focus on the interaction with the SME´s digital infrastructure, in order to succed in implementing AM technology in to the value chain. More concrete, what output a certain method and tool produces, and how this can be used during the DfAM process and throughout the lifecycle of the AM technology (ibid).

Conclusion

In summary, the researchers aimed to analyze the impact of Design for Additive Manufacturing (DfAM) methods and tools on the digital infrastructure. And to explore their effects on the industrialization of additive manufacturing (AM). Two primary conclusions were drawn: Firstly, the manner in which data and information are processed may detrimentally affect industrialization due to the additional time and effort expended on activities that do not add value. This is particularly evident when data is generated and interpreted; it must be integrated into DfAM activities to fully exploit AM's potential. Secondly, current DfAM methods appear to give limited consideration to digital infrastructure, suggesting a need for further attention in this area (ibid).

A2 - 10 of the biggest challenges in scaling additive manufacturing for production in 2020

Introduction

This article present expert insights into the key challenges hindering the adoption of Additive Manufacturing (AM) technology by Small and Medium-sized Enterprises (SMEs). It aims to present a detailed list of 10 specific issues companies encounter in adopting and optimizing their AM production set-ups (AMFG 2023).

Method

This is a blog post. It forms an integral part of AMFG's extensive knowledge base. It is dedicated to presenting expert insights and perspectives from different specialities within the Additive Manufacturing (AM) sector. The article serves as a valuable resource for understanding the nuanced and evolving landscape of AM, highlighting key trends, challenges, and innovations as articulated by leading professionals in the field (AMFG 2023).

Results

For effective utilization of 3D printing in production, it's crucial for companies to have an appropriate digital infrastructure in place for efficient management of their 3D printing processes. Numerous companies are creating this infrastructure by adopting readily available IT solutions. However, these solutions are frequently designed to cater to the needs of conventional manufacturing and may not be ideally suited for the unique demands of 3D printing workflows (AMFG 2023).

Mitigating initiatives

Addressing this specific challenge, the industry has to focus on creating specialized workflow management software tailored for 3D printing. This type of software is designed to streamline the entire process, encompassing various stages such as managing requests, analyzing printability, monitoring machine analytics, organizing production schedules, overseeing post-processing activities, and facilitating communication with suppliers (AMFG 2023).

Conclusion

In conclusion, the adoption of specialized workflow management software is pivotal for integrating 3D printing into production. This software not only streamlines the 3D printing process but also enhances project traceability and simplifies communication with suppliers. It is becoming essential for creating a robust digital infrastructure in additive manufacturing, significantly improving efficiency and easing the integration of 3D printing into broader digital manufacturing systems. This advancement represents a key stride in optimizing operations and fostering innovation within the industry (AMFG 2023).

A3 - Information flow analysis enabling the introduction of additive manufacturing for production

Introduction

This study describes the need for new ways of thinking in AM design, which often relies on different sets of requirements and constraints than traditional manufacturing processes. The established workflow in companies around conventional methods can hinder the full exploitation of AM's benefits. This challenge is compounded by the reliance of designers on tacit knowledge, which can make the adaptation to new technologies like AM difficult. Furthermore, the integration of AM into existing information flows is essential but challenging. This integration can significantly impact various aspects, such as supply chain management, components, and overall business strategies. Recognizing the importance of design for AM (DfAM) guidelines is emphasized as a critical factor in utilizing AM's full potential (Brahma et. al 2023: 2316).

Method

The method used in this study was an information workflow analysis. In relation to concept infrastructure, this analysis focus on a case where a pre-excisting manufacturing setup is present. This means that the company already has made an investment in the digital infrastructure. The main focus of the study is therefore to elucidate the process workflow and its related information flow within a typical industrial setting for product design and manufacturing. An important aspect of the analysis was comparing the workflow dynamics before and after integrating Additive Manufacturing (AM), to describe it's impact on design decision-making processes (Brahma et. al 2023: 2317).

Results

The observations comes from a two step approach. The first refers to the "As is" process investigation. This emphasizes the exploration of pre-excisting tool design and manufacturing. The second approach refers to the "To be" process investigation, where the emphasis is on the identification and the required steps when introducing AM to the current tool setup. Two process diagrams was produced, one from the "As is" proces and the "To be" process (Brahma et. al 2023: 2318). The results is:

Collection of information

- The production tool design process relied on engineers with high proficiency in AM and their ability to share information with each other. The problem here is that alot of the information may not be captured properly (Brahma et. al 2023: 2318).

Relevant collection of information

- It's important to describe the functional and non-functional requirements of the product. For example, a tool might have specific attributes such as durability and strength requirements. This information can optimize material selection process and traceability (ibid).

A decision support tool

- There's a demand for a tool aimed at design engineers and managers. This tool would ease the process of making trade-offs in a factory production environment. The importance of such a systematic comparison escalates when there are changes in criteria or when new criteria become necessary for the product (ibid).

A sustainability aspect

- Additive Manufacturing (AM) presents numerous benefits for eco-friendly product development. Research indicates that this technology can be a greener alternative, as it promotes longer product lifespans, minimizes material waste, and shortens the supply chain. As a result, AM holds potential for more sustainable, circular solutions. However, it's important to note that various important factors, such as social and environmental life cycle analyses (ibid).

Ability to account for uncertainty

- Integrating Additive Manufacturing (AM) into established workflows increases uncertainty. Engineers, familiar with traditional methods, face changes in design and material choices with AM. For instance, a case study describes a shift from metal to polymers, reducing cost and production time but raising questions about product longevity and safety. These uncertainties necessitate rigorous testing and potentially new test procedures to ensure reliability and safety (ibid).

PLM software

- Implementing a Product Lifecycle Management (PLM) system is key for better data recording and reuse in design processes. A PLM system manages extensive data throughout these processes. However, existing PLM systems in companies are often tailored for end products, not for manufacturing aids like tools. This results in a mismatch in information complexity between end products and tools (ibid).

Mitigating initiatives

It's recommended to create a method that makes it easier to compare different manufacturing techniques by gathering information from various steps in the workflows. However, processes that currently use smooth and agile methods should also think about how they use digital tools. These tools shouldn't make the process too complicated and hinder innovation, but instead should be practical and provide good help in making decisions (Brahma et. al 2023: 2323).

Conclusion

To reach a well-rounded design decision, it's essential to gather information from various stages of the activity. When implementing Additive Manufacturing (AM) as a new technology, it's crucial to systematically record both tacit and implicit information. Moreover, this change in the system necessitates the collection of extra information that wasn't needed before. Gathering this information helps in conducting a more detailed comparison between traditional manufacturing methods and AM (ibid).

A4 - Design for sustainable additive manufacturing: A review

Introduction

The escalating environmental concerns have heightened global urgency to embrace sustainable manufacturing practices as a means to mitigate issues like global warming, resource depletion, and waste management. In response to these challenges, Additive Manufacturing (AM) offers significant improvements in energy consumption, production costs, and lead times. This is primarily because the technology generates less material waste and it emits lower levels of CO_2 compared to other technologies (Hegab et. all 2023: 1).

Method

This body of knowledge is derived from an extensive review of previously conducted life cycle assessments (LCA) available in public literature. The aim of this study is to comprehensively collect and analyze all aspects of sustainability related to Additive Manufacturing (AM), encompassing environmental, economic, and social dimensions. It also examines a range of economic strategies that are supported and enhance d by the adoption of AM technology. Lastly, the knowledge from the review highlights the positive outcomes from AM adoption and the negative outcomes from AM adoption (Hegab et. all 2023: 2).

Results

The results from this study presents some benefits as well as challenges companies face when they want to adopt sustainable AM systems (SAM) (Hegab et. all 2023: 10). The advantages of sustainable manufacturing systems are:

- Reduced cost and production time in the product redesign phase.
- More design freedom and shortened time during the design - and production phase.
- Lower cost during the product and component phase.
- Enhanced durability during the product use phase.
- Improved recycling by using waste byproducts as inputs.

The challenges of sustainable manufacturing systems are:

- To provide engineers with proper education about product redesign.
- Resource efficiency and recycling is confined to specific materials.
- Limited durability and speed during the component and manufacturing cycle.
- Low technological maturity makes it difficult to predict how products and parts work toghether.
- Materials such as plastics have limited sustainability and recyclable opportunities (ibid).

Mitigating initiatives

This paper aims to support the AM community in describing challenges associated with sustainable additive manufacturing systems. Three mitigating directions are therefor recommended:

1. The creation of standard test samples for AM that can describe the geometric complexity and structures. (Hegab et. all 2023: 14). This recommendation helps to collect data points and other statistical parameters (ibid)
2. Create a collective database that contains information about the life cycle of different kinds of AM technologies. This ensures that important information is gathered on material, equipment, manufacturing conditions and more (ibid).
3. Create collaboration among the AM community. By collecting reliable life cycle data and inventory that can be shared within the community is of vital importance (ibid).

Conclusion

This article has presented some reliable sustainability guidelines, and some benefits and challenges that are correlated with sustainable additive manufacturing systems(SAM). (Hegab et. al 2023: 14). Investing in SAM can greatly improve ressource efficiency, improve the production system, and enable a company to create a more sustainable business model. But several areas has to be studied to improve the performance of a more sustainable additive manufacturing technologies in the in the future (Hegab et. al 2023: 15). such as, collaborating with stakeholders, and perform more in depth evaluation of AM technologies (ibid).

A5 - Additive manufacturing from the sustainability perspective: proposal for a self-assesment tool

Introduction

It can be a complex challenge to implement a sustainable principles in additive manufacturing (Despeisse et. al 2019: 482). It's important to evaluate the long term effect of the additive manufacturing process and utilization (ibid). Several factors are connecting AM technologies with increased sustainability operations. Among others such as resource efficiency, improved product livecycle, better health and safety conditions for workers (ibid). Despite benefits, potential issues should also be considered, these are: fusion methods use alot of energy. Increased emissions from organic compounds can have a negative effect on workers' health, and limited data availability for life cycle assessment (Despeisse et. al 2019: 483).

Method

This study is a complement of previous studies on the AM sustainability area. The sustainability benefits and challenges comes from a selection of 14 individual cases. The knowledge from the cases serves a exploratory purposes, where the cases are classified as examples of successful implementation during different life cycle stages. Data points for all 14 cases was stored in Excel sheets (Despeisse et. al 2019: 485).

Results

The purpose of this analysis was to identify the best sustainable practices across 14 cases, and to used SDG's as a framework of operationalization. The following results was visible:

- Product performance is a good dimension since it is present in case 9, 4 and 5, because sustainability is present in the production and use phase.
- Extending product life cycle and improved quality and durability was present in cases 1, 2, 8, 9, 10 and 14.
- Decreased logistics impacts was an important dimension aswell in case 3 and 4.
- A reduction in the production process steps was visible in case 9 and 12.

Mitigating initiatives

A critical mitigating initiative aims to operationalize the checklist on a concrete business problem. It's important to use the tool as a four-step approach in relation to the sustainable development goals (SDG's). SME's should use this as a tool to evaluate the sustainability benefits and implication, and thereby take more informed decision for the adoption of new AM technologies (Despeisse et. al 2019: 487).

Conclusion

Results from the case analysis indicate that investment in sustainable AM technologies can result in a more sustainable production operation. But it has to be implemented strategically so that all the sustainability parameters has a positive effect on all the life cycle phases. As of now, issues with AM processes have not been explored in depth, which causes a knowledge gap. More case studies has to be done to increase the knowledge output on this subject matter in the future (Despeisse et. al 2019: 487).

A6 - Skill requirements of additive manufacturing - A textual analysis of job postings using Natural language processing

Introduction

The AM market is projected to keep expanding with a Compound Annual Growth Rate (CAGR) of 23.3% from 2023 to 2030, achieving a valuation of $80 billion by the end of 2023 (Chavez et. al 2023: 301). As the additive manufacturing (AM) industry continues to expand and develop, there's an urgent need for a skilled workforce to satisfy the demand for this technology across various industries. However, to fully harness this potential, it is essential to have a workforce equipped with the necessary knowledge and skills. This encompasses proficiency in design software, understanding material properties, and grasping the manufacturing process. Both companies and educational institutions are acknowledging the importance of training programs and courses to bridge this skills gap and prepare the workforce for the future of additive manufacturing. However, the required knowledge and skills are not static but dynamic, evolving as new and emerging skills surface due to the rapid technological advancement and market expansion in AM (Chavez et. al 2023: 300).

Method

In this study, three distinct natural language processing (NLP) algorithms were applied to extract relevant skill-related information from online job listings. The total number of observations is 11.274, after removing duplications related to job postings. Approximately 57% of these originated from the United States, followed by 11% from the United Kingdom, 10% from Canada, 7% from Australia, 6% from Ireland, 5% from Singapore, and 4% from New Zealand, as illustrated in Figure 4. LinkedIn was the primary platform for job advertisements, accounting for 50% of the data set analyzed (Chavez et. al 2023: 305).

The subsequent sections will clarify the fundamental concepts underlying these algorithms. In the realm of machine learning, there are two primary types of learning: unsupervised and supervised. Unsupervised learning involves a machine learning approach where the model identifies patterns in unlabelled data without direct instructions. On the other hand, supervised learning is where the model is trained using labelled data, with clear directions on the expected output. Supervised learning typically includes both a training phase and a testing phase, where the model's accuracy in predicting the correct output is assessed. The differences between unsupervised and supervised learning are notable. Unsupervised learning tends to be more exploratory, aimed at uncovering hidden patterns or structures within data. In contrast, supervised learning focuses on predicting a specific result. Unsupervised learning is usually applied in situations with little prior data knowledge, whereas supervised learning is preferable when a specific prediction outcome is required (Chavez et. al 2023: 302-303).

Results

The skill demand is divided into two pillars, one is hard skills and the other one is soft skills. (Chavez et. al 2023: 310). The skills are as follows:

Hard Skills:

- CAD (Computer-Aided Design)
- CATIA (Computer-Aided Three-dimensional Interactive Application)
- Proengineer (Product Design Software)
- Solidworks (3D CAD Design Software)
- SiemensNX (Advanced Engineering Software)
- GD&T (Geometric Dimensioning and Tolerancing)
- Creo (3D CAD Software)
- Fusion360 (Cloud-based 3D Modeling Software)
- ANSYS (Engineering Simulation Software)
- Magics (Software for the AM industry)
- Simulation (Digital Testing)
- AM materials knowledge (e.g., metals, polymers)
- LPBF (Laser Powder Bed Fusion)
- SLA (Stereolithography)
- FDM (Fused Deposition Modeling)
- SLS (Selective Laser Sintering)

- Binder jetting (AM Process)

Soft Skills:

- Project management
- Detail-oriented
- Proactive
- Good communication skills
- Multitasking
- Time management
- Critical thinking
- Ability to work with minimal supervision
- Creative
- Sustainability focus

Mitigating initiatives

The study sheds light on the additive manufacturing (AM) industry's challenges, notably the shortage of firsthand insights from operations managers, which could result in overlooking strategic and managerial aspects. Despite these limitations, the research findings from this article offer valuable information on job requirements and competencies, providing a foundation for mitigating initiatives aimed at training providers, job seekers, recruiters, and policymakers (Chavez et. al 2023: 314).

Conclusion

This article presents an analysis of three advanced natural language processing (NLP) methodologies—Word2vec, LSTM, and Named Entity Recognition (NER) with BERT—to pinpoint skills pertinent to the field of additive manufacturing (AM). The Word2vec model proves adept at identifying related skills through cosine similarities, establishing connections between them. LSTM emerges as a useful tool for determining frequently demanded skills in job datasets, facilitating targeted analysis by industry, design software, and AM techniques. NER with BERT, utilizing a predefined dictionary, excels at recognizing less commonly cited skills, though it requires a user well-versed in the subject matter for optimal use (Chavez et. al 2023: 314).

For the dictionary construction necessary for NER with BERT, the study employed a dual-strategy approach: bottom-up, informed by LSTM outputs, and top-down, guided by the established AM standard ISO/ASTM 5290. The study suggests a path forward that includes the creation of a dynamic data collection method, potentially harnessing web scraping or API integration. The culmination of these efforts could be the launch of an online skills observatory platform, which would afford users the ability to track job market trends and emerging skills in real-time, particularly valuable for those keen on monitoring the rapid technological evolution within the AM industry. This conclusion highlights the study's contribution to the understanding of AM skills requirements and anticipates its practical applications for various stakeholders in the job market (Chavez et. al 2023: 315).

A7 - Research and needs analysis on metal additive manufacturing

Introduction

In recent years (within the past five years), the UK and EU have seen a substantial output of reports from government bodies, collaborative research efforts, and industrial initiatives, all scrutinizing the economic and strategic significance of AM, as well as the challenges of advancing and leveraging this technology. The evolution of AM is poised to transform manufacturing and consumer industries. Nonetheless, the complex nature of AM products and their production processes demands a workforce with new, specialized skills, which are currently in short supply. Not only is there a deficit of engineers skilled in AM, but also a noticeable absence of training programs aimed at closing this skills gap (Cruchley et. al 2018: 5). To reach this goal, the ADMIRE project will utilize this report to assess the needs of the AM industry and prospective students. The goal is to establish a collaborative Master of Science program in Metal Additive Manufacturing, fulfilling the demand for skilled professionals in this innovative field (ibid).

Method

Two digital surveys were created to gather the perspectives of industrial managers, who are stakeholders in a potential Master of Science program in Metal Additive Manufacturing. The surveys included a variety of questions, which are detailed in the Appendix. The initial survey garnered 126 responses, while the second received 88, all from professionals and experts in the field and industry. A curated set of findings from these surveys is presented and examined in the following sections. Figure 9 depicts the assortment of organizations that participated in the survey, highlighting the variety of industries related to AM and the range of stakeholders involved (Cruchley et. al 2018: 15).

A protocol was developed to guide the focus group sessions. Each group was structured to include at least three but no more than ten participants, with no strict time limit set for the overall discussion or for addressing individual questions. The facilitator used their judgment to determine the appropriate time to proceed to subsequent questions or to conclude the session. Before beginning the discussions, participants were briefed on the project's objectives (Cruchley et. al 2018: 17).

In total, four focus group meetings were conducted. The first session was organized by ISEMP at the University of Bremen, catering to the higher education stakeholder group. The second was held at the University of Birmingham for the prospective student stakeholder group. The third and fourth sessions took place at Cranfield University, again for the higher education stakeholders and the industrial end-users, respectively. Detailed records of these focus group discussions can be found in the Appendix (ibid).

Results

The collective outcomes from both the online surveys and focus group sessions have underscored a clear demand and enthusiasm for a Master of Science degree in Metal Additive Manufacturing. The feedback has emphasized several critical elements that should influence the course's structure. There is a consensus on the necessity for substantial industrial engagement within the course, ensuring it aligns closely with the needs of the industry. The incorporation of industry-sponsored or relevant projects was deemed essential, along with the cultivation of hands-on skills using AM equipment.

Yet, there was a recognition of the need for flexibility in other areas, such as assessment techniques, where there was unanimous agreement on the importance of employing a variety of methods. Another significant consideration was the approach to learning, with the emphasis on adapting to the students' backgrounds (Cruchley et. al 2018: 21).

Mitigating initiatives

Strengthening partnerships between academic institutions and the broader industrial sector is critically important and is particularly vital in the field of additive manufacturing (AM). AM stands out as a swiftly advancing method of production, offering distinct benefits in efficiency, adaptability, and environmental sustainability. The intricate nature of AM products and their production methods demands a workforce that is not only highly skilled but also equipped with a novel set of competencies. It has been recognized that the pool of employees possessing such specialized skills is notably scarce (Cruchley et. al 2018: 33).

Conclusion

This report has conducted a thorough review and analysis of the current field of the Additive Manufacturing (AM) industry and the requirements of key stakeholders regarding the establishment of a specialized joint Master of Science program in Metal Additive Manufacturing. Insights from online surveys and focus groups, aimed at these key stakeholders, have clearly indicated a group of individuals interested in this proposed master's program. There is a recognized need for closer and more integrated cooperation between academic institutions and the industry in crafting an all-encompassing curriculum for an appropriate metal AM course, especially to bridge the current gap in suitable training offerings.

Additionally, the gathered feedback has pinpointed specific aspects of the course's syllabus and structure that are critical for its success. The report also notes that while there are numerous short courses on AM available across Europe, there is a lack of master's level programs focusing exclusively on Metal AM to meet the educational needs within the industry. Consequently, there is a significant demand for a well-structured, industrially relevant master's program in metal additive manufacturing (ibid).

A8 - The role of service providers in 3D print adoption

Introduction

The decision to adopt 3D printing (3DP) technologies is influenced by the perceived benefits and expected performance improvements. This motivation, along with a company's readiness to expand 3DP operations, can vary based on the organization's current position in the adoption cycle and their maturity level in adopting new technologies. Discrepancies between expectations and actual satisfaction, as well as between anticipated and realized service quality, impact a user's inclination to embrace new technologies, as Ha outlined in 2018. But, research specifically addressing the adoption of 3DP, especially within industrial manufacturing firms, remains sparse. This includes studies on the challenges these companies face in adoption, the disparity between expected and actual services received, and strategies to mitigate such issues. The focus on understanding and overcoming the hurdles in adopting 3DP in industrial contexts is important, considering the technology's growing importance and potential benefits. This illustrate the need for more comprehensive research in this area, addressing the specific challenges and needs of manufacturing companies as they integrate 3DP into their operations (Chaduri et. al 2019: 2).

Method

In this study, the adopted approach for exploratory interviews and case study analysis. The analysis was aimed at determining the extent of challenges encountered by companies in establishing 3D printing (3DP) facilities. This examination included perspectives from companies that attempted to set up 3DP operations (customers) and those offering supportive services in this area (service providers). To explore these aspects, two distinct interview questionnaires were created, one tailored for 3DP users and the other for 3DP service providers. These were formulated based on gaps identified in the literature review (Chaduri et. al 2019: 6).

Results

Challenges was identified in different adoption phases. In the adoption phase, one challenge was evident: Setting up machines and optimizing processes for specific parts were significant challenges. Additionally, there was a notable lack of ‘plug and play’ solutions from equipment manufacturers, coupled with a scarcity of training or educational support. One service provider, SG1, noted the difficulties arising after machine delivery and setup. They observed that, despite the expertise of the start-up engineer, issues like incomplete prints or defects were common. This often led to misconceptions about the technology’s reliability, though the real issue was generally the need for optimization of general parameters for specific parts. SG1 highlighted their role in assisting customers, especially less experienced ones, in this optimization process (Chaduri et. al 2019: 8). Another identified challenge was the difficulty in designing for 3DP, acknowledged by four customer firms, but only one service provider. This was compounded by the lack of a trained workforce with a deep understanding of both the equipment and the processes involved. Three customer firms and one service provider recognized this as a substantial hurdle to effective 3DP implementation (ibid).

Mitigating initiatives

Service providers are essential in guiding customers through the adoption of new technologies in several ways, as outlined by Autry et al. in 2010. They play a crucial role in assisting customers with selecting appropriate technology, equipment, and processes. Additionally, they keep customers informed about future advancements and provide opportunities for experimentation and training with the technology. Reflecting on Sandström's 2016 study on 3DP's impact on the hearing aid industry, the initial uncertainty surrounding new technology makes it challenging to decide on the most suitable technological approach. Therefore, it's important for firms to closely monitor technological developments, particularly before a dominant design emerges, and to develop absorptive capacity, a concept introduced by Cohen and Levinthal in 1990. The concerns raised by firms in this context echo these observations, highlighting the need for support and guidance in navigating the complexities of adopting novel technologies like 3DP (Chaduri et. al 2019: 12).

Conclusion

Research on the involvement of service providers in the adoption of 3D printing (3DP) by industrial users is notably scarce. In the Technology Acceptance Model (TAM) literature, the role of service providers is seldom considered in explaining how customers adopt technology. Therefore, this article has made significant academic contributions by 1) detailing the ways in which 3DP service providers can aid customers in overcoming the challenges of 3DP adoption during pre-adoption, adoption, and post-adoption stages, and 2) analysing the role of these service providers through the lens of TAM (ibid). This knowledge is particularly relevant for 3DP service providers aiming to enhance the adoption of 3DP among their clients. It provides them with insights into specific services required at different stages of adoption and the suitable service delivery models to implement. Additionally, it offers valuable information to industrial users about potential challenges in adopting 3DP, preparing them to face these challenges or to seek necessary services from their providers (ibid).

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