LCAMP

Learner Centric Advanced Manufacturing Platform

D3.2 - M24 - Analysis of the Impacts and Evolution of jobs in Advanced Manufacturing

D3.2 - M24 - G Germany sub-report

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GLOSSARY AND/OR ACRONYMS

AI Artificial Intelligence

AKF Ablative Keyhole Fusion

B2B Business to Business

B2C Business to Consumer

CNC Computer Numerical Control

CAM Computer-Aided Manufacturing

EQF European Qualification Framework

ESCO European Skills, Competences, Qualifications and Occupations

FDM Fused Deposition Modelling

HVET Higher Vocational Education and Training

IOT Internet of Things

LCAMP Learner-Centric Advanced Manufacturing Platform

OEE Overall Equipment Effectiveness

SLA Stereolithography

SLS Selective Laser Sintering

SME Small and Medium-sized Enterprises

VET Vocational Education and Training -

CONTENT TABLE

EXECUTIVE SUMMARY

The LCAMP (Learner-Centric Advanced Manufacturing Platform) project under the CoVE initiative aims to enhance regional skill ecosystems in Advanced Manufacturing.

LCAMP plans to establish a European Platform of Vocational Excellence for Advanced Manufacturing, promoting resilience and innovation across regions through collaboration.

This report is a result of the LCAMP Observatory, which is one of the services the LCAMP platform will make available for the final users. The Observatory is led by the French cluster *Mecanic Vallée* and the French VET centre CMQEIf.

During this second year of work, the Observatory Work Package 3 launched an analysis on the impacts of digital and green transitions trends on jobs and skills of the workforce in the advanced manufacturing industry. The analysis focused on a selection of jobs occupied mainly by people qualified by European Qualification Framework (EQF) 3-6 studies.

These analyses are detailed in each regional / national sub-reports written by five countries (the Basque Country, France, Germany, Italy and Turkey) on 28 jobs in the advanced manufacturing industry.

Despite some variations in study methods and presentation of results, this year has established a shared methodological approach and a standardised format for reporting findings, paving the way for further progress.

Drawing from literature review and interviews conducted with companies in the field, several key findings have emerged.

This report is focused on German analysis and results.

Collaborative Work Process:

- **Methodology:** Each country relied on its own network of experts, with their differences in terms of areas of expertise and availability.
- **Frame:** A detailed presentation, described within a structured database, allows quick cross analysis, based on different axis: trends, skills, jobs/tasks.
- **Results:** Major tendencies of digital and green transition trends, impact on jobs, and required skills have been identified as a result of this analysis.
- **Year 3:** To obtain complete, usable, and certified results going forward, it will be necessary to combine efforts on common analyses. This could result in analysing the impacts of common jobs and reporting in a harmonized framework.

1. METHODOLOGY OF THE D3.2-M24 OBSERVATORY REPORT[1]

To build up the database and keep it up to date, the Observatory's operating methodology comprises a five-stage process, which takes place on a regular basis.

- Stage 1: Diagnosis and Priority - Set up Priorities and Fields to Observe.
- Stage 2: Search and Information Gathering
- Stage 3: Information Analysis
- Stage 4: Create value. Development of LCAMP Reports
- Stage 5: Disseminate-Communicate.

In this section, the structure of the LCAMP Observatory is explained, focused for this 2024 year, on trends impacts description on selected jobs.

That structure follows the process cycle as shown in **Erreur ! Source du renvoi introuvable.** below:

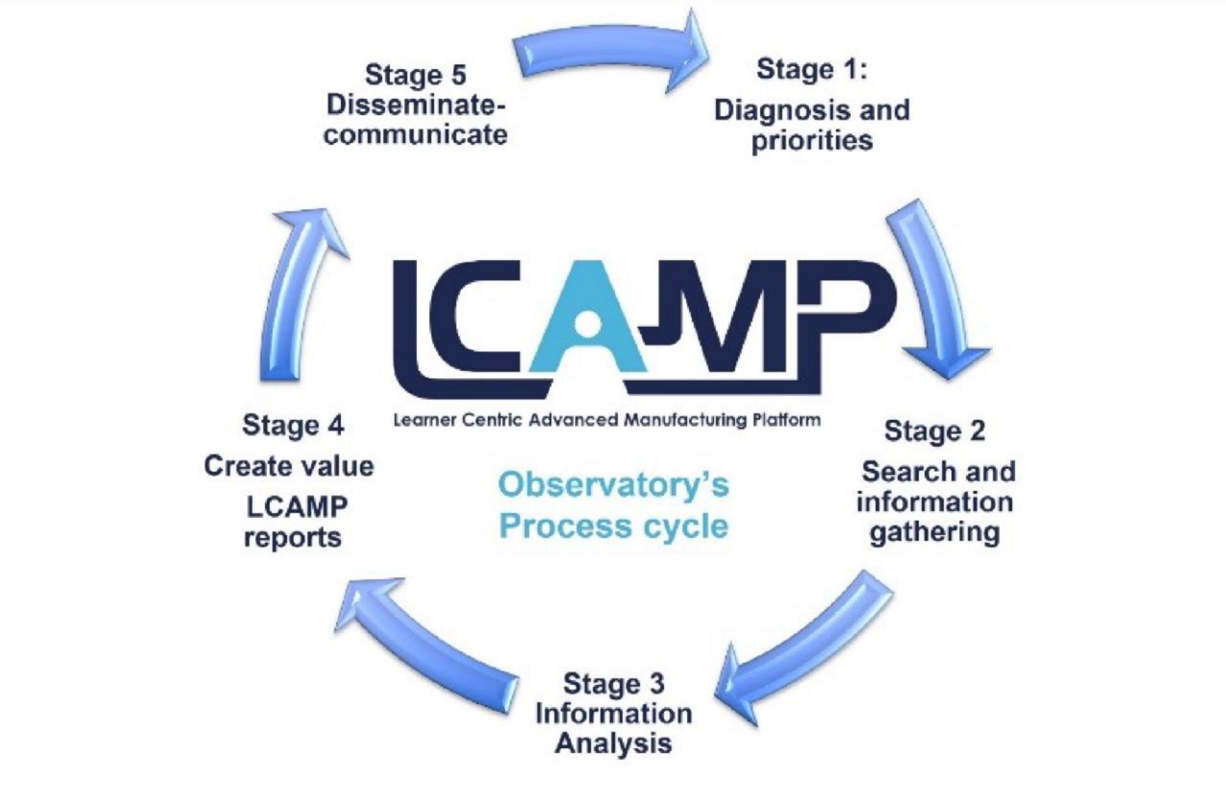

Figure 1 : Process cycle for the observatory

[1] Danton, H. (in press, 2024). D3.2 - M24 - A Methodological sub-report. Mecanic Vallée.

1.1. STAGE 01 DIAGNOSIS AND PRIORITIES

Before advancing to the analysis of job impacts and objectives for subsequent phases, the diagnostic stage began by addressing key questions. These questions are designed to consistently align with the goals, tasks, and processes necessary for producing the expected deliverables:

1. What is expected from the Observatory D3.2 - M24?
2. What do those outcomes do?
3. What are the outcomes of the Observatory Report 2: June 2024, D3.2 –M24?

Hereafter, are the answers to the above questions:

1. Describe how jobs are impacted by Advanced Manufacturing Digital Technologies and the Green Transition and the related knowledge/skills to be developed.
2. D3.2 outcomes are the inputs of other LCAMP services, mainly:
    - Learner Centric Training for Advanced Manufacturing (WP5)
    - Platform (WP8) and Impact Assessment
3. The Sub-reports are detailed in the above paragraph 2-Outcomes.

1.1.1. FIELDS & AREAS OF OBSERVATION

To define the scope / areas of observation, the following process took place:

- **First statement:** this Report describes which digital and green transition trends identified in D3.2 – M12 (LCAMP, 2023), are impacting a selection of jobs, instead of describing how each digital and green transition trend is already impacting jobs.
  Based on this statement and because it was not possible to analyze all the industrial jobs, the analysis focuses on a list of jobs selected by each country.

- **Second statement:** it was decided not to select new jobs, during the "research phase". The job to select already exists in industry.

  Each country has selected a list of relevant jobs based on the following 5 criteria:

  1. **Industry sectors:** the selected job is to be included in the LCAMP industry sector scope.
  2. **Jobs Impacted:** it has been verified that the jobs related to the digital and green transitions are impacted by the new trends previously identified in–D3.2 – M12;
  3. **Employability:** evaluate the employability / demand within industry.
  4. **Smart Specialisation Strategy** (https://s3platform.jrc.ec.europa.eu/): jobs must belong to industrial sectors included in the regional Smart Specialisation Strategies.
  5. **Education level:** it is validating that VET and high VET jobs - I4.0-centred Qualifications are delivered at EQF (European Qualification Frame) level 3 to 6.

To facilitate harmonisation, each job is listed in the following tables with the corresponding ESCO occupation name and code. This enables the identification of jobs that are common across countries and those that are country specific. These are classified into three groups:A – Job selected by 3 countries and more.
B – Job selected by 2 countries.
C – Job selected only by one country.

- The initial global list was condensed to shorten the report's length; each country submitted a brief list of jobs for analysis.

From these submissions, selected jobs were approved for further examination in the Sub-reports. Industry Sectors

With regard to the sectors, the jobs chosen are included in the list below, representing the areas of greatest interest for observation by the LCAMP:

- Machine tools (Mechanical Engineering)
- Automotive
- Aerospace
- Electric and Electronic Industries
- Transport
- Maritime.

Sectors defined by the EU Commission (EU commission, 2022).

Jobs Impacted

Analysis is built by analysing which and how tasks are impacted by the Digital and Green transition trends identified in previous Report (lcamp.eu/wp-content/uploads/sites/53/2023/07/D3.2-Observatory_reportN1-2.pdf) (Danton-a, 2023). Below is the reviewed list:

Table 1 : list of transition trends

TREND REF	DIGITAL TRANSITION TRENDS
1-1	Internet of Things (IoT) / Smart Sensors / 5G technology
1-2	Artificial Intelligence (AI) / Machine learning / Big Data Analytics
2-1	Virtual and Augmented Reality
2-2	3D scanning
3-1	Cybersecurity
3-2	Edge Computing vs Cloud Computing / Blockchain for Supply Chain / Quantum Computing

4-1	3D Printing/Additive Manufacturing
4-2	Robotics and Automation
4-3	Collaborative Robots (Cobots)
4-4	Digital Twins
4-5	Adaptive Manufacturing Systems
4-6	Predictive Maintenance
TREND REF	**GREEN TRANSITION TRENDS / SUSTAINABLE MANUFACTURING**
5-1	Renewable Energy Integration
5-2	Circular Economy
5-3	Energy Efficiency
5-4	Waste Reduction
5-5	Green Logistics and Supply Chain
5-6	Sustainable Material Innovation
5-7	Carbon Footprint Management
5-8	Eco-friendly Packaging
5-9	Biomimicry in Design
5-10	Sustainable IT Infrastructure
5-11	Environmental Monitoring and Reporting
5-12	Corporate Social Responsibility (CSR) Initiatives

Employability

Based on common European reports, available regional reports, regional surveys, and other regional methodologies (refer to the following tables), it has been verified that the selected jobs are in high demand and/or experiencing rapidly increasing demand.

Smart Specialisation Strategy

It was necessary to confirm that the selected jobs are relevant to the Smart Specialisation Strategy (European Commission, n.d.) in the respective country.

Education Levels

LCAMP is focused on advanced manufacturing for the European VET and HVET Education systems. According to the European Qualifications Framework (EQF) (Europass, 2017), education levels from EQF3 to EQF6 are covered by VET and Higher VET Education systems.

Then it is validated that selected jobs can be performed at EQF (European Qualification Frame) 3 to 6 level.

1.2. STAGE 02 AND 03 SEARCH & INFORMATION GATHERING AND ANALYSIS

Consortium partners employ various methodologies within the Technology Surveillance and Competitive Intelligence systems. The information gathering strategy outlined in the Observatory incorporates the best practices from these methods. It adapts their use according to the observation targets, as detailed in the D3-1 Observatory Methodology document. (Danton-b, 2023).

In this section, the methodologies and tools to be used by partners are described. There are also some software and IT applications that could be used by the project, if tailored to LCAMP requirements: The section classifies as follows:

- Different methodologies, how they are used.
- Software or other tools used in each methodology (if any).
- When each methodology or combination of those are used.

During this second year of the project, and specifically its analysis phase, the Observatory is based mainly on secondary research activities, to do desk research activities, which have a predominant role in the Observatory.

1. Web Scraping, “Real time” information.
2. Publications, Professional magazines, clusters’ reports, etc.
3. EU project’s results review.

Desk research activities were conducted at the national level in the LCAMP partner countries of France, Germany, Italy, Slovenia, Spain, and Turkey. Based on these regional and national desk research efforts, national reports were produced. This forms part of Stage 04: Extracting Value & Report Creation.

1.2.1.EXTRACT VALUE & REPORT CREATION

It is proceeded in two steps:

- **Step 1:** Sum-up all jobs' impacts within the following document:

Table 2 : Tasks and skills impacted related to occupation.

OCCUPATION REFERENCE	OCCUPATION TITLE	TASK	IMPACTING DIGITAL TECHNOLOGY AND/OR GREEN TRANSITION	IMPACT DESCRIPTION	RELATED NEEDED SKILLS/ KNOWLEDGE IMPACTED	EXPECTED TENDENCY FOR SKILL EVOLUTION	SKILL TYPE	MATURITY LEVEL TO REACH	SKILL ESCO URL	SKILL DESCRIPTION
Code of the occupation in ESCO	Specify the Occupation title (Preferred Term)	Name of task	Reference s from « D3.2 M12 » reviewed (see table provided below)	Main impacts identified on this task	If Skill available in ESCO data base: ESCO Skill name.	Code of the occupation in ESCO	Skill/ knowledge	L4 (Expert) Bloom descriptors: (create, evaluate, analyse, apply, understand, remember) L3 (Intermediate+) Bloom descriptors: evaluate, analyse, apply, understand, remember) L2 (Intermediate) Bloom descriptors: (analyse, apply, understand, remember) L1 (Basic/Beginner) Bloom descriptors: (apply, understand, remember)	If Skill availa ble in ESC O data base: http:// dxxx	If Skill available in ESCO data base: ESCO Skill description. If not indicate skill description.

- **Step 2:** Write the relevant sub-report with all the detailed information.

1.2.2.VALIDATION PROCESS

The validation process assures the quality of the reports generated within the Observatory.

The process of validation of the results of the analyses carried out by the Observatory must be very exhaustive. The credibility of the results published is based on three pillars.

1. The contrasted quality of the sources used.
2. The transparency of the process of analysis of information.
3. The validation of the conclusions by authorities with expertise in the relevant fields.

Considering the high relevance of the validation process, it is carried out on 3 levels:

1. Internal validation at a thematic team level and/or at regional level.
2. Validation at consortium level.
3. External validation carried out by panels of experts.

Internal Validation

The Observatory's steering group approves the reports. The final internal evaluation is led by the Observatory leader and co-leader, that are *Mecanic Vallée* (MV).

The internal validation is a prerequisite to call the panel of experts and continue with the external validation steps.

Panel of Experts

An international panel of experts was created during the first year of the project. This panel has to approve the conclusion and finding to be included in the reports elaborated in the LCAMP Observatory.

Composition, duties, frequency and timing of the panels of experts was already described in the D3-1-Observatory Methodology" (https://lcamp.eu/wp-content/uploads/sites/53/2023/07/D3-1-Observatory-Methodolgy-Final-version-1.pdf) document (Danton-b, 2023).

Once the research teams of the LCAMP Observatory established the main conclusions and findings to be included in the reports of the observatory, and after the validation of those reports by the Observatory's steering group, the regional panel of experts met and approved the findings.

Each panel decided the format of their meetings and the methodology.

The reports by the LCAMP partners () documented the findings and conclusions from the panel discussions. The respective partner prepared the final regional report to be submitted to the observatories' steering committee. To enhance communication, stimulate collaboration, and collect feedback for final validation, each country was encouraged to adopt a review process using shared tools that facilitate the examination of documents and statements.

1.3. STAGE 05 COMMUNICATION

All sub-reports are shared with Work Packages 5 and 8 (WP5 and WP8). They are designed to be practical and structured for use by WP5 and WP8. The subsequent tables titled "Tasks and Skills Impacted Related to Occupation" (e.g., Table 12), which summarize the impacts on all jobs, serve as a database for both WP5 and WP8.

1.4. LOCAL SPECIFICITIES

Due to the unique context of each country, the general methodology was clarified and/or adjusted as needed. These modifications are detailed in the respective sub-reports. Below is a summary of these adjustments.

In the Basque Country the research methodology combines a) an analysis of regional reports; b) a selection of jobs for the analysis; c) interviews with companies.

In Italy and France, a combination of these specificities / clarification was applied.

In Germany, the analysis follows a mixed academic approach that aims to combine different methods. AI was used to identify a trend and provide supporting data. Business surveys were conducted to confirm the results and gain further insights. This comprehensive approach allows a broad understanding of the issue to be developed and sound conclusions to be drawn.

In Turkey, the development of the report follows a methodology that is in line with other partners' approach. In terms of selecting the jobs, the Smart Specialisation Strategy for Turkey was considered as the main source while the outline of the jobs inspected in this report were decided after discussions and distribution among other project partners from different countries.

Analysis of the impacts were carried out by the Turkish project partners from different backgrounds and occupations, trying to cover as much variety as possible and consider each and every aspect.

The emerging report was validated by experts from the advanced manufacturing sector by sharing the draft version and gathering feedback / using a Survey Tool where individual statements from the report are converted into a survey to make the validation process easier for the experts.

(Jensen, 2007)(Hippel, 2005)(EU commission, 2022)(Europass, 2017)(Europass, 2017)(Europass, 2017)(Europass, 2017)

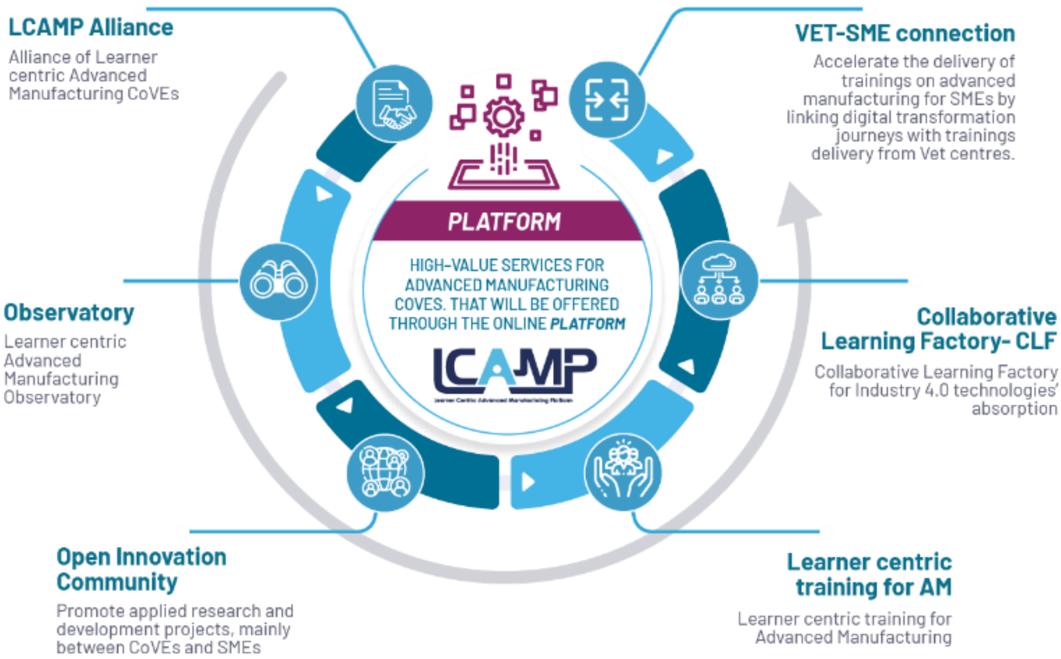

Figure 2 : Outputs and services to be delivered by the LCAMP platform

2. JOB'S IMPACT ANALYSIS

This section deals with the analysis of the selected job. As mentioned in the methodology it was analysed the changes faced by companies and identifying the **levers of those changes** affecting the specific jobs; then it was described the **changes in skills and knowledges** detected in the analysis.

2.1. LIST OF SELECTED JOBS

Here is the short list selected by Germany (comes from "job selection list GE V10 Germany V09; 31.05.2024"):

Table 3 : List of selected jobs: 3D printing technician and CNC machine operator

ESCO CODE	ESCO OCCUPATION	1 - INDUSTRY SECTORS	2 - DIGITAL AND GREEN TRANSITIONS NEW TRENDS IMPACTING	3 - EMPLOYABILITY	4.RELEVANCE FOR THE SMART SPECIALISATION STRATEGY – AT REGIONAL/COUNTRY?	5 - EDUCATION LEVEL.
3118.1	3D printing technician	**Automotive,** **Aerospace,** **Electric and electronic Industries,** **Machine tools (Mechanical Engineering),** **Maritime**	1-1 Internet of Things (IoT) / Smart Sensors / 5G technology, 1-2 Artificial Intelligence (AI) / Machine learning / Big Data Analytics, 2-2 3D scanning, 4-1 3D Printing/Additive Manufacturing, 4-2 Robotics and Automation, 4-4 Digital Twins, 4-5 Adaptive Manufacturing Systems, 4-6 Predictive Maintenance, 5-4 Waste Reduction, 5-2 Circular Economy, 5-3 Energy Efficiency, 5-6 Sustainable Material Innovation, 5-11 Environmental Monitoring and Reporting	**Employability in 2024:** **The rapid adoption of additive manufacturing in aerospace, automotive, healthcare, and consumer goods is driving demand for skilled operators. Additive manufacturing's benefits, like reduced lead times and design flexibility, boost job opportunities across sectors. High demand exists for operators skilled in managing Advanced Manufacturing equipment, preparing digital models, post-processing, and quality control.** **Employability in 5 Years (2029):** **Technological advancements require operators to update their skills to enhance speed, accuracy, and material diversity. More integrated roles in hybrid manufacturing settings create additional jobs, blending traditional and additive manufacturing skills. Specialisation in specific types of additive manufacturing, such as metal or polymer printing, offers new career paths.** **Employability in 10 Years (2034):** **Seasoned operators find opportunities in leadership, training, or entrepreneurial roles within the industry. Full integration with Industry 4.0 necessitates a deep understanding of digital technologies and data analytics. Staying competitive will require continuous learning and adaptability to modern technologies and market demands.** **Conclusion:** **Promising employability prospects exist for Additive Manufacturing Operators, with rapid growth expected in this sector.**	The region of Baden-Württemberg considers Advanced Manufacturing as one of the priorities in its S3. https://ec.europa.eu/regional_policy/assets/s3-observatory/regions/de1.html	EQF Level 4 (trained skilled worker or equivalent): Operators undertake corresponding tasks, potentially with supervisory roles, troubleshooting, and process optimisation.
7223.4	Computer Numerical Control machine operator	**Machine tools (Mechanical Engineering), Automotive, Aerospace, Maritime, Electric and electronic Industries**	1-2 Artificial Intelligence (AI) / Machine learning / Big Data Analytics, 3-1 Cybersecurity, 4-2 Robotics and Automation, 4-3 Collaborative Robots (Cobots), 4-4 Digital Twins, 4-5 Adaptive Manufacturing Systems, 1-1 Internet of Things (IoT) / Smart Sensors / 5G technology, 5-3 Energy Efficiency, 5-4 Waste Reduction	**Current Factors (2024):** **CNC machining is crucial in industries like aerospace, automotive, electronics, and medical devices, ensuring steady demand for skilled operators. Technological advancements in automation, precision, and efficiency require highly skilled operators. Integration of robotics and CAM software boosts efficiency, increasing the need for proficient operators. A skill shortage has created a competitive job market with many opportunities for qualified individuals.** **Employability in 5 Years (2029):** **Increased automation and robotics integration sustain high demand for adaptable CNC operators. Advanced digital skills, including proficiency in CAD/CAM software and CNC programming, are essential. Specialisation in areas like additive manufacturing, multi-axis, or high-speed machining could offer new career paths based on industry needs.** **Employability in 10 Years (2034):** **CNC machining remains vital to manufacturing, ensuring continued demand for skilled**	The region of Baden-Württemberg considers Advanced Manufacturing as one of the priorities in its S3. https://ec.europa.eu/regional_policy/assets/s3-observatory/regions/de1.html	EQF Level 5 (technician or equivalent): CNC-Technicians at this level have advanced CNC skills, capable of programming complex operations, proficient in multi-axis machining, adaptive control, and integrated CAD/CAM systems optimizing tool paths, and conducting comprehensive troubleshooting. They also

				operators. Engaging with emerging technologies such as nanotechnology, advanced materials, and digital twins are crucial, necessitating ongoing learning. Global economic and industry trends will influence employability, emphasizing flexibility and adaptability in skills and practices. **Conclusion:** **CNC operators who continuously update their skills and adapt to innovative technologies and industry trends can expect to remain highly employable, supporting the hypothesis provided.**		manage less experienced operators and contribute to process improvements.

2.2. 3D PRINTING TECHNICIAN

2.2.1. JOB DESCRIPTION AND SCOPE

Job Description

3D Printing Technician (ESCO 3118.1) ESCO description: *“3D printing technicians assist in the designing and programming of products, ranging from prosthetic products to 3D miniatures. They may also provide 3D printing maintenance, check 3D renders for customers and run 3D printing tests. 3D printing technicians can also repair, maintain, and clean 3D printers”* (ESCO, n.d.).

LCAMP description proposal: 3D printing technicians, also known as additive manufacturing technicians or specialists, are responsible for operating and maintaining 3D printing equipment and processes to create three-dimensional objects from digital models.

Here after the **ESCO table for reviewing an existing Occupation** filled to propose a change on the description:

Table 4 : ESCO template for reviewing an existing Occupation.

OCCUPATION URI	OCCUPATION TITLE	COMMENTS ON THE PREFERRED TERM	NEW DESCRIPTION OF AN EXISTING OCCUPATION	ALTERNATIVE LABELS TO BE REMOVED/ MODIFIED/ ADD	ESSENTIAL SKILLS AND KNOWLEDGE CONCEPTS TO ADD/REMOVE	OPTIONAL SKILLS AND KNOWLEDGE CONCEPTS TO ADD/REMOVE
3118.1 **http://data.europa.eu/esco/occupation/4cf7be91-fed9-47a7-9ca9-e74c7eb6becb**	3D printing technician	Description ESCO should now contain “operating 3D printers”	3D printing technician is now part of serial production processes, not only focused on design phase and prototype production	N/A	N/A	N/A

Business Area

The job profile of a 3D Printing Technician spans across various sectors, including engineering, manufacturing, medical, aerospace, automotive, consumer goods, electronics, tooling, jigs and fixtures, custom machine parts, and even emerging areas such as concrete printing. This summary explores the responsibilities and impact of 3D Printing Technicians in these industries, compare traditional manufacturing processes with additive manufacturing methods, analyse the benefits for B2B and B2C sectors, discuss technical developments, the Green Factory transformation, and the implications for German SMEs.

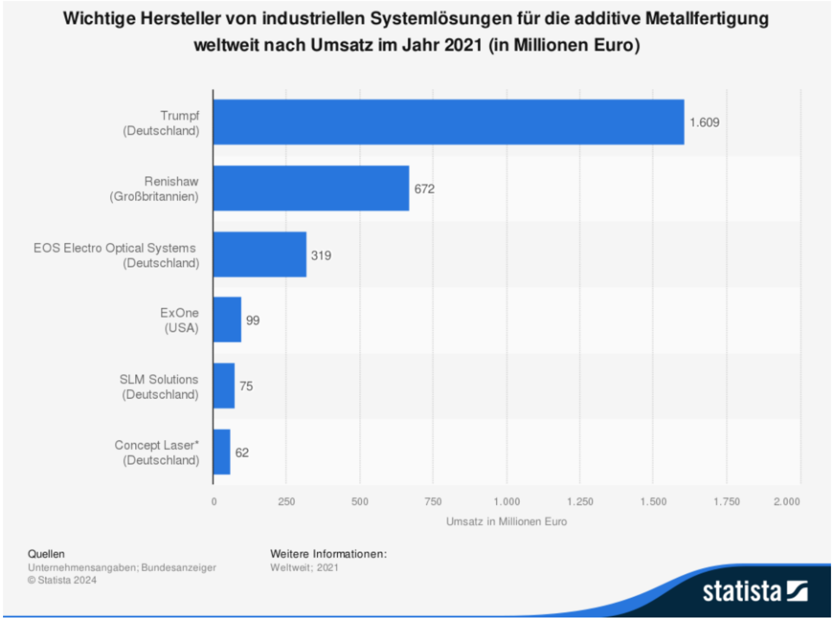

Figure 3 : [Digital Trends: Additive Manufacturing]. In Statista Digital Trends Report (p. 33).

The chart provides valuable insights into the current state and future projections of additive manufacturing technologies.

- **Adoption rates:** Shows the increasing adoption rates of additive manufacturing in various industries.
- **Market growth:** The chart illustrates the projected market growth and investment trends within the industry worldwide.

This ensures that the essential information is accessible to English-speaking readers while providing proper attribution to the original German source.

Engineering and Manufacturing

In engineering and manufacturing, 3D Printing Technicians contribute to rapid prototyping, tooling, and final part production. They work with engineers to optimise designs for additive manufacturing, select appropriate materials and operate 3D printers. Quality control, process optimisation and troubleshooting are essential aspects of their role to ensure efficient production. According to the OECD (2018), "*3D printing is transforming traditional manufacturing processes by enabling decentralised production, thus enhancing the entire value chain from design to delivery*." (Rural regions of the future: Seizing technological change).

Medical

3D printing technicians play a critical role in the medical field, producing patient-specific implants, surgical guides, and anatomical models. They work closely with healthcare professionals to translate medical imaging data into 3D printed objects for surgical planning and training. Regulatory compliance and quality control are paramount in medical applications. As highlighted by Conner et al. (2014), "*The medical sector is significantly benefiting from 3D printing technologies, which allow for the creation of customized medical devices tailored to individual patient needs*" (Rural regions of the future: Seizing technological change).

Aerospace and Automotive

In the aerospace and automotive industries, 3D printing technicians contribute to lightweighting, part consolidation and rapid prototyping. They use additive manufacturing to produce complex geometries, reducing material waste and assembly time. Applications include engine components, air ducts, brackets, and interiors, where additive manufacturing offers design freedom and performance benefits. Beyer (2014) notes, "*Boeing has integrated 3D printing into their manufacturing process, producing over 20,000 parts, thus illustrating the significant impact of additive manufacturing on reducing production time and costs*"

Consumer Goods and Electronics

3D printing technicians in the consumer goods and electronics sector produce customised articles, wearables, and electronic housings. They use additive manufacturing for rapid iteration, low-volume production, and product personalisation. From smartphone cases to home appliances, additive manufacturing enables efficient production of intricate designs with minimal tooling requirements. As mentioned in "*Introduction to Digital Economics," "Additive manufacturing allows for high customization and rapid production cycles, making it ideal for consumer goods and electronics sectors.*" (Ebin, 2021).

Tooling, Jigs, and Custom Machine Parts

In tooling, jigs and custom machine parts, 3D printers create specialised tools, fittings and components to optimise production processes. Additive manufacturing offers benefits such as design complexity, lead time reduction and cost effectiveness compared to traditional machining methods. According to the OECD (2018), "*The ability to produce custom tools and fixtures quickly and at a lower cost gives manufacturers a competitive edge in optimizing production workflows.*" (Rural regions of the future: Seizing technological change).

Concrete Printing

Emerging areas such as concrete printing also fall within the remit of 3D printing technicians. They are contributing to the development and deployment of large-scale 3D printers capable of constructing buildings, infrastructure and architectural elements using concrete-based materials. This innovative approach offers potential benefits in terms of construction speed, cost effectiveness and design flexibility. As noted by Conner et al. (2014), "*Concrete 3D printing has the potential to revolutionize the construction industry by enabling faster, more cost-effective building methods while allowing for complex architectural designs.*"

Wood Printing

The process of 3D printing with wood allows for the fabrication of objects from two principal materials: filaments or powders. The technology offers the advantage of producing objects with a natural look and feel, while also enabling the creation of complex shapes. The technology has applications in the fields of art, crafts, and education.

These examples demonstrate the broad applicability of additive manufacturing across different business sectors, with ongoing research aimed at advancing the technology and its integration into green factory practices. As noted by Chinga-Carrasco (2020), "*Biocomposite filaments, including those derived from wood, offer the potential for sustainable 3D printing applications due to their natural aesthetics and versatility in design.*"

Traditional Manufacturing vs. Additive Manufacturing Processes

While traditional manufacturing processes such as injection moulding, CNC machining and casting are well established, additive manufacturing offers unique benefits such as design freedom, reduced material waste and on-demand production capabilities. As Balubaid and Alsaadi (2023) explain, "*Additive manufacturing (AM) has been widely adopted in various industries to enhance new product development with minimal time constraints, offering significant advantages in terms of design flexibility and reduced waste*". Additive manufacturing processes such as Fused Deposition Modelling (FDM) and Selective Laser Sintering (SLS) enable the production of complex geometries and customised parts without the need for expensive tooling.

Benefits for the B2B and B2C Sectors

Additive manufacturing brings several benefits to both the B2B and B2C sectors. For businesses, it offers faster time-to-market, lower production costs and improved product customisation, leading to increased competitiveness and profitability. According to Perifanis and Kitsios (2023), "*The integration of advanced manufacturing technologies such as additive manufacturing enhances business agility, reduces lead times, and allows for greater product customization, which are critical factors for maintaining competitiveness in today's fast-paced market*". Consumers gains from access to personalised products, on-demand manufacturing and sustainable solutions tailored to their preferences.

Technical Developments and Future Expectations

Recent advances in additive manufacturing include the development of high-performance materials, multi-material printing and improved process automation. Innovations such as bioprinting, 4D printing and in-situ monitoring systems hold promise for applications in healthcare, construction, and aerospace. Future developments may focus on improving the printing speed, scalability, and sustainability of additive manufacturing processes. As noted by Tuvayanond and Prasittisopin (2023), "*The integration of advanced technologies such as bioprinting and 4D printing is set to revolutionize sectors like healthcare and construction, offering unprecedented capabilities in design and functionality.*"

They are also contributing to emerging areas such as concrete and wood printing, where additive manufacturing techniques are providing innovative solutions for the construction and furniture industries. According to a report by The Business Research Company (2023), "*The use of 3D printing in construction, including concrete printing, is expected to grow significantly, driven by the need for efficient, sustainable building practices*".

Green Factory Transformation

Additive manufacturing contributes to the green factory transformation by reducing material waste, energy consumption and carbon emissions compared to classic production methods. According to Gopal, Lemu, and Gutema (2023), "*Using additive manufacturing over traditional subtractive technologies may result in considerable material and energy resource savings, especially if the component is appropriately designed for manufacture.*" Material recycling, the use of bio-based resins, and localised production further enhance the sustainability of additive manufacturing processes, in line with the growing emphasis on environmental responsibility in manufacturing.

Impact on German SMEs

German SMEs are increasingly adopting additive manufacturing technologies to remain competitive in global markets. According to the German Engineering Federation (VDMA), the number of companies using additive manufacturing in Germany is steadily increasing. SMEs are using additive manufacturing to streamline production, offer customised solutions and differentiate themselves from the competition. As highlighted by Yaqub and Alsabban (2023), "*Industry 4.0 technologies, including additive manufacturing, are key drivers of digital transformation, enhancing competitiveness and operational efficiency for contemporary organizations*." In the future, it can be expected to see further integration of additive manufacturing into the workflows of German SMEs, fuelling innovation and economic growth. According to Zhang et al. (2021), "*The continuous evolution of smart manufacturing paradigms, driven by advanced information technologies and digital twins, will enable SMEs to innovate and scale their operations more effectively*".

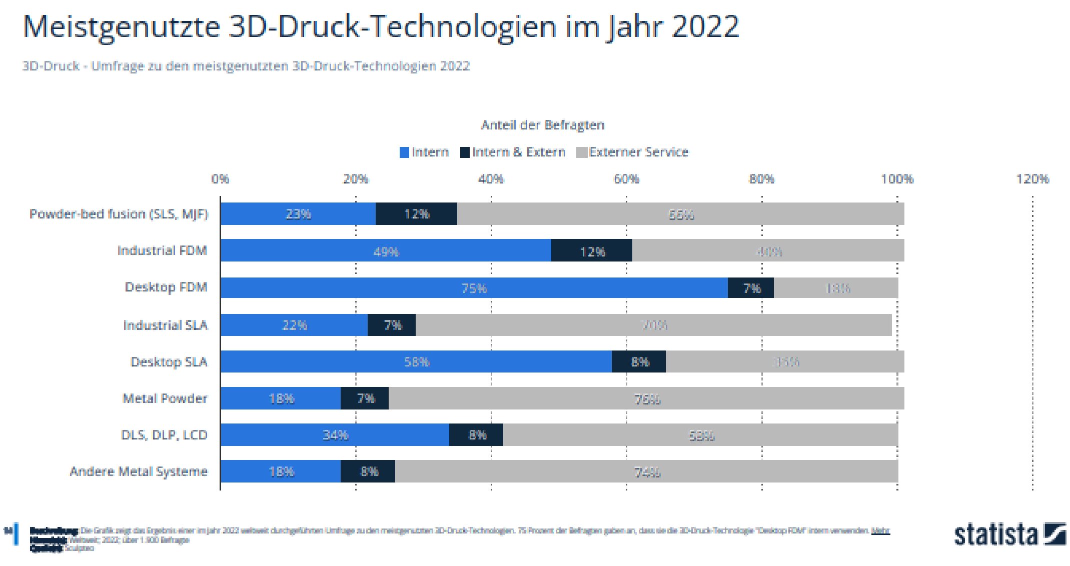

Figure 4 : Most used 3D printing technologies in 2022]. In Statista Digital Trends: Additive Fertigung (p. 14).

This graphic, sourced from the "Statista Digital Trends: Additive Fertigung" report, is presented in German. It offers valuable insights into the prevalent 3D printing technologies based on a worldwide survey conducted in 2022 with over 1,900 respondents.

The graphic highlights several key points:

- **Desktop FDM:** 75% of respondents reported using desktop FDM technology internally.
- **Powder-bed Fusion:** Includes technologies such as SLS and MJF, widely used across various sectors.
- **Industrial FDM and SLA:** Both are significant, with notable usage both internally and externally.

This ensures that the essential information is accessible to English-speaking readers while providing proper attribution to the original German source.

Key Figures

- **Global Additive Manufacturing Employment Trend:** The employment trend in global additive manufacturing has shown significant growth over the past decade. According to industry reports, the market growth in the additive manufacturing sector has been around 20% in recent years. This indicates a strong upward trend in employment opportunities within the additive manufacturing industry, driven by increased adoption in various sectors such as aerospace, automotive, healthcare and consumer goods.
- **Global Development of Additive Manufacturing Patents:** The development of additive manufacturing patents has increased globally, reflecting continued innovation and investment in 3D printing technologies. According to the European Patent Office, the annual growth rate of patent applications related to additive manufacturing has been overwhelming over the past decade. This suggests a robust expansion of intellectual property protection and technological advancement in the field of additive manufacturing.
- **Evolution of 3D Printing Technologies:** 3D printing technologies have evolved significantly over the past decade, with advances in speed, accuracy, material diversity and scalability. The annual growth rate of technological advances in 3D printing has been stunning based on industry analysis. This includes improvements in additive manufacturing processes such as selective laser sintering (SLS), fused deposition modelling (FDM), stereolithography (SLA) and binder jetting, as well as the development of new materials and software tools to improve functionality and efficiency.

While these figures provide a general indication of trends, specific percentages may vary depending on the source and timeframe of the data analysed see Figure 5 below.

2.2.2. CONTEXT AND LIMITATIONS

Context and Evolution

Over the past two decades, the additive manufacturing (AM) industry in Germany has experienced significant growth and evolution. Initially, additive manufacturing was primarily used for rapid prototyping and low-volume production. However, advances in technology and materials have expanded its applications to include end-use parts, tooling and even components for critical industries such as aerospace and automotive. According to The Business Research Company, "*The growth observed in the additive manufacturing market can be attributed to the increasing demand for prototyping, the necessity for customization, and handling complex geometries, especially in the aerospace and automotive industries.*" (Additive Manufacturing Global Market Report, 2024). While large industrial companies have been quick to adopt additive manufacturing, small and medium-sized enterprises (SMEs) have faced with unique dares combined with chances in utilizing this technology. As highlighted by IMARC Group (2023), "*Despite the rapid adoption of additive manufacturing technologies by large industrial firms, SMEs encounter both challenges and opportunities that require addressing specific technological, financial, and skill-related barriers to fully leverage AM's potential*".

Development of Different Additive Manufacturing Applications

- **Rapid prototyping**: Additive manufacturing has gained traction in Germany for rapid prototyping, allowing companies to quickly iterate designs and validate concepts.
- **Positive development:** Rapid prototyping has become more accessible and affordable, leading to increased adoption across industries.
- **Production of end-use parts:** Advances in materials and process reliability have enabled additive manufacturing to produce end-use parts in industries such as aerospace, automotive and medical.
- **Positive development:** The use of additive manufacturing for end-use parts has resulted in reduced lead times, cost savings, and design flexibility.
- **Tool and jig making:** Additive manufacturing is increasingly used to produce customized tools, jigs, and fixtures, offering benefits in terms of design complexity and lead time reduction.
- **Positive development:** The adoption of additive manufacturing for tooling has enabled manufacturers to optimise production processes and reduce downtime.

2.2.3. FACTORS SHOWING POSITIVE DEVELOPMENT, STAGNATION, OR NEGATIVE TRENDS FOR SMES

Positive Development Factors for SMEs

- **Accessibility:** Low-cost 3D printers and accessible materials have made additive manufacturing more feasible for SMEs.
- **Customisation:** Additive manufacturing allows SMEs to offer highly customized products without the need for expensive tooling.
- **Innovation:** SMEs often have the agility to adopt new technologies and innovate in their respective industries.

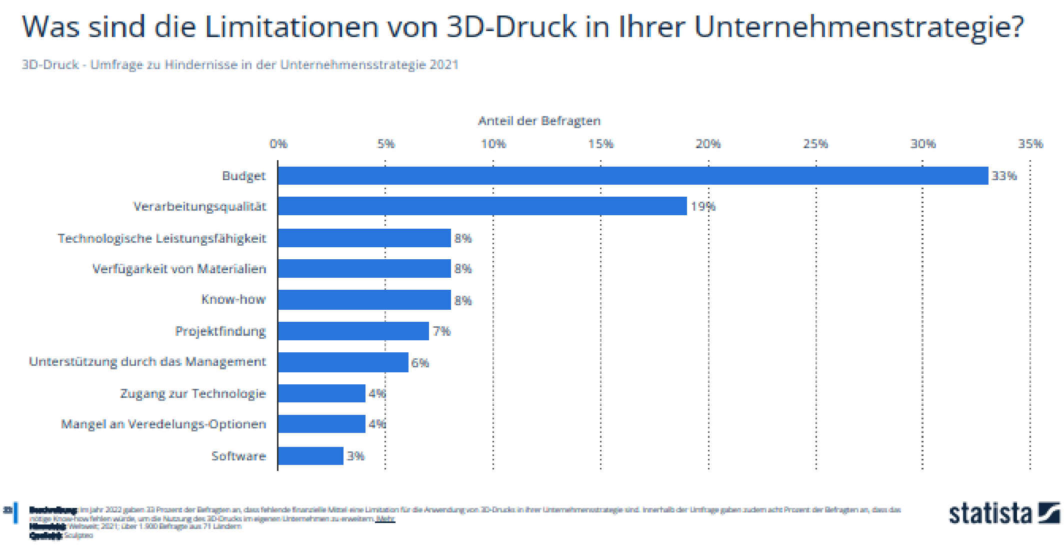

Figure 5: S [What are the limitations of 3D printing in your business strategy?]. In Statista Digital Trends: Additive Fertigung (p. 22).

In this study, a graphical interpretation detailing the limitations of 3D printing in business strategies is provided in Figure 16. The graphic provides valuable insights into the challenges faced by companies in adopting 3D printing technologies based on a worldwide survey conducted in 2022 with over 1,900 respondents from 71 countries.

The graphic highlights several key points:

- **Budget Constraints:** 33% of respondents indicated that financial limitations are a major barrier.
- **Lack of Know-how:** 8% reported a lack of necessary expertise to expand 3D printing usage.
- **Technological Capabilities and Material Availability:** Other significant barriers include processing quality, technological performance, and material availability.

Stagnation or Negative Trend factors for SMEs

- **Lack of resources:** SMEs may lack the financial resources and expertise required to invest in and fully exploit additive manufacturing technologies.

- **Scalability issues:** Scaling up additive manufacturing processes for mass production can be challenging for SMEs due to limited resources and infrastructure.
- **Skills gap:** SMEs may struggle to find skilled personnel with expertise in additive designing, additive manufacturing, hindering adoption and implementation.

2.2.4. FROM CURRENT SITUATION TO ON-GOING SITUATION

Here after the description of the main tasks impacted by **Digital Technology** and/or **Green transition**, modifications and evolutions of the related needed skills.

Table 5 : Tasks and skills impacted related to Printing technician occupation.

	Occu-pation Title	3D Printing Technician						
TASK	IMPACTING DIGITAL TECHNOLOGY AND/OR GREEN TRANSITION	IMPACT DESCRIPTION	RELATED NEEDED SKILLS/KNOW-LEDGE IMPACTED	EXPECTED TENDENCY FOR SKILL EVOLUTION	SKILL TYPE	MATURITY LEVEL TO REACH	SKILL ESCO URL	SKILL DESCRIPTION
Material Handling	5-6 Sustainable Material Innovation	Integrate 3D Printing Technology ability, constraints in Material Handling	**Material Science**	+	Knowledge	L2	http://data.europa.eu/esco/skill/142f3f7f-f15f-412e-a5fe-f75755b5dbe0	Field of science and engineering that researches new materials based on their structure, properties, synthesis, and performance for a variety of purposes, including increasing fire resistance of construction materials.
			Data Analysis		Skill	L3	http://data.europa.eu/esco/skill/2b92a5b2-6758-4ee3-9fb4-b6387a55cc8f	Collect data and statistics to test and evaluate to generate assertions and pattern predictions, with the aim of discovering useful information in a decision-making process.
Operate, Control & Monitor	1-1 Internet of Things (IoT) / Smart Sensors / 5G technology	Integrate 3D Printing Technology ability, constraints in Machinery Operation	**IOT Integration**		Knowledge	L2	http://data.europa.eu/esco/skill/f049d050-12da-4e40-813a-2b5eb6df6b51	The general principles, categories, requirements, limitations and vulnerabilities of smart connected devices (most of them with intended internet connectivity).

	1-2 Artificial Intelligence (AI) / Machine learning / Big Data Analytics	Integrate 3D Printing Technology ability, constraints in Quality	**Real Time Data Analytics**			L3	http://data.europa.eu/esco/skill/97bd1c21-66b2-4b7e-ad0f-e3cda590e378	The science of analysing and making decisions based on raw data collected from various sources. Includes knowledge of techniques using algorithms that derive insights or trends from that data to support decision-making processes.
		Integrate 3D Printing Technology ability, constraints in CAD/CAM	**AI Applications**				http://data.europa.eu/esco/skill/7a757fa5-9a6f-43ab-9e66-f8f4dba1ffcb	Use computer-aided manufacturing (CAM) programmes to control machinery and machine tools in the creation, modification, analysis, or optimisation as part of the manufacturing processes of workpieces.
	4-6 Predictive Maintenance	Integrate 3D Printing Technology ability, constraints in safety standards	**Dynamic Risk Management**		**Skill**	L2	http://data.europa.eu/esco/skill/96550830-539b-4746-96aa-92aa4959945d	Identify risks and apply a risk management process, e.g. hazard analysis and critical control points (HACCP).
Problem Solving		Integrate 3D Printing Technology ability, constraints in Basic Troubleshooting	**Predictive Maintenance**		**Knowledge**	L3	http://data.europa.eu/esco/skill/334e3e49-fb02-4051-809a-f06adfdc1c40	Identify operating problems, decide what to do about it and report accordingly.
			Advanced Creative Problem Solving		**Skill**		http://data.europa.eu/esco/skill/adc6dc11-3376-467b-96c5-9b0a21edc869	Find solutions to practical, operational or conceptual problems in a wide range of contexts.
Machine & Process Safety	**3-1 Cyber-security**	Integrate 3D Printing Technology ability, constraints in safety standards	**Cybersecurity Basics**		**Knowledge**		http://data.europa.eu/esco/skill/a4346013-a967-4a58-a533-6b32ad1364c5	The principles, ethical issues, regulations and protocols of data protection.

General Advanced Manufacturing	**4-1 3D Printing/Additive Manufacturing**	Integrate 3D Printing Technology ability, constraints in Advanced Manufacturing Processes	**Digital Literacy**		**Skill**		http://data.europa.eu/esco/skill/c8fa4313-80b0-4f37-8b1b-1739707bc362	Instruct students in the theory and practice of (basic) digital and computer competency, such as typing efficiently, working with basic online technologies, and checking email. This also includes coaching students in the proper use of computer hardware equipment and software programmes.
Work with multidisciplinary teams		Integrate 3D Printing Technology ability, constraints in Teamwork and Customer Interaction	**Enhance Collaboration**			L2	http://data.europa.eu/esco/skill/e4da156d-a6c4-4b29-935b-eff9c9553cf1	Working confidently within a group with each doing their part in the service of the whole. Understanding and respecting the roles and competencies of other team members.

2.2.5. IMPACT ON SKILLS

The previous analysis described impacts on skills. Here after new skills changes on skills/knowledges already identified in ESCO database and new skills/knowledges.

Table 6: Impact on Skills - 3D Printing Technician

EXISTING SKILL/ KNOWLEDGE URI	NEW RELEVANT SKILL/KNOWLEDGE NAME ADDED	ESSEN-TIAL SKILL	NEW RELEVANT SKILL/KNOWLEDGE DESCRIPTION	EXISTING SKILL/KNOWLEDGE NAME TO BE UNLINKED	ASSOCIATED OCCUPATIONS TO BE ADDED /REMOVED
http://data.europa.eu/esco/skill/f049d050-12da-4e40-813a-2b5eb6df6b51	IOT Integration	Skill	Keep up with latest I4.0 applications	No	Production Engineers Process Engineers R&D Engineers SCM
http://data.europa.eu/esco/skill/8d4271ca-c9fd-40b3-875f-15f78332a49e	Real Time Data Analytics	Know-ledge	Keep up with Real Time Quality Control	No	Production Management Quality Management Process Engineers
http://data.europa.eu/esco/skill/cb1b0777-0388-4b01-a0cf-7c6bbfbbd61d	AI Applications	Skill	Keep up with the latest I4.0 applications	No	Production Engineers Process Engineers R&D Engineers SCM
http://data.europa.eu/esco/skill/d55e3866-3ec1-4bbb-b946-2c16696d0dcb	Material Science	Skill	Keep up with material specifications	Add to ESCO Database: “material specification”	Process Engineer R&D Engineer

http://data.europa.eu/esco/skill/2b92a5b2-6758-4ee3-9fb4-b6387a55cc8f	Data Analysis	Skill	Collect data and statistics to test and evaluate to generate assertions and pattern predictions, with the aim of discovering useful information in a decision-making process.	No	Process Engineer Quality Engineer
http://data.europa.eu/esco/skill/13d301d0-98cb-414f-a8f9-a3f059228133	Advanced Creative Problem Solving	Skill	Ability to develop innovative solutions to complex engineering challenges. This ability includes the critical thinking to identify and apply novel approaches to machine programming, process optimisation and production planning, increasing efficiency, quality, and performance in the advanced manufacturing environment.	Add to ESCO Database: “Ability to develop innovative solutions to complex engineering challenges”	Production Management Process Engineers R&D

2.3. CNC MACHINE OPERATOR

2.3.1. JOB DESCRIPTION AND SCOPE

Job Description

CNC Machine Operator (ESCO 7223.4) ESCO description: *"Computer numerical control machine operator's set-up, maintain and control a computer numerical control machine to execute the product orders. They are responsible for programming the machines, ensuring the required parameters and measurements are met while maintaining quality and safety standards"* (ESCO, n.d.).

Here after the **ESCO table for reviewing an existing Occupation** filled to propose a change on the description:

Table 7 : CNC machine operator occupation definition

OCCUPATION URI	OCCUPATION TITLE	COMMENTS ON THE PREFERRED TERM	NEW DESCRIPTION OF AN EXISTING OCCUPATION	ALTERNATIVE LABELS TO BE REMOVED/ MODIFIED	ESSENTIAL SKILLS AND KNOWLEDGE CONCEPTS TO ADD/REMOVE	OPTIONAL SKILLS AND KNOWLEDGE CONCEPTS TO ADD/REMOVE
7223.4 **http://data.europa.eu/esco/occupation/5c082067-ea18-4ccb-8c43-e70b18ad8120**	computer numerical control machine operator	Smart Factory content expansion	CNC operator should include I4.0 contents	N/A	Advanced Machining Enhance Collaboration Advanced Creative Problem Solving Advanced Creative Trouble Shooting Adapt To Changing Situations Predictive Maintenance Advanced Coding Robotics And Automation Data Analysis	Cybersecurity Basics

Business Area

CNC (Computer Numerical Control) operators are an integral part of many industries, operating sophisticated machinery to produce precise parts and components. Their job profiles cover a wide range of sectors, including engineering and manufacturing, medical, aerospace, automotive, consumer goods and electronics, tooling and jigs, and bespoke machine parts. In addition, this summary provides an insight into traditional manufacturing processes as well as newer techniques such as 3D measurement and additive manufacturing. The benefits for both the B2B and B2C sectors are identified together with current technical developments, the Green Factory transformation, and its impact on German SMEs.

- **Engineering and manufacturing**: In the manufacturing process, the role of the CNC operator is significant, as they are responsible for interpreting intricate technical drawings and ensuring that the fabricated parts comply with the exacting specifications set out. Their expertise ensures that all components produced meet the required standards for precision and quality. According to the U.S. Bureau of Labor Statistics (2023), "*CNC operators play a critical role in the manufacturing process by interpreting complex technical drawings and ensuring that the produced parts meet stringent specifications*".
- **Medical**: In the medical field, CNC operators are responsible for the precise manufacturing of implants, prosthetics, and medical instruments. They use biocompatible materials and strictly adhere to rigorous quality standards to ensure the safety and efficacy of these medical products. As noted by Legg (2024), "*The high precision and accuracy of CNC machining allow for the creation of custom implants and surgical instruments that meet stringent medical standards, ensuring the safety and effectiveness of these critical medical products*".
- **Aerospace:** CNC machinists in aerospace manufacturing produce critical components for aircraft and spacecraft that meet stringent requirements for strength, durability, and reliability. They work with advanced materials and complex geometries to meet aerospace standards. As noted by the U.S. Bureau of Labor Statistics (2023), "*CNC machinists play a pivotal role in aerospace manufacturing by producing components with high precision and tight tolerances, essential for ensuring the safety and reliability of aircraft and spacecraft*".
- **Automotive**: In the automotive industry, CNC operators are responsible for the precision manufacturing of crucial components, including powertrains, parts for electrical and combustion engines, and numerous other components. Their work ensures that the produced vehicles adhere to stringent standards of safety, performance, and efficiency. By maintaining tight tolerances during the machining process, they contribute significantly to the overall quality and reliability of automotive products. As stated by Mastercam (2023), "*CNC machining is essential in the automotive industry for manufacturing complex parts such as engine components and transmission systems, ensuring high precision and adherence to stringent safety and performance requirements*".
- **Consumer goods and electronics**: CNC machinists produce intricate parts for consumer electronics, appliances, and gadgets. By meticulously assembling components, they enhance both the functionality and the visual attractiveness of consumer products. According to Grand View Research (2023), "*The demand for CNC machines in the consumer electronics sector is driven by the need for precision in manufacturing intricate components, which are essential for the functionality and aesthetic appeal of modern electronic devices*".
- **Tooling and jigs**: CNC machinists produce tools, moulds and fixtures used in various manufacturing processes. By manufacturing high quality tools intended for mass production, they significantly enhance profitability. As noted by Yusof and Latif (2019), "*CNC machining is essential for creating precise tooling and fixtures, which significantly enhances manufacturing efficiency and productivity by ensuring accurate and repeatable processes*".
- **Custom Machine Parts**: CNC machinists address the custom machining demands of diverse industries by fabricating specialised components tailored to distinct customer specifications. Leveraging their proficiency in CNC programming and machining methodologies, they provide highly customized and precise solutions. As noted by Prakash (2022), "*The ability of CNC machinists to produce customised, precision parts are vital across multiple sectors, including automotive, aerospace, and consumer electronics, ensuring that specific customer requirements are met with high accuracy*".

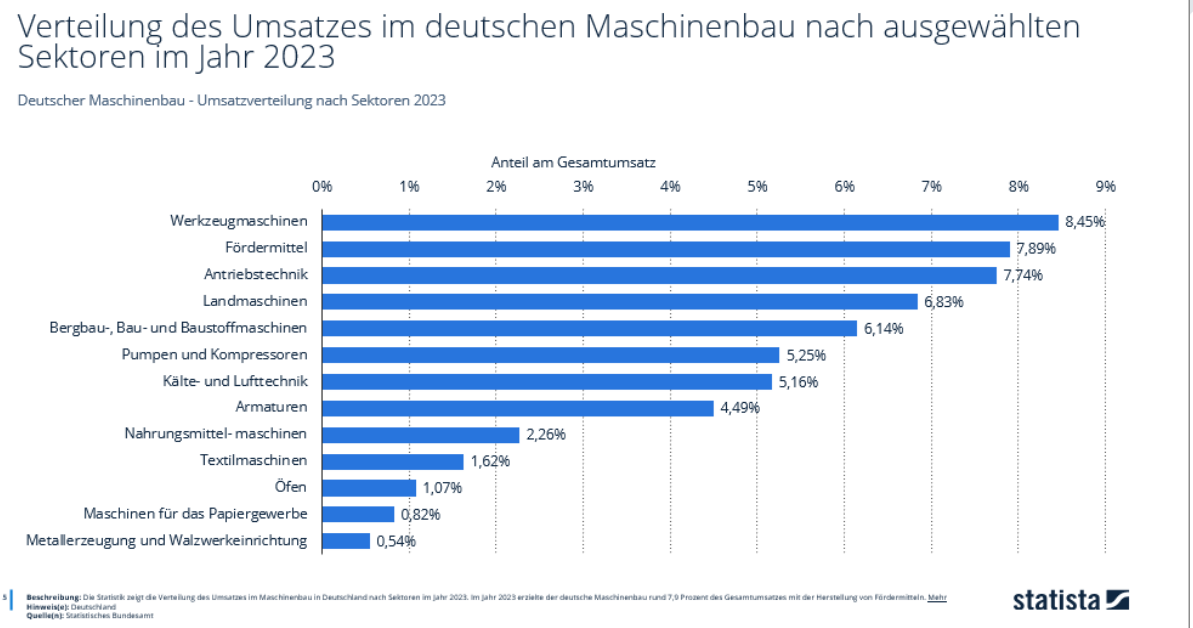

Figure 6: [Distribution of revenue in German mechanical engineering by selected sectors in 2023]. In Statista Industrien & Märkte: Werkzeugmaschinen in Deutschland (p. 5).

The graphic provides valuable insights into the revenue contributions of different sectors within the German mechanical engineering industry.

The graphic highlights several key points:

- **Tool Machinery:** Constitutes 8.45% of the total revenue in the mechanical engineering sector.
- **Conveying Machinery:** Accounts for 7.89% of the total revenue.
- **Drive Technology:** Represents 7.74% of the total revenue.

This ensures that the essential information is accessible to English-speaking readers while providing proper attribution to the original German source.

Traditional Manufacturing Processes

- **CNC milling machine:** Used for cutting and shaping solid materials, CNC milling machines enable the production of complex shapes with high precision.
- **CNC Lathe:** CNC lathes rotate workpieces while cutting tools remove material, facilitating the production of cylindrical parts with precise dimensions.
- **CNC wire EDM:** Using electrically charged wire, CNC wire cutting machines accurately shape conductive materials, ideal for intricate designs.
- **CNC Eroding:** Using electrical discharges, CNC eroding machines remove material from workpieces, suitable for producing complex shapes and hardened materials.
- **CNC 3D Measurement:** Advanced metrology techniques such as 3D measuring systems are used to inspect and verify the dimensional accuracy of machined components.

Benefits for the B2B and B2C sectors

- **B2B Sector**: CNC machining offers B2B customers cost-effective solutions to produce customised parts, reducing lead times and improving supply chain efficiency. As noted by Attar et al. (2022), "*The integration of CNC machining into B2B operations has streamlined production processes, allowing for greater customization and efficiency in supply chains, which are critical for maintaining competitiveness*".
- **B2C Sector:** Consumers derive considerable benefit from the use of CNC machining. This process enables the production of products that are not only meticulously engineered with high precision, but also exhibit enhanced functionality and fancy appeal. According to Perifanis and Kitsios (2023), "*CNC machining enables the production of consumer goods with high precision and quality, enhancing the functionality and aesthetic appeal of products, thus meeting the growing demand for high-standard consumer items*".

Technical and Innovative Developments

- **Automation and robotics:** The integration of advanced automation with CNC machining has the potential to significantly enhance productivity, as it allows for the minimisation of cycle times and the reduction of labour expenses. Furthermore, this integration has the capacity to enhance the overall efficiency of manufacturing processes. As noted by Monzón et al. (2024), "*Combining advanced automation with CNC machining enhances productivity by reducing cycle times and labour costs, while improving the overall efficiency of manufacturing processes".*
- **Advanced materials:** The application of CNC machining in the processing of advanced materials, such as composites and high-performance alloys, significantly expands the potential for innovation and development within the aerospace, automotive, and other high-technology sectors. This technological advancement facilitates the creation of intricate and high-precision components, thereby enhancing the capabilities and performance of products in these industries. Monzón et al. (2024) further highlight that "*the use of CNC machining to process advanced materials, including composites and high-performance alloys, opens up new possibilities in aerospace, automotive, and other high-tech industries*".
- **Digitalisation:** Industry 4.0 technologies enable simulations, real-time monitoring, predictive maintenance, and data-driven decision-making in CNC machining processes, optimising efficiency, and quality. According to a study by Yu et al. (2024), "*The integration of digital twin frameworks and AI algorithms in CNC systems significantly enhances the accuracy and efficiency of machining processes by enabling real-time monitoring and predictive maintenance*".
- **Hybrid manufacturing:** Integrating additive manufacturing with traditional CNC machining processes offers hybrid manufacturing solutions that combine the benefits of both techniques for complex geometries and rapid prototyping. The OpenHybrid project demonstrated that "*hybrid machines equipped with both subtractive and additive manufacturing technologies provide unmatched flexibility and efficiency in producing complex parts, reducing the overall production time and costs*" (3DPrint.com, 2021).

Green Factory Transformation

- **Sustainable practices:** CNC operators contribute to sustainability efforts by optimising machining parameters, reducing material waste and implementing environmentally friendly manufacturing processes. As noted by the Energy Efficiency Directive (2023), "*Optimizing energy usage and adopting advanced manufacturing techniques are crucial for improving sustainability in industrial operations, which significantly contributes to reducing waste and conserving resources*".
- **Energy Efficiency:** The integration of energy-efficient technologies alongside renewable energy sources within computer numerical control (CNC) machining processes is essential for reducing energy usage and decreasing the environmental impact of manufacturing operations. By adopting such practices, manufacturers can significantly reduce their carbon emissions and enhance the sustainability of their production activities. According to Félix and Mena (2023), "*Incorporating energy-efficient technologies and renewable energy in CNC machining processes is vital for minimizing energy consumption and lowering the carbon footprint of manufacturing activities*".

Impact on German SMEs

- **Competitive Advantage:** German SMEs using advanced CNC technologies gain a competitive edge through improved productivity, quality, and innovation. According to Altintas et al. (2022), "*The adoption of advanced manufacturing technologies enables SMEs to enhance their competitive position by improving operational efficiency and product quality*" (Management International Review, 62(3), 456-478).
- **Skills Development:** Training programmes and education initiatives ensure a skilled workforce capable of driving technological innovation and growth in the manufacturing sector. As highlighted by Proksch et al. (2021), "*Continuous skill development and education initiatives are vital for SMEs to maintain technological competitiveness and foster innovation*".
- **Collaborative Networks:** Collaborative networks play a pivotal role in bolstering the innovation capabilities of small and medium-sized enterprises (SMEs). Through these networks, SMEs gain access to a wealth of new knowledge and cutting-edge technologies, which are instrumental in enhancing their competitiveness on a global scale. This interconnected approach facilitates the exchange of expertise and resources, thereby driving technological advancement and market leadership. Neumeyer et al. (2021) note that "*Collaborative networks significantly contribute to the innovation capacity of SMEs, allowing them to access new knowledge and technologies that enhance their global competitiveness*".

2.3.2. CONTEXT AND LIMITATIONS

Over the past two decades, CNC (Computer Numerical Control) manufacturing has played a significant role in the industrial landscape of Germany. This summary provides an overview of the development of CNC use in German industry, identifying factors that show growth, stagnation, or negative trends. It also examines the constraints and challenges facing CNC manufacturing, including employee turnover, training, and recruitment.

- **Technological advances:** Germany has been at the forefront of technological innovation, leading to the widespread adoption of CNC machines in manufacturing processes. The implementation of sophisticated CNC technologies has notably enhanced efficiency, accuracy, and adaptability within industrial contexts. According to the German Trade & Invest report (2024), "*Germany's leadership in industrial technology and continuous innovation have positioned it as a global hub for CNC manufacturing, enhancing productivity and precision in various sectors.*"
- **Industry 4.0 integration:** The concept of Industry 4.0, which emphasises the digitalisation and automation of manufacturing processes, has driven the development of CNC manufacturing in Germany. This integration has enabled seamless communication between CNC machines, production systems, and enterprise networks, facilitating data-driven decision-making and optimising production efficiency. "*Industry 4.0 has revolutionized German manufacturing by integrating digital and physical systems, leading to smarter and more efficient production processes*" (SAP News, 2024).
- **Diversification of applications:** The use of CNC technology has broadened significantly, extending its applications beyond the traditional automotive and engineering sectors. It is now used in fields as diverse as aerospace, medical device manufacturing and consumer electronics. This expansion into diverse industries has not only created new opportunities for CNC manufacturers and service providers but has also been a catalyst for innovation and economic progress. "*The expansion of CNC technology into new industries has opened up significant opportunities for growth and innovation, particularly in high-precision sectors like aerospace and medical devices*" (SpringerLink, 2024).
- **Focus on precision engineering**: German manufacturers prioritise precision engineering in their CNC manufacturing processes. By using advanced machining techniques and high-quality materials, they are able to produce components with tight tolerances and superior surface finishes. This focus on precision and quality has established Germany's reputation for manufacturing excellence. This focus on quality has reinforced Germany's global reputation for manufacturing excellence. "*The emphasis on precision and quality in CNC manufacturing has solidified Germany's reputation as a leader in high-quality industrial production.*" (SpringerLink, 2024).

Factors for Positive Development

- Investment in research and development: Germany's commitment to research and innovation has catalysed significant advances in CNC technology. This focus has facilitated the development of state-of-the-art machining and improved process optimisation methods. According to Cunningham et al. (2023), "Germany's robust investment in R&D fosters technological innovation in CNC manufacturing, enhancing the country's competitive edge through the development of advanced machining solutions".
- Skilled workforce: Germany boasts a highly skilled workforce of technicians, engineers, and machinists skilled in CNC programming, operation, and maintenance. This skilled labour pool has contributed to the successful implementation and utilisation of CNC machines across all industries. As highlighted by Monzón et al. (2024), "A highly skilled workforce is crucial for the successful adoption and operation of advanced CNC technologies, driving efficiency and innovation in manufacturing processes".
- Industry Collaboration: Government agencies, industry associations and academic institutions have worked together to advance CNC manufacturing through knowledge sharing, technology transfer and skills development, creating an environment that supports innovation and growth. Neumeyer et al. (2021) state that "Collaborative networks significantly enhance the innovation capacity of SMEs by facilitating knowledge exchange and technology transfer, which are essential for maintaining competitive advantage in global markets".

Factors Indicating Stagnation or Negative Trends

- **Skills shortage:** Germany's shortage of CNC operators and technicians persists despite its skilled workforce. This issue is compounded by an ageing workforce and a decreasing interest in technical careers among younger generations, making it increasingly difficult to fill CNC-related positions. According to Salco Global (2023), "*The CNC industry is currently grappling with a significant skills gap, partly due to an ageing workforce and a declining interest in technical trades among younger people, making it challenging to find qualified CNC operators and technicians.*"
- **Decline in apprenticeships:** The number of apprenticeships in CNC machining and related disciplines has declined in recent years. This decline can be attributed to changing perceptions of vocational education, an increased emphasis on academic routes and a lack of awareness of the opportunities available in CNC manufacturing. As noted by Monzón et al. (2024), "*The shift in educational preferences towards academic degrees over vocational training has led to a noticeable decline in apprenticeships in the CNC sector, which poses a risk to maintaining a skilled workforce.*"
- **Global competition:** Germany faces significant competition from emerging economies in Asia and Eastern Europe, which benefit from lower labour and production costs. This competitive landscape has created challenges for Germany, particularly in maintaining market share and profitability within certain CNC manufacturing sectors. Reduced operating costs in these regions provide a competitive advantage, forcing German CNC manufacturers to continually innovate and improve efficiency to remain viable in the global marketplace. This economic dynamic has necessitated strategic adjustments and an increased focus on improving productivity to counter the cost advantages of their international competitors. According to the Emerald Insight report (2022), "*Intense global competition, especially from countries with lower labour costs, continues to pressure German CNC manufacturers to maintain their market position and profitability*."

- **Investment costs:** The initial investment required to purchase and implement CNC machines can be significant, creating a barrier to entry for small and medium-sized enterprises (SMEs) and start-ups. In addition, ongoing maintenance and training costs add to the overall cost of CNC manufacturing. KnowCNC (2024) emphasizes, "*High upfront costs and continuous expenses for maintenance and training are significant barriers for SMEs looking to adopt advanced CNC technologies.*"
- **Complexity of programming:** CNC programming requires specialised knowledge and skills, making it difficult for companies to find qualified programmers. The complexity of programming languages and the need for ongoing innovation and optimisation add to the complexity of CNC operations. Salco Global (2023) states, "*The intricacies of CNC programming and the necessity for constant updates pose significant challenges for businesses in recruiting and retaining skilled programmers*."
- **Quality control:** Ensuring rigorous quality control in CNC manufacturing is crucial, as even small errors can have a significant impact, leading to expensive defects and the need for rework or scrap. This highlights the importance of implementing comprehensive quality assurance protocols to maintain high standards and efficiency. KnowCNC (2024) notes, "*Maintaining stringent quality control is paramount in CNC manufacturing, as minor errors can result in costly defects and rework, underscoring the need for comprehensive quality assurance protocols.*"

Figure 7: [Apprentices: Newly concluded apprenticeship contracts in the most popular training professions in Germany in 2022]. In Statista Arbeit & Beruf: Beliebteste Ausbildungsberufe in Deutschland 2022 (p. 4).

In this study, an essential graphic detailing the newly concluded apprenticeship contracts in the most popular vocational training professions in Germany for the year 2022. The graphic offers valuable insights into the distribution and popularity of various vocational training programs among apprentices in Germany.

The graphic highlights several key points:

- **Most Popular Professions:** Lists the top 20 vocational training professions by the number of new apprenticeship contracts.
- **Quantitative Data:** Provides the exact number of apprenticeship contracts for each profession, showing trends and preferences among apprentices.

This ensures that the essential information is accessible to English-speaking readers while providing proper attribution to the original German source.

While CNC manufacturing in Germany has experienced significant growth and technological advancement over the past two decades, challenges such as skills shortages, declining apprenticeship numbers - *this is also confirmed by the number of apprenticeship contracts concluded, which indicates that the CNC operator profession does not appear in the top 20 in Germany* - and global competition are limiting its further development. Addressing these challenges through targeted initiatives, investment in education and training, and fostering industry collaboration is essential to maintaining the momentum of CNC manufacturing in Germany.

Despite the availability of advanced simulation tools like “CNC Lehrgang / SINUTRAIN”, “VERICUT” or “NCSIMUL”, there may still be room for improvement in the training of skilled workers, particularly in the integration of theory and practice. The constant evolution of technology and the demands of industry mean that training institutions must constantly update their curricula and integrate the latest simulation technologies to effectively prepare students for the challenges of the labour market. To fully address potential gaps, there is a need for continued collaboration between industry, software providers and educational institutions to ensure that training content remains current and that learners acquire the skills they need for successful careers.

2.3.3. FROM CURRENT SITUATION TO ON-GOING SITUATION

Here after the description of the main tasks impacted by **Digital Technology** and/or **Green transition**, modifications and evolutions of the related needed skills

Table 8 : Tasks and skills impacted related to CNC Machine operator occupation

TASK	IMPACTING DIGITAL TECHNOLOGY AND/OR GREEN TRANSITION	IMPACT DESCRIPTION	RELATED NEEDED SKILLS/KNOWLEDGE IMPACTED	EXPECTED TENDENCY FOR SKILL EVOLUTION	SKILL TYPE	MATURITY LEVEL TO REACH	SKILL ESCO URL	SKILL DESCRIPTION
Operate, Control & Monitor	**1-2 Artificial Intelligence (AI) / Machine learning / Big Data Analytics**	Integrate CNC Manufacturing ability, constraints in CAD/CAM	**Advanced Machining**	+	**Knowledge**	L3	**http://data.europa.eu/esco/skill/7a757fa5-9a6f-43ab-9e66-f8f4dba1ffcb**	Use computer-aided manufacturing (CAM) programmes to control machinery and machine tools in the creation, modification, analysis, or optimisation as part of the manufacturing processes of workpieces.
		Integrate CNC Manufacturing ability, constraints in Basic CNC Programming	**Advanced Coding**				**N.N.**	"Advanced Coding" in the context of CNC machining usually refers to advanced CNC programming techniques and methods that go far beyond basic G-code commands. It involves the use of complex and highly automated strategies to machine workpieces to maximise the efficiency, precision and quality of the parts produced.
		Integrate CNC Manufacturing ability, constraints in Measurement	**Data Analysis**			L2	**http://data.europa.eu/esco/skill/ad59afe4-6f8a-4bc4-acfd-0f228277508a**	Specific software system (SAS) used for advanced analytics, business intelligence, data management, and predictive analytics.

	4-2 Robotics and Automation	Integrate CNC Manufacturing ability, constraints in Operating Standard Machines	**Advanced Machining**			L3	**http://data.europa.eu/esco/skill/4f0e579d-ca7b-427c-ace6-9e2de3eb19c7**	Improve production rates, efficiencies, yields, costs, and changeovers of products and processes using relevant advanced, innovative, and cutting-edge technology.
		Integrate CNC Manufacturing ability, constraints in Automation	**Robotics And Automation**			L2	**http://data.europa.eu/esco/skill/f4a6e9f7-5cff-46c0-894c-59c20bb78694**	Set of technologies that make a process, system, or apparatus operate automatically using control systems.
Problem Solving	**4-6 Predictive Maintenance**	Integrate CNC Manufacturing ability, constraints in Problem solving	**Advanced Creative Problem Solving**		**Skill**	L3	**http://data.europa.eu/esco/skill/adc6dc11-3376-467b-96c5-9b0a21edc869**	Find solutions to practical, operational, or conceptual problems in a wide range of contexts.
		Integrate CNC Manufacturing ability, constraints in Troubleshooting	**Advanced Creative Trouble Shooting**				**http://data.europa.eu/esco/skill/334e3e49-fb02-4051-809a-f06adfdc1c40**	Identify operating problems, decide what to do about it and report accordingly.
		Integrate CNC Manufacturing ability, constraints in Maintenance	**predictive maintenance**		**Knowledge**		**http://data.europa.eu/esco/skill/7d913551-e17a-40ba-baf7-48d0c3b12e50**	The use of data analytics and mathematical calculation to manage and monitor the conditions of machines and production processes.
Machine & Process Safety	**3-1 Cybersecurity**	Integrate CNC Manufacturing ability, constraints in Safety Standards	**Cybersecurity Basics**				**http://data.europa.eu/esco/skill/a4346013-a967-4a58-a533-6b32ad1364c5**	The principles, ethical issues, regulations, and protocols of data protection.
General Advanced Manufacturing	**4-5 Adaptive Manufacturing Systems**	Integrate CNC Manufacturing ability, constraints in Adaptability	**Adapt To Changing Situations**		**Skill**	L2	**http://data.europa.eu/esco/skill/49de9958-2aa4-4eef-a89d-fe5d5bcd28c4**	Alter one's attitude or behaviour to accommodate modifications in the workplace.

Work with multidis ciplinary teams	**5-12 Corporate Social Responsibility (CSR) Initiatives**	Integrate CNC Manufacturing ability, constraints in Limited Teamwork	**Enhance Collaboration**				**http://data.europa.eu/esco/skill/e4da156d-a6c4-4b29-935b-eff9c9553cf1**	Working confidently within a group with each doing their part in the service of the whole. Understanding and respecting the roles and competencies of other team members.
		Integrate CNC Manufacturing ability, constraints in Internal Communication						Working confidently within a group with each doing their part in the service of the whole. Understanding and respecting the roles and competencies of other team members.

2.3.4. IMPACT ON SKILLS

The previous analysis described impacts on skills. Here after new skills changes on skills/knowledges already identified in ESCO database and new skills/knowledges.

Table 9: Impact on Skills - CNC Machine Operator

EXISTING SKILL/KNOWLEDGE URI	NEW RELEVANT SKILL/KNOWLEDGE NAME	ESSENTIAL SKILL	NEW RELEVANT SKILL/KNOWLEDGE DESCRIPTION	EXISTING SKILL/KNOWLEDGE NAME TO BE UNLINKED	ASSOCIATED OCCUPATIONS TO BE ADDED/REMOVED
No ESCO code available	Advanced Machining	Knowledge	Ability to understand and optimize CNC-controlled processes	Add to ESCO Database: "Efficient and complex machining in high-tech industries"	CNC Operator Production Management Process Engineers
http://data.europa.eu/esco/skill/85b379e7-e0b7-48b8-baa7-631f50a7cdd5	Enhance Collaboration	Skill	Effective collaboration between technical disciplines to develop innovative solutions	No	CNC Operator Production Management Process Engineers R&D
http://data.europa.eu/esco/skill/13d301d0-98cb-414f-a8f9-a3f059228133	Advanced Creative Problem Solving	Skill	Ability to develop innovative solutions to complex engineering challenges. This ability includes the critical thinking to identify and apply novel approaches to machine programming, process optimisation and production planning, increasing efficiency, quality, and performance in the advanced manufacturing environment.	Add to ESCO Database: "Ability to develop innovative solutions to complex engineering challenges."	CNC Operator Production Management Process Engineers R&D
http://data.europa.eu/esco/skill/14832d87-2f2f-4895-b290-e4760ebae42a	Advanced Creative Trouble Shooting	Skill	Ability to effectively identify and solve complex problems. This includes creatively applying technical knowledge to not only overcome existing challenges, but also to develop preventative measures for potential problems.	Add to ESCO Database: "Ability to effectively identify and solve complex problems."	CNC Operator Production Management Process Engineers R&D
http://data.europa.eu/esco/skill/14832d87-2f2f-	Adapt To Changing Situations	Skill	Identify technical problems when operating devices and using digital environments and solve them (from troubleshooting to solving more complex problems).	No	Production Management Maintenance Management Lean Management

4895-b290-e4760ebae42a					General Management Production Engineers Process Engineers Quality & Logistic Management R&D Engineers SCM SFM
http://data.europa.eu/esco/skill/4b88b1ee-c2d9-473a-9fe8-ba3b9c0c179a	Advanced Coding	Skill	In the CNC context, this refers to the use of sophisticated software solutions for the simulation, control, and optimisation of CNC machines. This capability includes the development of algorithms for precise machine control in the production environment. Effective application requires in-depth knowledge of machine programming, system analysis and process optimisation.	No	CNC Operator Process Engineer R&D Engineer
http://data.europa.eu/esco/skill/f4a6e9f7-5cff-46c0-894c-59c20bb78694	Robotics And Automation	knowledge	Set of technologies that make a process, system, or apparatus operate automatically by control systems.	No	CNC Operator
http://data.europa.eu/esco/skill/8088750d-8388-4170-a76f-48354c469c44	Cybersecurity Basics	Skill	Fundamental knowledge in securing and protecting information systems used to control CNC machines and production processes.	Add to ESCO Database: “Production machine protection”	CNC Operator Production Management Process Engineers
http://data.europa.eu/esco/skill/2b92a5b2-6758-4ee3-9fb4-b6387a55cc8f	Data Analysis	Skill	Collect data and statistics to test and evaluate to generate assertions and pattern predictions, with the aim of discovering useful information in a decision-making process.	No	CNC Operator Process Engineer Quality Engineer

3. EXPERTS' COMMENTS

3.1. 3D PRINTING TECHNICIAN EXPERTS' COMMENTS

The summarized comments presented here from the industrial environment refer only to two sources at the current stage of preparation.

Table 10: Table of Additive Manufacturing experts' comments [ED = Expert Discussion, SV = Survey, EW = Experts Workshop]

CODE		DIALOGUE PARTNER
ED	Company	Additive Printing Expert
ED	Company	Additive Printing Expert
ED	Company	Expert in education and training

Definition and Responsibilities

The roles and responsibilities associated with machine operation and safety are many and varied. For skilled workers, training like that of a CNC machine operator is sufficient for competent operation. In addition, a learning curve of no more than two weeks is sufficient for career changers or unskilled workers. Data preparation and optimisation, integral tasks for the 3D printing process, are typically performed by engineers in advance, streamlining the process for the printer operator. Safety protocols emphasise the delicacy of component handling, the need for personal protective equipment and strict compliance with health and safety regulations. Awareness of potential hazards such as metal dust, underlined by past incidents such as the explosions in China, demands the utmost caution. Qualifications for machine/plant operation emphasize an interest in technology and a commitment to lifelong learning, without demanding extensive prior experience. Training, including individualized instruction tailored to prior knowledge, is available for FDM and AKF printer operators, facilitated by multilingual operating software. In addition, incentives in the form of learning and training vouchers accompany machine purchases to encourage skills development. In addition, a pro-active attitude towards modern technical applications and the ability to maintain composure and objectivity are valued attributes in this field, fostering a culture of innovation and safety awareness.

Skills and Competencies

The need to adapt to technical developments is underlined by the introduction of a new machine on an annual basis. To emphasise the importance of continuous development, autonomous maintenance activities should be acquired and used proactively. In addition, the integration of predictive maintenance management applications into machines streamlines maintenance processes. Notable areas of focus include data analysis, BDE (Operational data collection), 5S/order & cleanliness, and the exploration of technology-enabled human-robot collaboration, with ongoing trials. Furthermore, it is worth noting that, dependent on the chosen 3D additive manufacturing system technology, the user may possess a basic knowledge of technology and software, such as computer-numerical control (CNC), coupled with an enthusiasm for learning new skills. In such a scenario, favourable outcomes may be achieved in short order.

Education and Training

Trainees and dual students receive production-related training, with specialisation determining the length of the work placement, which ranges from 6 weeks to 6 months in the Additive Manufacturing department, emphasising a hands-on approach. There is also in-house training in additive design open to all interested employees. While learning pathways are still to be established, initial experience with learning analytics is being sought. A three-stage training program focuses on direct application areas and maintenance, covering electrical and mechanical aspects. Compliance mapping is required for electricians prior to service. The company does not require talent scouting because its reputation positively influences the number of applications.

Implementation and Strategy

While 3D printing offers potential economic solutions, not all technical challenges are best approached through this method. Instead, it is essential to identify the right parts for each process and ensure efficient use of resources.

In addition, achieving consistent build-up performance and maintaining high print quality standards are paramount objectives in additive manufacturing. This requires strategic planning to effectively optimise 3D printer use.

In furthermore, the approval and implementation of remote maintenance via 5G technology underlines the importance of stable connectivity in production environments. However, concerns about health protection and cybersecurity remain, pointing to the need for further analysis and safeguards.

Finally, practical recommendations include starting with a classic FDM printer to gain an initial insight into design and CAD/CAM processes before moving on to more advanced techniques such as metal printing. Management expectations must be realistic to avoid disillusionment on the shop floor, emphasizing the importance of balanced project planning and execution.

Employee Perspectives

During the 2023/2024 recession, transfer projects generated interest in 3D printing among CNC milling specialists and other professionals. While complementary to conventional manufacturing methods, additive manufacturing is not a substitute. Investing in innovative technology is recommended, if the expected run time exceeds 1,000 hours per year, and the application is tested in advance.

Sustainability and Management

There are significant costs associated with the use of powder in manufacturing processes, and significant efforts are made to recycle it. Currently, 30-50% of the powder used is recycled internally. In addition, there is a growing trend to provide technical upgrades to ageing machinery to extend its life and improve efficiency.

Prognose

Ongoing developments in machine technology, software and materials will drive the evolution of technical applications, moving from specialised products to the production of small and medium series.

3.2. CNC MACHINE OPERATOR EXPERTS' COMMENTS

The summarised comments presented here from the industrial environment refer only to one source at the current stage of preparation.

Table 11: Table of CNC experts' comments [ED = Expert Discussion, SV = Survey, EW = Experts Workshop]

CODE		DIALOGUE PARTNER
ED	SME	Management

ED = Expert Discussion, SV = Survey, EW = Experts Workshop

A CNC Operator - currently only refer to CNC milling - in 2024 is a skilled technician responsible for operating computer numerical control machines, which are crucial in the precision machining in processing of different steels and aluminum alloys. They oversee the efficient running and are increasingly involved in autonomous maintenance of CNC machines to produce parts as per detailed specifications. Their specific tasks include setting up CNC machines, interpreting blueprints, adjusting machine settings, and ensuring that the output meets quality standards. Without simulation, no production job is released for manufacturing.

A CNC Operator must possess several essential skills, including technical proficiency, attention to detail, "5S/ order and cleanliness".

The effective implementation of CNC manufacturing technologies requires technical and economic understanding in the selection of machine technology, technical skills in machine operation, programming skills and corresponding software for simulation, among other things, for setting up precise machine instructions in the production department and arising predictive maintenance know-how.

Tasks include machine setup, program troubleshooting, and maintenance, which require skills in precision measurement, software proficiency, and mechanical troubleshooting.

Knowledge in LEAN management can optimise any workflow, give quick results and reduce waste, while a background in industrial electronics helps in understanding and fixing machine circuitry.

The interest of today's young people in training as skilled workers is very limited; nobody wants to get their hands dirty anymore.

One of the challenges of implementing CNC technologies is the high initial cost, the need for skilled personnel, and the ongoing maintenance requirements. A "CNC manufacturing technology light" might involve simpler, less costly machines that are suitable for smaller businesses, in contrast with full-scale, highly automated systems.

The idea of recycling, e.g., chips and saving energy is realised sustainably within the scope of the given possibilities.

A future "green factory" would integrate more renewable energy, maintaining efficiency but focusing more on reducing environmental impact.

The relationship involves the use of soft skills such as teamwork and communication to complement technical expertise.

The effective use of technologies necessitates the implementation of tailored training programs that accommodate different skill levels and learning paces. Supportive training and mentorship programs can ensure that all employees are competent in using advanced technologies without discrimination.

Promoting a culture of inclusivity involves the implementation of regular training sessions, updates on technological advancements, and the encouraging of a mindset of lifelong learning.

The demand for CNC operators is expected to grow as companies increasingly invest in advanced manufacturing technologies. The precise quantification of this demand would depend on the growth rates of the relevant industries and the technological adoption in specific regions.

4. CONCLUSIONS AND OUTLOOKS

4.1. 3D PRINTING TECHNICIAN CONCLUSION AND OUTLOOKS

The future of additive manufacturing in Germany's industrial applications and SMEs is promising, with further advances in materials, processes and software expected. Increased collaboration between industry, academia and government is crucial to overcoming challenges and realizing the full potential of additive manufacturing. Addressing issues such as cost, scalability, and skills gaps are essential for further integration into mainstream manufacturing processes, particularly for SMEs.

4.2. CNC MACHINE OPERATOR CONCLUSION AND OUTLOOKS FROM EXPERTS’ COMMENTS

A CNC Operator in 2024 plays an instrumental role in the machining of diverse materials with precision, with a particular focus on the efficient operation and rising autonomous maintenance of CNC machines. Their duties include the setup of machines, the interpretation of blueprints, the adjustment of settings, and the verification of quality compliance. It is essential that the individual in question possesses the requisite technical proficiency, attention to detail, and an understanding of e.g., Lean Management 5S principles. The key competencies required include an understanding of machine technology, the use of simulation software for production purposes, and the implementation of predictive maintenance strategies. One of the challenges currently facing the industry is the high cost of machinery, the necessity for highly skilled workers, and the maintenance demands placed upon them. There is a decline in the interest of young trainees in this field, and future developments are aimed at creating more environmentally friendly factories, with tailored training programs to accommodate various skill levels.

Future changes are expected, in the following areas:

- It is necessary to enhance the attractiveness of CNC operator training to younger generations by increasing visibility of the role's technological aspects and benefits.
- It would be beneficial to implement more cost-effective, e.g., scaled-down CNC technologies, which could be referred to as "CNC light". This would encourage the adoption of such technologies by smaller businesses.
- It is essential that comprehensive training programs be developed and adapted to different learning paces and which emphasis further the importance of inclusivity.
- Integration of sustainable manufacturing practices and renewable energy sources is necessary to advance toward the establishment of "green factories."
- It is recommended that an ongoing program of education and teamwork initiatives are implemented to promote the intersection of soft skills and technical expertise.

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