LCAMP

Learner Centric Advanced Manufacturing Platform

Observatory Report N1

Author: Hervé DANTON (*Mecanic Vallée*)

Co-authors: Mikel Ayani, Lara Burgoa, Richard Burman, Hervé Danton, Firat Arslan, Richard Gale, Misha Handman, Eda Ipek, Israel de Lamo Blas, Audrey Le Bras, Vlado Milosevic, Geoff Minto, Juan Carlos Molinero, Aitor Otaño, Klaus-Dieter Rupp, Leire Solaberrieta, Nadine Venet.

Contributors: AFIL, AFM, Camosun College, CMQ, DHBW, KIC, KPDoNE, Simumatik, TKNIKA

Co-funded by the Erasmus+ Programme of the European Union

The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

LCAMP partners:

TKNIKA – Basque VET Applied Research Centre; CIFP MIGUEL ALTUNA Centro Integral de Formación Profesional; DHBW Heilbronn – Duale Hochschule, Baden-Württemberg; Curt Nicolin High School; Da Vinci College; AFM – Spanish Association of Machine Tool Industries; EARLALL – European Association of Regional & Local Authorities for Lifelong Learning; FORCAM; CMQE: Association campus des métiers et des qualifications industrie du future; MV: Mecanic Vallée, KIC: Knowledge Innovation Center; MADE Competence Center Industria 4.0; AFIL: Associazione Fabbrica Intelligente Lombardia; SIMUMATIK AB; Association HVC Association of Slovene Higher Vocational Colleges; TSCMB: Tehniški šolski center Maribor; KPDoNE: Kocaeli Directorate Of National Education; GEBKİM OIZ and CAMOSUN college

Project name	Learner Centric Advanced Manufacturing Platform for CoVEs
Acronym	LCAMP
Start date	15/06/2022
End date	15/06/2026
Budget, maximum grant amount	3,999,988.00 €
Project Officer	Helene Barry
Coordinator contact	Iñigo Araiztegui iaraiztegui@tknika.eus Susana Espilla sespilla@tknika.eus Unai Ziarsolo uziarsolo@tknika.eus
Partners	P1: TKNIKA and MIGUEL ALTUNA, DEPARTMENT OF EDUCATION, BASQUE GOVERNMENT P3: AFM P4: DHBW P5: FORCAM P6: CMQ P7: MECANIC VALLEE P8: DA VINCI COLLEGE P9: KIC P10: MADE P11: AFIL P12: EARLALL P13: KPDoNE P15: GEBKIM OIZ P16: CNG P17: SIMUMATIK P18: TSCMB P19: SKUPNOST VSŠ P20: CAMOSUN COLLEGE
Project summary	The fifth industrial revolution is built upon the technologies of the fourth, with an increased emphasis on a human-centric, sustainable and resilient industrial base, emphasising the digital and green transitions. A key pillar of this economic

	transformation is the role played by Advanced Manufacturing systems such as Robotics, 3D & 4D printing, artificial intelligence and high-performance computing. I5.0, requires VET to develop 'learning centric approaches' that focus on the holistic competences of humans that plan, manage, oversee or operate technologies. LCAMP will tackle this by incorporating a permanent European Platform of Vocational Excellence for Advanced Manufacturing, seeded from a consortium of 20 partners and over 50 associate organisations including leading VET/HVET centres, companies, regional government, R&D centres, associations of companies and clusters. By collaborating across borders, LCAMP's goal is to support and empower regional Advanced Manufacturing CoVEs to become more resilient, innovative, and better equipped to train, upskill, and reskill young and adult students to successfully face the digital and green transitions. We will help regions grow and be more competitive through their VET systems. The Alliance is service-oriented, planning to establish permanent structures for: • Teaching & Learning: establishing Advanced Manufacturing skills frameworks and curricula; launching or revising Advanced Manufacturing programmes (including micro-credentials); creating or capacity building learning factories (special Advanced Manufacturing labs, jointly run by VET and industry) • Cooperation and Partnerships: launching a skills & jobs observatory for advanced manufacturing; accelerating industry/VET/region cooperation ideas via an open innovation community and providing consultancy to SMEs on integrating SME/VET connections. • Governance & Funding: creating a one-stop-shop portal for all our services; ensuring a business case for continuing services to stakeholders in the long-term, while enhancing participation
Work Packages	WP01: Project management and coordination. WP02: Learner Centric Advanced Manufacturing CoVEs Alliance. WP03: Observatory. WP04: Open Innovation Community. WP05: Human-Centric Learning for Advanced Manufacturing. WP06: Industry 4.0 technology absorption through the Collaborative Learning Factory. WP07: SME-VET connection. WP08: Advanced Manufacturing Excellence Discovery Platform. WP09: Dissemination. WP10: Roadmap for Continued Development Learner Centric Advanced Manufacturing CoVEs Alliance.

GLOSSARY AND ACRONYMS

Acronyms

AI - Artificial Intelligence

AM - Advanced Manufacturing

Cedefop - European Centre for the Development of Vocational Training

CoVE - Centres of Vocational Excellence

EAfA - European Alliance for Apprenticeships

EC - European Commission

ECVET - European Credit System for Vocational Education and Training

EntreComp - The Entrepreneurship Competence Framework

EQAVET - European Quality Assurance in Vocational Education and Training

EQF - European Qualifications Framework

ESCO - European Skills, Competences and Occupations

ETF - European Training Foundation

EU - European Union

HE - Higher Education

HVET - Higher Vocational Education and Training

I4.0 - Industry 4.0

KET - Key Enabling Technology

OECD - Organisation for Economic Cooperation and Development

SME - Small and Medium Enterprises

SWOT - Strengths, Weaknesses, Opportunities, Threats

TVET - Technical and Vocational Education and Training

VET - Vocational Education and Training

WBL - Work Based Learning

CONTENT TABLE

1 EXECUTIVE SUMMARY

Advanced Manufacturing (AM) and Higher Vocational Education and Training (HVET) need to update their training, implement new technologies, and get quicker access to data.

These new needs have been brought forward by technological factors (Industry 4.0), factors conditioned by educational systems and educational methodologies, as well as social- and environmental factors (e.g., the European Green Deal with its emphasis on green industry).

Under the CoVE initiative, the LCAMP project aims to support regional skill ecosystems and various stakeholders in providing new skills and implementing new or updated technologies in VET centres. LCAMP will tackle this by incorporating a permanent European Platform of Vocational Excellence for Advanced Manufacturing.

By collaborating across borders, LCAMP's goal is to support and empower regional Advanced Manufacturing CoVEs to become more resilient, innovative, and better equipped to train, upskill, and reskill young and mature students, to successfully face the digital and green transitions. We will help European regions and countries grow and be more competitive through their VET systems.

The LCAMP OBSERVATORY is one of the services which will be provided by the LCAMP platform to support that cause. The Observatory is led by the French cluster *Mecanic Vallée* and the French VET provider Campus des Métiers et des Qualifications d'Excellence Industrie du Futur.

This document details the first results of the LCAMP Observatory, laying bare the methodology that the LCAMP consortium used to set up and run the Observatory. We had set up a process cycle for the observation consisting of 5 stages:

- **Stage 1:** Diagnosis and prioritisation.
- **Stage 2:** Search and information-gathering.
- **Stage 3:** Information analysis.
- **Stage 4:** Creating value. Writing LCAMP reports.
- **Stage 5:** Dissemination and communication.

Twenty different authors wrote sub-reports on specific subjects, addressing some of the main questions of future trends within AM, turned into future-trend predictions or statements. The sub-reports are all included inside this report. The statements from the sub-reports were gathered inside a questionnaire and shared with and evaluated by volunteer experts from Europe, helping to validate the future trends identified in our LCAMP process.

2 INTRODUCTION

The LCAMP Observatory will be one of the services provided by the LCAMP platform.

The LCAMP Observatory must be a reliable and easily accessible source of information and data for trainers, VET teachers, and professionals, continuously updated with new information from Digital / Advanced Manufacturing / Smart Industry, delivered through the multimedia and interactive LCAMP platform, and be customizable according to individual interests (the LCAMP platform itself is being developed in WP8).

The Observatory must feed other Work Packages (WPs), for instance, WP5 on Learner Centric Training, and the Open Innovation Community in WP4.

In a first document about methodology, we have set up a process cycle for the observation of future trends following 5 stages:

- **Stage 1:** Diagnosis and prioritisation.
- **Stage 2:** Search and information-gathering.
- **Stage 3:** Information analysis.
- **Stage 4:** Creating value. Writing LCAMP reports.
- **Stage 5:** Dissemination and communication.

Following this process cycle, we have detailed the main aspects of the observation methodology:

- **Identify reliable sources that we can find in Europe about Advanced Manufacturing.**
- **Classify and filter data gathered from different sources.**
- **Present several ways to collect and to analyse data.**
- **Define the methods for the creation of annual reports.**
- **Validate process for those reports.**

The Observatory will publish periodical reports for VET and HVET target audiences about technology trends, labour market changes, skill needs, and occupations in Advanced Manufacturing. It is expected that SMEs, industry clusters and other associations will also find valuable information in the Observatory.

The publication of a yearly report is planned.

- **Report 1:** June 2023,
- **Report 2:** June 2024,
- **Report 3:** June 2025.

This first annual report gathers sub-reports written by around twenty writers from the main partners involved in the LCAMP project. 39 Topics were determined as priorities, of which 22 were analysed and worked on during this first period.

LCAMP partners from different partner countries took responsibility for covering at least one topic.

1. **MV (France):** Megatrends, Cybersecurity, Energy Efficiency, Predictive Maintenance, Assisted Jobs.
2. **CMQ (France):** Metal Forming, Metal Additive Manufacturing.
3. **TKNIKA (Spain):** Trends & Insights for VET, Mobile Robotic, Metal Additive Manufacturing, 3D Scanning, Virtual / Mixed reality, Digital Twins.
4. **INVEMA (Spain):** Digitalisation Trends, Mapping of EU Projects.
5. **DHBW (Germany):** Robotic Trends.
6. **KPDoNE (Turkey):** ROS Technology.
7. **Camosun College (Canada):** Generative Design, Topology Optimisation.
8. **KIC (Malta):** Learning Analytics, Selective Laser Sintering.
9. **Simumatik (Sweden):** Simulation of the Manufacturing Process, Digital Workspace.
10. **AFIL (Italy):** Classification, Mapping of EU Projects in Industry 4.0.

3 OBSERVATION RESULTS

The main goal of the Observatory is to offer high-value reports to VET stakeholders by gathering, filtering, and organizing relevant information (while considering regional contexts) and taking the best from existing Advanced Manufacturing platforms and observatories (in business and in education/training).

The operational goals are:

- To provide a one-stop-shop service for accessing all data and information generated by the Observatory.
- To collect the information needed to create all the LCAMP deliverables and services.
- To create the structure and tools to assure the sustainability of the Observatory.
- To foster the LCAMP Platform and Open Innovation Community.
- To summarise the results of the Observatory in easy-to-read yearly reports that will be shared with all stakeholders to promote information-based decision-making.
- To create panels made of national experts in the advanced manufacturing sector in partner countries to approve the findings and conclusions of the reports.

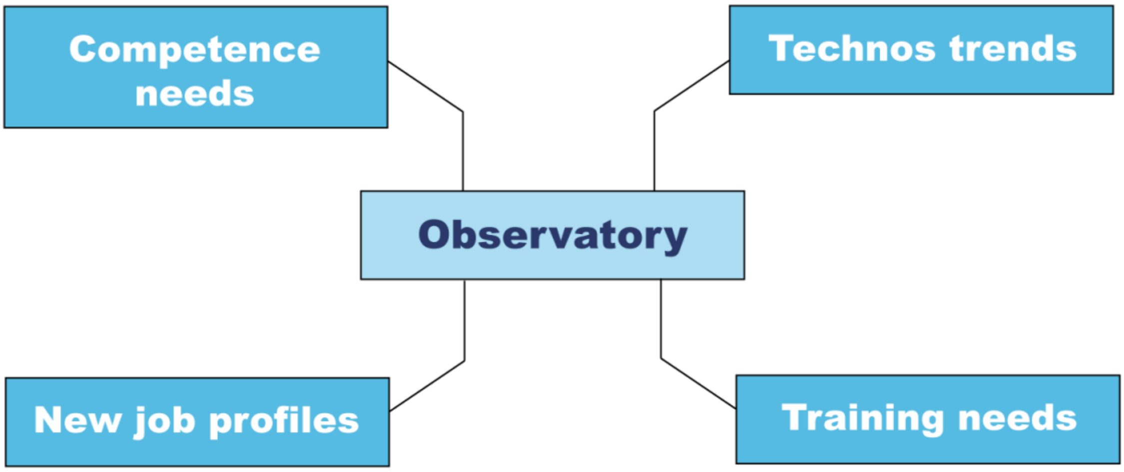

Figure 1: LCAMP observatory description

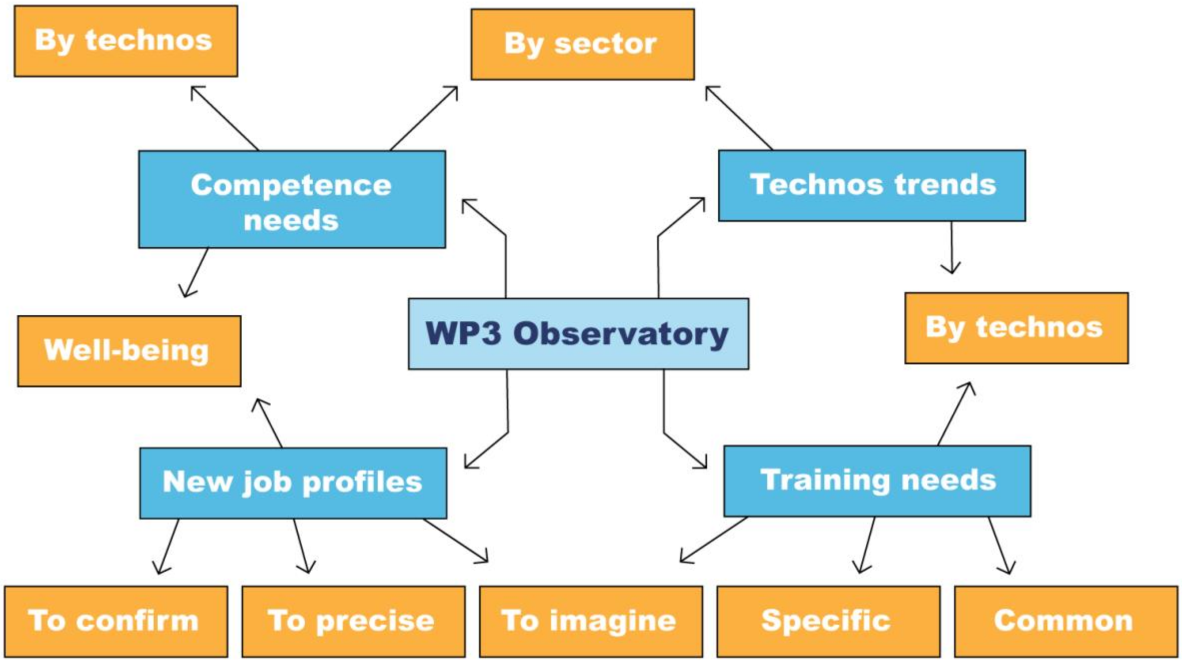

Figure 2: Links among observatory items

Expected services on the platform are:

- To detect technology trends in Advanced Manufacturing: closely screen and gather the topics related to Advanced Manufacturing in Industry 4.0, that impact the manufacturing world (sustainability, servitization, Industrial Smart Working, Resilient Supply Chain, Virtualization). It will help to understand how Smart / Advanced Manufacturing / Digital Technologies can support its evolution.
- To screen and gather the evolutions of digital & smart innovations on operations processes, at national and international levels regarding technologies, application environments, and national regulations.
- To screen and gather the spread of Industry 4.0 for Advanced Manufacturing in Europe, in terms of knowledge and applications.
- To screen and gather companies' best practices regarding the areas of in-depth listed studies.
- To detect skill needs in Advanced Manufacturing.
- To detect new job profiles in Advanced Manufacturing.
- To detect education trends in Advanced Manufacturing.
- To connect existing networks, platforms, clusters, etc.
- To screen and gather the application and technology of Industrial frameworks in Europe.

- To examine more closely the most representative successful case studies.
- To screen and gather interconnections and cooperation abilities among resources (physical assets, people, and information both within the factory as well as distributed across the value chain), which will dramatically change their efficiency and competitiveness.
- To prepare employees, job seekers and teachers for the digitalisation of companies in the main aspects of Industry 4.0 for Advanced Manufacturing.
- To check standard training courses: courses related, for instance, to the discovery of digitalisation, social and psychological considerations of the evolution, techniques that facilitate daily operations, environments, the interest of digitalisation and IOT tools, soft skills useful within this digitalisation etc.
- To catalogue school courses, university courses, apprenticeships and continued education courses.
- To survey what different actors across Europe are doing in terms of future trends, and to connect the different actors.
- To generate and spread knowledge on Advanced Manufacturing in Industry 4.0, about opportunities and the impact of digital and smart technologies.

The observatory relates to other LCAMP services:

- The Learner Centric Advanced Manufacturing CoVEs Alliance (WP2)
- The Open Innovation Community (WP4)
- The Learner Centric Training for Advanced Manufacturing (WP5)
- The Collaborative Learning Factory for i4.0 Technologies Absorption (WP6)
- The SME-VET connection (WP7)
- The LCAMP Platform (WP8) and Impact Assessment
- The Roadmap for Continuous Development of the LCAMP Alliance and Impact Assessment (WP10).

3.1 THE METHODOLOGY

As we will see, there is a lot of high-quality information about Advanced Manufacturing available online, but it is not reaching VET/HVET centres.

- Observatories already exist, some of them producing high-quality data.
- There are many data sources, including statistics from official sources such as Cedefop, OECD and others.
- Each agent has a form of knowledge[1]. The information that each agent has, tends to be very "sticky"[2]. The transfer of information from one agent to the other is key for the EU Advanced Manufacturing sector to thrive.
- There are plenty of observatories, white papers, trend forecasts etc. focused on Advanced Manufacturing. However, from a VET perspective, the information is dispersed and difficult to gather and use effectively.
- The human factor: the way Industry 4.0 and Advanced Manufacturing are affecting workplaces and jobs, and through that, the people are of strategic importance.
- VET practitioners are usually aware of their regional realities. However, they lack the international perspective.
- There is no international cooperation network of VET/HVET centres in Advanced Manufacturing to monitor and share information.
- Students of all levels have difficulties to learn about the career opportunities they may have.

The LCAMP Observatory methodology is created within Technology Surveillance (TS) and Competitive Intelligence (CI) systems.

1 Morten Berg Jensen et al., "Forms of Knowledge and Modes of Innovation," Research Policy 36, no. 5 (June 2007): 680–93, https://doi.org/10.1016/j.respol.2007.01.006.
2 Eric von Hippel, "Democratizing Innovation: The Evolving Phenomenon of User Innovation," Journal for Betriebswirtschaft 55, no. 1 (2005): 63–78, https://doi.org/10.1007/s11301-004-0002-8.

The Observatory follows the classical steps of such systems that are:

- **Stage 1:** Diagnosis and prioritisation:
    - Set up priorities and fields to observe
    - Identify data sources
    - Classify the sources.
- **Stage 2:** Search and information-gathering
- **Stage 3:** Information analysis
- **Stage 4:** Creating value. Writing LCAMP reports.
- **Stage 5:** Disseminate-communicate

That structure follows the process cycle as shown in Figures 3 and 4.

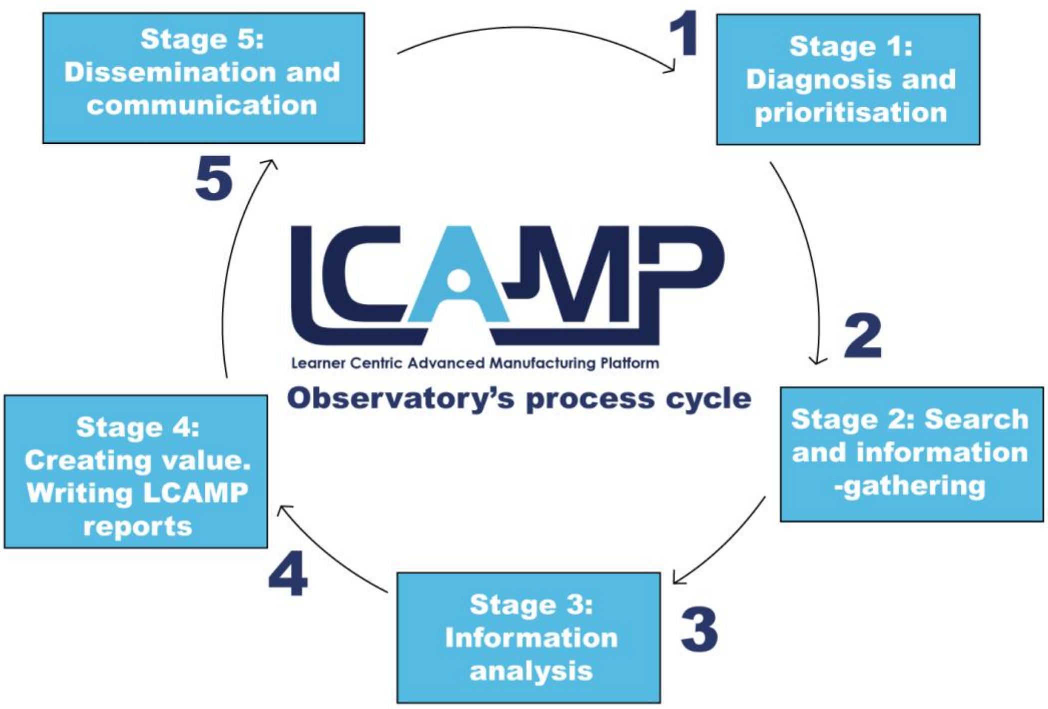

Figure 3: Process cycle for the Observatory

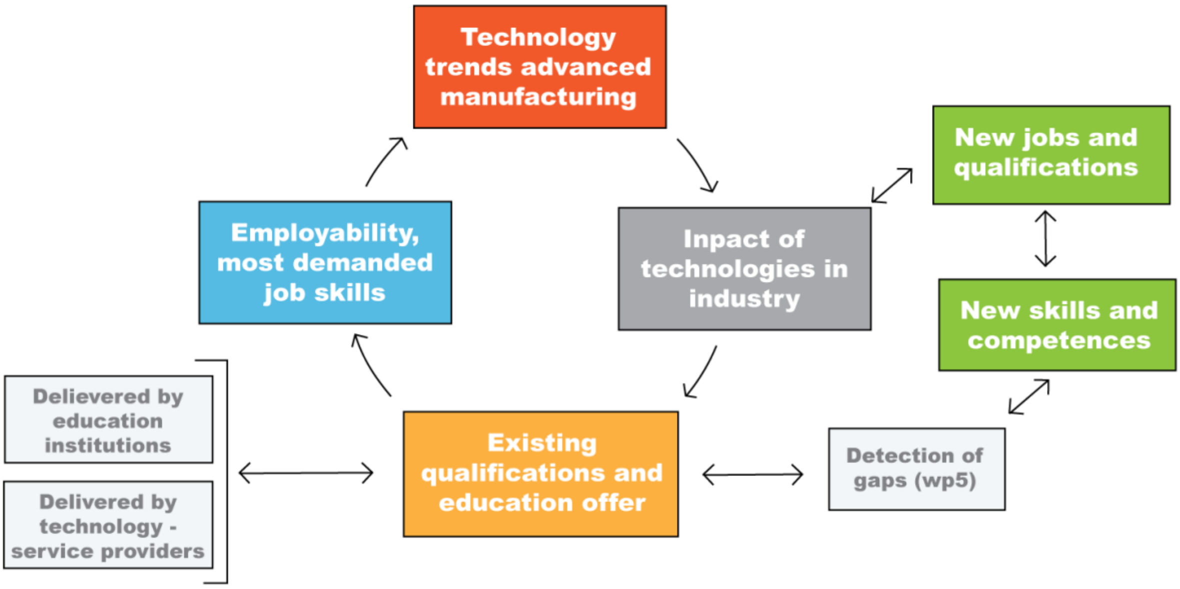

Figure 4: Areas of observation

The validation process assures the quality of the report generated with the information gathered from the Observatory.

The credibility of the results published is based on three pillars.

1. The contrasted quality of the sources used.
2. The transparency of the information analysis process.
3. The validation of the conclusions by experts from the relevant fields.

Considering the high relevance of the validation process, it was carried out on three levels:

- Internal validation at a thematic team level or/and at the regional level.
- Validation at LCAMP consortium level.
- External validation carried out by expert panels.

The internal evaluation was led by the observatory leader, Mecanic Vallée (MV) with the help of Dual Hochschule Baden Württemberg (DHBW), and TKNIKA. All partners had to follow the same process and approve the proposed ‘future trend’ statements. Then, the Observatory’s steering group assessed and approved the ‘future-trend’ statements of the report. The final validation step was fulfilled by external experts.

Composition of the expert panels

Seven regional panels of experts were created, representing the expertise from Spain, France, Germany, Italy, Slovenia, Sweden and Turkey. Each panel consisted of:

- Industry representatives,
- VET representatives,
- Government representatives,
- At least one LCAMP partner organisation.

That gave us a total number of 45 experts composed of 19 industry representatives, 14 VET representatives, and 12 government representatives.

Duties of the expert panels: To approve the conclusion and findings of the reports elaborated in the LCAMP Observatory.

Work methodology for validation by the expert panels

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 to approve those findings.

The experts:

1. Volunteering their time to LCAMP (not compensated)
2. Willig to- and able to work in groups.
3. Committed for 3 years.
4. Specialists in Advanced Manufacturing / VET / Industry 4.0.

What is expected from experts:

1. To offer their expertise and perspectives on the work of LCAMP.
2. To give feedback on the LCAMP work/findings/results of the Observatory.
3. To validate results and conclusions of the report.

Delphi methodology

LCAMP partners decided to use the Delphi methodology to eliminate bias and to get a real consensus on the outcomes. It is usually done through an anonymous questionnaire which is answered multiple times, and in which each closed questions (such as the Likert Scale below) is followed by an open-ended question asking for justification of the first response. This was difficult to organise in the first year of the LCAMP project due to time shortages, which is why the Delphi methodology will be applied as of next year. This year, the experts have evaluated each statement only once.

The grading scale is:

Answer from 1 (short-term) to 4 (already fulfilled) based on how soon you expect these forecasts to become reality

- 1 = Short-term (in a 3-year period)
- 2 = Mid-term (in a 3 to 10-year period)
- 3 = Long-term (after 10 years)
- 4 = Already fulfilled
- Disagree (It will not happen)
- No opinion / Out of competency

We have also added an open-ended question to understand whether the experts agree with the statements regarding the future challenges for Advanced Manufacturing the LCAMP representatives have identified ("Please state your opinion on these challenges (should anything be added or removed, do you agree or disagree)").

Scoring of responses for results analysis:

Response	Scoring
4 = Already fulfilled	4
1 = Short-term (in a 3-year period)	3
2 = Mid-term (in a 3 to 10-year period)	2
3 = Long-term (after 10 years)	1
Disagree (It will not happen)	0
No opinion / Out of competency	/

Choice "No opinion / Out of competency" was not counted.

Choice "4 = Already fulfilled" awarded the maximum score of 4 to a future trend identified, because we have considered it to be a technological development that has only recently been put in place (in the past couple of years), and whose implementation is not yet fully integrated, but which is relevant to the very near future of AM. That's why we're asking the experts for their opinion.

For each statement, we've added the challenges we think the LCAMP team should take up next year. We have also asked the experts for their views on these challenges.

Statement 1: *

Mega trends in Advanced Manufacturing: Industry 5.0 paradigm is emerging in Europe towards a more human-centric, resilient and sustainable industry.
Transformations are not technology-driven but simultaneously technology and human-centric.

Answer from 1 (short-term) to 4 (already fulfilled) based on how soon you expect these forecasts to become reality

- 1 = Short-term (in a 3-year period)
- 2 = Mid-term (in a 3 to 10-year period)

Challenges for LCAMP concerning Statement 1

Here are the challenges we have in mind:

Definition of I5.0 aspects, including the i5.0 skills:

- Human-centric skills, resilience skills and sustainability skills
- What does it mean to move from I4.o to I5.0?
- How should we update skills frameworks to i5.0?
- How should we update training programmes to i5.0?

Please state your opinion on these challenges (should anything be added or removed, do you agree or disagree)

Detailed methodology

We will use different survey methodologies, depending on the topic of research:

- **Exploratory survey research**

To dive deeper into research subjects and find out more about their context. The focus is to discover ideas and insights instead of gathering statistical data.

- **Predictive survey research**

Also called "causal survey research". It's pre-planned, structured, and quantitative in nature. It's often referred to as conclusive research as it tries to explain the cause-and-effect relationship between different variables. The objective is to understand which variables are causes and which are effects and the nature of the relationship between both variables.

- **Research method**

Quantitative Research to collect numeric data systematically. Quantitative research methods include polls, systematic observations, and one-on-one interviews.

Qualitative Research to collect non-numeric data from research participants. Qualitative research methods include focus groups, one-on-one interviews, observations, and case studies.

In all cases, the Survey Process will cover:

- Survey design
    - Sample selection
    - Sample size
    - Stratification and clustering
    - Choice of survey media
- Survey development
    - Survey questions
- Survey execution
- Data analysis and reporting the survey results

3.2 MEGA TRENDS IN ADVANCED MANUFACTURING

In this part, the research analysis is presented, including the sources and data examined, and an explanation of the Observatory process. Some sub-reports will omit the entire analysis process, to keep the annual report succinct.

Below an example of the main sources is presented and briefly described.

- All cover at least one of the following:
    - **F1: Trends**
    - **F2: Impact on jobs**
    - **F3: Skills & qualifications**
    - **F4: Future skills**
- Geographical Scope: World/ Europe / a specific country / a specific region
- Sectorial Scope: Multisector, IT…
- Type of sources: newspapers, social networks, European projects, announcements, Scientific articles, websites …

Identification	Type of source	Link to source	Description	Geographical scope	Sectorial scope
PUBLIC SOURCES					
CORDIS	European data base	LINK		Europe	Multisector
TRAINING SOURCES					
EFVET	Website	LINK		Europe	Multisector
CETIM	Website	LINK 1 LINK 2		Mainly France	Multisector
MINALOGIC	Website	LINK		EU & Regional France	IT
NCVER Australia	Website	LINK	National Centre for Vocational Education Research Informing and influencing the VET sector	World	Multisector
SKILLMAN	Website	LINK	A European Project	Europe	Multisector
PwC	Website	LINK		World	Multisector

ECCOE	Website	**LINK**	European Credit Clearinghouse for Opening up Education	Europe	Multisector
CEDEFOP	Website	**LINK**		Europe	Multisector
INDUSTRY SOURCES					
ECCP	Website	**LINK**	European Cluster Collaboration Platform	Europe	Multisector
DELOITTE		**LINK**		World	Multisector
E&Y	Website	**LINK**		World	Multisector
i-scoop		**LINK**	Reporting on digital transformation, Industry 4.0, Internet of Things, and emerging technologies in context.	World	Multisector
FORBES	Forbes Technology Council	**LINK**		World	Multisector
McKinsey & Co.		**LINK**		World	Multisector

3.2.1 Context and Limitations

The source review was done using European, French and country-non-specific sources, in English and French. It is not an exhaustive analysis yet, and will continue through to next year, by extending the review to all national sources we can gather.

Relevance

Relevant sources are the ones that provide documents on the focal topics. The sources that do not do so might still be interesting but are less relevant.

3.2.2 Main Data

Presentation and brief description of DATA. Data are the specific documents or websites we can use in the Observatory, and which we have found through the source exploration.

Identification	Date	Topic name	Internet links
PUBLIC SOURCES			
CORDIS		ADMA Trans4mers	LINK
CORDIS		Why does the EU support research and innovation for advanced manufacturing?	LINK
CORDIS		Making our Workforce Fit for the Factory of the Future	LINK
CORDIS	Closed 2017	Skill development and firm upgrading to sustain the competitiveness of the EU manufacturing sector	LINK
CORDIS		FIT4FoF (Making our Workforce Fit for the Factory of the Future)	LINK
CORDIS		FIT4FoF (Making our Workforce Fit for the Factory of the Future)	LINK
Orgalim	June 2022	Seizing Europe's opportunity to lead the global manufacturing transformation	LINK
TRAINING SOURCES			
EXAM 4.0	Year 2020	The Excellent Advanced Manufacturing 4.0 project: Report on Most Relevant Trends for Advanced Manufacturing	LINK
EFVET	January 2021	DTAM: A new EU project to facilitate the digital transformation in advanced manufacturing	LINK
CETIM	July 2022	« IIoT & artificial intelligence: two key tools to optimize your Manufacturing process"	LINK
CETIM	December 2020	French Mechanical Industry supports the Future European Aerospace Research towards Green Aviation	LINK
MINALOGIC		SmartEnergy. Accélérez la transition énergétique	LINK

NCVER Australia		VET's response to Industry 4.0 and the digital economy: what works	**LINK**
SKILLMAN	Year 2021	Report On Vet Providers and Educational Challenges In Europe In The Field Of Advanced Manufacturing In The Transport Sector	**LINK**
PwC	January 2020	Curriculum Guidelines 4.0 Future-proof education and training for manufacturing in Europe	**LINK**
ECCOE	July 2022	Quality criteria for credential description	**LINK**
CEDEFOP	Year 2021	Understanding technological change and skill needs, Technology and skills foresight	
CEDEFOP	Year 2021	Technological change and skill needs, big data and artificial intelligence methods	
CEDEFOP	Year 2021	Understanding technological change and skill needs, Skills surveys and skills forecasting	**LINK**
INDUSTRIAL SOURCES			
CETIM	March 2018	le guide des technologies de l'industrie du futur	**LINK**
WMF	Year 2019	THE 2019 WORLD MANUFACTURING FORUM REPORT	**LINK**
WMF	Year 2021	THE 2021 WORLD MANUFACTURING FORUM REPORT	**LINK**
CORDIS	Year 2017	Assessment of relevant technologies	
CORDIS	Year 2019	i4EU Handbook	
ECCP		CAMT - Centre for Advanced Manufacturing Technologies Poland:	**LINK**
DELOITTE		Considering a greenfield manufacturing investment?	**LINK**
DELOITTE	June 2022	The manufacturing talent shortage: how to appeal to younger workers	**LINK**
DELOITTE		2023 Global Human Capital Trends	**LINK**
DELOITTE		Exploring the world of connected enterprises	**LINK**

E&Y		How manufacturers can capture the knowledge of experienced workers	**LINK**
E&Y		Why manufacturing is setting the bar for climate-related disclosures	**LINK**
i-scoop		Manufacturing and manufacturing technologies – evolutions in convergence	**LINK**
FORBES	April 2023	Trends Shaping Strategic Recruitment and New Hiring Trends	**LINK**
FORBES		The Top 5 Manufacturing Trends In 2023	**LINK**
MAC KINSEY		Industry 4.0: Reimagining manufacturing operations after COVID-19	**LINK**

3.2.2.1 Context and Presentation

The source review was done using European, French and country-non-specific sources, in English and French. Next year the review will continue by exploring further national sources.

3.2.3 Data Analysis

3.2.3.1 Introduction

Why does the EU support training and innovation for advanced manufacturing?[3]

The manufacturing industry is an important driver of employment and prosperity in Europe. The sector accounts for: 28.5 million people employed in almost 2 million companies, out of which 99.2% are SMEs (small and medium-sized companies).

The EU27 has 22% of the world's manufacturing output, yielding a trade surplus in manufactured goods of €421 billion annually. Research institutes and companies in Europe, in particular SMEs are key players in innovation. Manufacturing companies represent 64% of private sector research development expenditure and 49% of innovation expenditure in Europe.

[3]European Commission, « Advanced Manufacturing », European Commission, 2021, https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/key-enabling-technologies/advanced-manufacturing_en.

Europe is strong in Advanced Manufacturing technologies, with the highest share of world patent applications and the highest number of venture capitalist-backed firms.

Advanced Manufacturing represents a Key Enabling Technology for Europe. It uses new knowledge and innovative and cutting-edge technologies such as robotics, 3D printing, artificial intelligence (all addressed inside this report), and high-performance computing and modelling, to produce complex products, for example, machine tools, aircraft and medical devices. It also optimises processes towards products having no defects, avoiding waste, and reducing pollution, material consumption and energy use.

Advanced Manufacturing will contribute to a competitive, green, digital, resilient and human-centric manufacturing industry in Europe. It will be at the centre of a twin **ecological and digital transition**, being both a driver and subject to these changes.

The 2030 vision for Europe is to reinforce the global position of Europe's manufacturing industry in terms of competitiveness, productivity, and technology leadership.

Disruption and transition[4]

Global manufacturing and industry are still reeling from the disruption of recent years, with supply chain and workforce disruption still key issues. At the same time, the world is heading into a period of unprecedented economic uncertainty: unexpected and unpredictable. On the face of it, this seems to suggest slowing growth and declining profits.

According to Jacqueline Kehoe, project coordinator from Munster Technological University, Ireland, and Paulo Leitão from the Polytechnic Institute of Bragança, Portugal, many jobs currently in demand (such as big data analysts and cloud services specialists) didn't exist 15 years ago, before industry 4.0. The data that we collected on industry 4.0 technology trends, alongside the associated skills requirements, is enabling us to develop an upskilling analysis tool which identifies which skills will help workers adopt new technologies.

The training framework is a fantastic achievement, allowing stakeholders to, in person or online, design a training programme in hours, says Kehoe. Involving workers in its design exceeded employer expectations. Feedback about the results of the framework has been very positive, with all pilot partners indicating they will continue using it.

[4]Bernard Marr, « The Top 5 Manufacturing Trends In 2023 », Forbes, 2023, https://www.forbes.com/sites/bernardmarr/2023/03/29/the-top-5-manufacturing-trends-in-2023/.

Advancing Industry 4.0 requires strong cooperation between ecosystem players, suppliers, and operators of factories, plants, and warehouses[5] [6]

The success of Digital Transformation is highly dependent on clear top-down governance. The right governance model provides appropriate levels of coordination and sharing for digital initiatives, in line with the company's structure, culture, and strategic priorities.

No matter the particularities, companies have to assess their vision of the industrial future and then decide how to move forward: pursuing existing strategies with reinforced strength or developing new strategic approaches to successfully emerge from the present uncertainty. Industry 4.0 forces manufacturers to rethink how to create value, i.e., to rethink the back end of their business models. Company leaders should decide on which fundamental drivers to base their business on in the future.

Company leaders thus have to focus on identifying additional skill sets needed for their vision of the future. Next, they must develop existing skills or hire new employees to fulfil these requirements. In terms of people development, the focus should lie on enabling learning all along the career, with flexible working models and blended learning methods.

A major component of successful leadership in Industry 4.0 will be the ability to create a learning organization: the value over time of fact-based knowledge is becoming smaller and smaller in a sector driven by digital innovation. In this context, the attitude and capability to continuously learn will be vital. Company culture should be open and ready to share knowledge. The challenges that Industry 4.0 poses require continuous innovation and learning, which is dependent on people's capabilities.

Industry 4.0 requires a labour force with higher skill levels. Therefore, training and continuous professional development of employees are of major importance to succeed in the early stages of the transition towards digitalization[7].

The full digital integration and automation of whole manufacturing processes in the vertical and horizontal dimensions imply that workers will be responsible for a broader process scope and will need the ability to understand relations between processes, and the information flows, and to cooperate ad-hoc in finding appropriate solutions for particular problems[8].

5«Home EXAM 4.0», Exam 4.0, 18 March 2022, https://examhub.eu/.

6«Making our Workforce Fit for the Factory of the Future», FIT4FoF, 2023, https://www.fit4fof.eu/.arr.

7 Henning Kagermann, "Change through Digitization—Value Creation in the Age of Industry 4.0," in Management of Permanent Change, ed. Albach H et al. (Wiesbaden: Springer Gabler, 2014), 23–45, https://doi.org/10.1007/978-3-658-05014-6_2.

8 Selim Erol et al., "Tangible Industry 4.0: A Scenario-Based Approach to Learning for the Future of Production," Procedia CIRP 54 (2016): 13–18, https://doi.org/10.1016/j.procir.2016.03.162.

Most Relevant Trends for Advanced Manufacturing[9]

Industry 4.0 implies components communicate independently with the production system and, if necessary, initiate repairs themselves or reorder material, when people, machines, and industrial processes are intelligently networked.

In the factory in Industry 4.0, intelligent machines independently coordinate production processes; service robots support people in assembly, automated guided transport vehicles take care of logistics and material flow independently. Networking does not only take place within "intelligent factories", but across company and industry boundaries - between different actors in the economy: From medium-sized logistics companies to specialized technical service providers to creative start-ups.

The use of digital technologies in the industry will result in a multitude of new production processes, business models, and products. For example, a production line has no longer to be restricted to one product.

Mass customization will have an impact on the design and product portfolio, supply chain management, and operations. This will change the requirements for industrial production or advanced manufacturing. New manufacturing concepts and IT technologies will make it possible to flexibly adapt processing stations to a changing product mix.

3.2.3.2 Contextualisation

Questions about megatrends[10]

The 2019 World Manufacturing Forum Report “Skills for the Future of Manufacturing” aims to explore in detail the skills gap phenomenon widely felt in the sector, identify the top skills needed by manufacturing workers, and outline the main mechanisms in skills assessments and development.

The rapid pace of technological innovation is continuously changing the skill sets required to effectively perform roles within manufacturing. The lack of, and inability to acquire the necessary skills and competencies amplify skill gaps in workers and as a result, the industry is having increased difficulty in finding the necessary talent to fill manufacturing roles.

[9] «Home EXAM 4.0», Exam 4.0, 18 March 2022, https://examhub.eu

[10] WMF, «Report 2019: Skills for the Future of Manufacturing», World Manufacturing Foundation, 13 novembre 2019, https://worldmanufacturing.org/report/report-2019/.

The 2019 WMF Report examines the key evidence regarding the existence of skill gaps such as changing jobs in manufacturing, lack of required skills among workers, and difficulty in finding talent.

It analyses key underlying causes of the skills gap such as the introduction of Advanced Manufacturing technologies and automation, challenges in the education system, disconnect between companies and institutions, lack of efficient training programmes, misperceptions of manufacturing jobs, demographic trends such as ageing population, and the lack of versatile skill sets in workers. The impacts of the skills gap on the competitiveness of the sector.

The 2019 WMF Report outlines the Top Ten Skills for the Future of Manufacturing that the WMF believes are increasingly relevant for workers to stay competitive in the years to come. The skills have been identified keeping in mind the particularity of manufacturing and are intended to apply to a wide group of workers within the sector.

Identifying skills and competencies creates the impetus to identify the mechanisms to assess and develop those skills. The 2019 WMF Report outlines the importance of skills assessments and the need for sustainable Human Resource Management (HRM) strategies in companies.

3.2.3.3 Objectives / Research Question / Problem Statement

Research question

Considering digital skills delivery within TVET (Technological Vocational Education & Training),[11]

- What would be relevant for the VET system?
- What would work or wouldn't work in the context?
- Should more digital skills-related elective units become core units?
- What criteria should be used to determine whether a unit is core or elective?
- Is embedding digital skills into courses feasible and how would it work?
- What elements constitute good practice in developing specific digital skills-related qualifications?
- Could modular training or shorter digital skills-related courses work in the VET system and are there any implications for quality?
- What are the implications for VET providers of a move to more digital forms of learning?

Considering workforce development for VET educators,

[11] National Centre for Vocational Education Research, «NCVER», NCVER (National Centre for Vocational Education Research, 19 décembre 2022), https://www.ncver.edu.au/.

- What are providers currently doing to assist VET educators to build digital skills capability and what could they do more of to facilitate this?
- Do VET educators need additional training in digital skills, either general or industry-specific, apart from maintaining industry currency?
- What approaches can be applied to ensure the integrity of competency-based assessment using digital tools?
- Are the elements described in the European Framework for Digitally Competent Educational Organisations (DigCompOrg) relevant?

Advancing Industry 4.0 requirements[12]

Should it be:

- an innovation-driven one, based on a strong partner network and Smart Innovation processes, whilst outsourcing major physical production processes?
- an extremely agile production focusing on customized products in batch sizes of one, enabled by Smart Factories?
- an efficiency-driven one, with low prices and market-beating lead times, made possible by a Smart Supply Chain?
- a service-based one, to transform the manufactured product to serve only as the source for valuable data and the door-opener to a wealth of Smart Services around which to form the actual value proposition?

[12] «Home EXAM 4.0», Exam 4.0, 18 mars 2022, https://examhub.eu

3.2.3.4 Findings

Five statements are emerging from sources and data analysis:

1. **More connected companies and more IA inside processes**
2. **Development of cybersecurity and standards**
3. **More Human-centred concern in technologies 4.0**
4. **Greener Advanced Manufacturing and Energy transition in Advanced Manufacturing**
5. **Introduction of circular economy in Advanced Manufacturing.**

1.A Exploring the world of connected enterprises[13]

The marriage of advanced manufacturing techniques with information technology, data, and analytics is driving another industrial revolution - one that invites manufacturing leaders to combine information technology and operations technology to create value in new and different ways.

1.B Re-imagining Manufacturing after pandemic and economic crisis

Business

The first step is a clear articulation of the company's desired future state, which is linked to business strategy and goals rather than the technology with the greatest buzz.

Outlining a clear business case becomes more complicated when expanding beyond the four walls of the factory but is even more important. For example, supply-chain integration reaps savings when factoring in hidden costs that often are not explicitly accounted for. Understanding these issues helps organizations formulate a positive business case that will convince suppliers to embark on an integration journey.

Technology[14]

Many, if not most, companies will want to assess their current IT systems, upgrading them to deliver the horsepower that advanced use cases in digital and analytics depend on - particularly

[13]Brenna Sniderman, Monika Mahto, et Mark Cotteleer, «Industry 4.0 and Manufacturing Ecosystems», Deloitte Insights, 23 février 2016, https://www2.deloitte.com/content/www/us/en/insights/focus/industry-4-0/manufacturing-ecosystems-exploring-world-connected-enterprises.html.

[14]Mayank Agrawal et al., «Industry 4.0: Reimagining manufacturing operations after COVID-19 | McKinsey», McKinsey, 29 février 2020, https://www.mckinsey.com/capabilities/operations/our-insights/industry-40-reimagining-manufacturing-operations-after-covid-19.

to support the Internet of Things. A scalable, obsolescence-resistant IT stack is essential. Similarly, upgrades of suppliers' IT systems might be required for end-to-end horizontal integration of data.

For upgrading the IT tech stack and implementing multiple use cases, companies can leverage external technology providers by creating an ecosystem of partners that can help them execute the digital transformation. Partnership models can vary among outsourcing, acquisitions, and strategic alliances, with successful ecosystems integrating a mix of start-ups and established technology and service providers.

1.C Trends and change management in the five functional areas of Industry 4.0.

An "I4.0 functional area" summarizes the applications in the company related to Advanced Manufacturing management processes (Zhong et al., 2017). They can be understood as cross-functions or I4.0 core processes within corporate divisions and are valid such as production, logistics, and maintenance functions.

The five "I4.0 functional area" are:

- Data acquisition and processing
- Assistance systems
- Networking and integration
- Decentralization and Service orientation
- Self-organization and autonomy

Data acquisition and processing[15] form the basis for Industry 4.0. The functional area includes the collection and evaluation of data on processes, quality, products, means of production, employees as well as their environment. Central for Industry 4.0 is the IT-based data acquisition of customer, product, production, and usage data. In the functional area of data acquisition and processing, the key focus is on discontinuous data evaluations, e.g., the consideration of the overall plant effectiveness down to big data analysis. The goal is a constant process or quality improvement.

Key elements:

- Sensor technology / RFID / barcode
- (Big data) analysis & AI
- Documentation and data management

[15] CEDEFOP, «Understanding Technological Change and Skill Needs: Big Data and Artificial Intelligence Methods», CEDEFOP, 12 avril 2021, https://www.cedefop.europa.eu/en/publications/4198.

- Simulation (product, production, plants, from candle to cradle method e.g., such as the Meman Project[16], etc.)

Data security: Assistance systems aim to make it as easy and quick as possible for the employee, anytime, anywhere to provide the information required on the shop floor. In the functional area of assistance systems, all technologies are summarized, to support and enable the employees in the execution of their work and get them concentrated on their core tasks. These are in particular, technologies for the provision of information such as visualization systems, mobile devices, tablets, and data glasses or tools that perform calculations or provide support in human-machine interaction.

Key elements:

- Visualization, augmented reality
- Mobile devices
- Human-machine interaction
- 3D printing / scan / prototypes

Simulation (product, production etc.): The networking and integration between departments within a company (vertical integration) but also between different companies (horizontal integration) is a central element of the industry 4.0 vision. The goal of digital networking is to improve collaboration, coordination, and transparency across the divisions as well as along the delivery and value chain. The functional area includes cross-departmental cooperation within the company and cross-company cooperation in value-creation networks. It includes the approaches of cloud computing and the Internet of Things.

Key elements:

- Vertical and horizontal integration
- Flexible networking of systems, processes, and products
- Cloud computing
- Internet of Things & AI

French Cetim experts[17] focus on how innovation, based on the use of the industrial Internet of Things and artificial intelligence tools, generate value, and reduce the capital and operating expenses.

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[16]MEMAN, «MEMAN Home», MEMAN, 2018, http://www.meman.eu/.

[17]Cetim, «Free Webinar: " IIoT & Artificial Intelligence: Two Key Tools to Optimize Your Manufacturing Process" - Cetim Engineering %», *Cetim Engineering* (blog), 26 juillet 2022, https://www.cetim-engineering.com/free-webinar-iiot-artificial-intelligence-two-key-tools-to-optimize-your-manufacturing-process/.

Decentralization & service orientation is the key driver for changing industry 4.0 business models. Industry 4.0 induces the change from central control to decentralized process responsibility and from a product orientation to a customer/service orientation. The functional area decentralization and service orientation, therefore, include the modularization of products and processes, decentralized control, and the change to a service orientation. Decentralization enables clear coordination and makes complexity manageable as the control task no longer has to be done in one place only.

Key elements:

- Apps, web service
- New business models
- Service orchestration
- Decentralized control
- Versatility

In the **self-organization and autonomy functional area**, the vision of Industry 4.0 – that the intelligent 'system' controls its own production – becomes reality. Technologies and processes are combined, which carry out an automatic data evaluation, and based on the results the systems react independently. Such control loops can be used for example, for self-configuration and self-optimization of systems up to complete self-organization. The ability to self-organize and control is an important characteristic of cyber-physical systems, that communicate with each other in addition to the collection, evaluation, and storage of data and having their own identity and interact with their surroundings. Examples of such autonomous systems are intelligent, flexible driverless transport systems (AGVs) solutions in intralogistics or intelligent containers, triggering automatic reordering.

Key elements:

- Control loops / self-organization
- Self-configuration / optimization
- Cyber-physical systems
- Process monitoring

The institutions' future scenario[18]

The institution's task will not only be to develop or further develop the education and training profiles for I4.0 in cooperation with the world of work involved, but also to promote the establishment of new forms of learning in HVET/VET institutions and companies.

One way to make the various qualifications transparent, understandable and comparable is to describe them in terms of learning outcomes.

It is widely understood at the institutional and world of work level, that the overall competence for mastering digital/advanced manufacturing cannot be summarised in one person or one training profile. Digitization and Advanced Manufacturing require increased collaboration in mixed teams. The development and establishment of team-related competencies and skills are a major challenge for training and education. To this end, new forms of education, training, and further training are to be developed that enable accompanying training of specialists at all levels. Institutional learning in seminars will be complemented by situational and experimental learning in labs and during apprenticeships. Continuing education and training are to be established in an everyday part of the work in an entrepreneurial context and established through appropriate offers for all ages and training levels.

2. Cybersecurity in Advanced Manufacturing 19 (see specific sub-topic)

With Industry 4.0, there is a change in progress in manufacturing systems, provided by the development of communication and information technologies, adding an intelligence component in manufacturing plants, through the possibility of connectivity and interaction throughout the production chain (intelligent manufacturing systems or cyber-physical systems). However, this new paradigm has an extremely sensitive component, which is the question of the security of the data that is transferred and of the production processes themselves.

[18]«Home EXAM 4.0», Exam 4.0, 18 mars 2022, https://examhub.eu

[19]Armando Araújo de Souza Junior et al., «The State of Cybersecurity in Smart Manufacturing Systems: A Systematic Review , *European Journal of Business and Management Research* 6, nº 6 (16 décembre 2021): 188-94, https://doi.org/10.24018/ejbmr.2021.6.6.1173.

3.A Re-imagining manufacturing after pandemic and economic crisis

Few digital transformations can succeed without putting people at the centre. Four factors provide crucial support[20].

1. **Governance.** A digital transformation without a clear owner can end up as an orphan. A cross-functional team and governance structures then help ensure quick execution.
2. **Top-management commitment.** Transformations are more likely to take hold when they are driven by top leaders, with a compelling change story to help mobilize the organization. To keep the momentum from flagging, leaders can celebrate quick wins—as well as failures that help the company learn to fail fast and learn fast.
3. **Digital capability acquisition.** Skills gaps can be addressed by hiring where necessary, as well as by upskilling existing employees to fulfil even advanced digital roles, such as analytics translator, data engineer, data scientist, or IoT architect.
4. **New ways of working**. Implementing agile working methodologies empowers teams with the tools, processes, and best practices for achieving success in a digital world.

3.B Trends shaping strategic recruitment and new hiring trends21

The HR industry is being shaped by a number of emerging trends, including advancements in technology, cost savings, globalization, work-life balance, access to a wider pool of candidates, environmental concerns, resilience, business continuity and, most recently, behavioural science.

3.C Generation-Z, younger workers, and new ways of training2223

While younger workers have grown up as digital natives, a significant section of the workforce needs to be upskilled in the use of the latest technologies. Specialists call to increase awareness and knowledge about the benefits of digitalisation, as well as employers to increase staff engagement in managing their own skills development. This can be supplemented with support for the sharing of industry best practice training initiatives, especially shorter and modular versions.

Acquiring new skills and competencies requires inventive approaches and collaboration among different actors. While approaches such as outsourcing and novel recruitment methods are

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[20]Agrawal et al., «Industry 4.0: Reimagining manufacturing operations after COVID-19 | McKinsey».

[21]Raghu Misra, «Council Post: Trends Shaping Strategic Recruitment And New Hiring Trends», Forbes, 2023, https://www.forbes.com/sites/forbestechcouncil/2023/04/04/trends-shaping-strategic-recruitment-and-new-hiring-trends/.

[22]FIT4FoF, «Making our Workforce Fit for the Factory of the Future », FIT4FoF, 2023, https://www.fit4fof.eu/.

[23]WMF, «Report 2019».

prevalent, we have to focus on training and education to develop the skills and competencies in the manufacturing workforce.

Different mechanisms are identified such as educational design, and the use of technology to improve learning outcomes such as digital learning platforms, mobile learning, virtual and augmented reality and (collaborative) learning factories (see sub-topics 1.7.6 & 1.7.7.). Interventions will ensure the participation of older workers, women and other lesser-represented groups.

3.D 2023 global human capital trends[24]

1. **Framing the challenge.** Think like a researcher: Organizations and workers should activate their curiosity, looking at each decision as an experiment that will expedite impact and generate new insights.
2. **Charting a new path.** Co-create the relationship: Organizations and workers will need to learn to navigate this new world together - co-creating new rules, new boundaries, and a new relationship.
3. **Designing for impact.** Prioritize human outcomes: Organizations should create an impact not only for their business, their workers, or their shareholders but for the broader society as well.

3.E Manufacturing talent shortage: how to appeal to younger workers[25]

Top three considerations of those surveyed from the younger generation related to manufacturing jobs:

- **Flexibility.** 63% of the surveyed younger workforce are likely to consider a career in the manufacturing industry if offered more flexibility in shift timings and locations. Manufacturers should continue to implement additional programs, such as shift swapping, flexible core hours, and reducing overtime requirements, among others.
- **Focus on career growth and development.** 60% of the surveyed younger workforce indicated that having a clear growth path is one of the factors that would encourage them to choose a manufacturing job. Yet, the study emphasizes that recent science, technology, engineering, and math graduates may not recognize the

[24] Deloitte, «2023 Global Human Capital Trends», Deloitte Insights, s. d., https://www2.deloitte.com/us/en/insights/focus/human-capital-trends.html.

[25] Deloitte, « Addressing Manufacturing Talent Shortage », Deloitte United States, 23 juin 2022, https://www2.deloitte.com/us/en/blog/human-capital-blog/2022/manufacturing-talent-shortage.html.

opportunity the manufacturing industry can provide them to use their skills and build a career path and so are less inclined to pursue a career in manufacturing. Employers could work with potential hires to provide greater emphasis on programs to build digital and technical skillsets.

- **Well-being.** According to this analysis, well-being has become an increasingly important aspect of workforce experience in the last year. Manufacturers can address well-being by increasing investments in transforming the physical working environment, including the actual workspace, tools, and equipment.
- **Diversity, equity, and inclusion (DE&I).** 33% of the surveyed workforce selected the ability to be their authentic self as one of the most important factors in their workplace experience. According to a recent Deloitte report, the current generation is the most ethnically and racially diverse generation in history. Having a robust DE&I strategy that factors in an organization's influence across the workforce, marketplace, and society can be an effective way to attract younger workers.

The opportunity exists for manufacturers to capitalize on this moment and deliver many of the things that younger workers want, such as flexible work schedules, defined career pathways, and greater support for well-being and DE&I. By listening to this next generation of the workforce, manufacturing can capture a greater share of prospective employees and lay the groundwork for a strong industry future.

3.F How manufacturers can capture the knowledge of experienced workers26

Digitalization presents a massive opportunity for manufacturers to capture experienced workers' knowledge. When a manufacturer builds models that combine shop floor data with the intuition of knowledgeable workers, it can generate truly powerful insights.

3.G Understanding technological change and skill needs27

The skills required by jobs are diverse and multidimensional, and they can be specified in potentially infinite levels of detail. No survey or study can capture all skills involved in a particular job because any description of what a job entails can always be enriched with further details. There is also a tension between detail and comparability across occupations: very detailed measures tend to be occupation-specific, while overly general measures risk being weakly

[26]EY, «How Manufacturers Can Capture the Knowledge of Experienced Workers», EY, 15 septembre 2021, https://www.ey.com/en_ie/alliances/how-manufacturers-can-capture-the-knowledge-of-experienced-workers.

[27]CEDEFOP, «Understanding Technological Change and Skill Needs: Skills Surveys and Skills Forecasting», CEDEFOP, 12 avril 2021, https://www.cedefop.europa.eu/en/publications/4197.

informative. The key is to measure transversal skills and to devise measures pitched at a mid-level of generality that are relevant across a range of occupations. It should also include a reasonably concise checklist of more specific requirements, such as an inventory of digital skills, which are particularly relevant for research and policy. Most of the interest in skills and job-skill requirements typically focuses on a division of the concept at a most general level into cognitive, interpersonal, and manual skills.

Interpersonal or 'soft' skills have proven to be weakly conceptualised, as they also often include more purely attitudinal and motivational aspects of work orientations (Moss and Tilly, 2001). By contrast, cognitive and manual skills tend to be more concisely measured and are usually associated with robust labour market outcomes for individuals.

3.H. Education and training for manufacturing in Europe28

The main emphasis still needs to be put on the technical skills forming the core of this profession. Those include the ability to interact with human-machine interfaces, data management skills, and specialised and interdisciplinary knowledge of technologies and processes. However, rapidly advancing technology requires a general mindset for continuous improvement and lifelong learning. It is no longer just about what one knows, but increasingly about one's ability to adapt to continuously changing circumstances and to constantly advance one's knowledge and skills. Focussing on technical skills only is thus not enough. Other crucial non-technical skills refer, among others, to critical thinking, creativity, communication skills and the ability to work in teams.

There is a need for creating hands-on opportunities within education systems, as well as the close collaboration of business and educational institutions. Additionally, there is a need for offering learners real-world experience, exposing them to real challenges and advancements of industry and focussing on real-world application of skills. Finally, special attention needs to be paid to developing and elevating micro-credentialing programs for students and workers and exploring new/alternative forms of education and training.

[28]Executive Agency for Small and Medium-sized Enterprises (European Commission) Now known as et al., *Skills for Industry Curriculum Guidelines 4.0: Future Proof Education and Training for Manufacturing in Europe* (LU: Publications Office of the European Union, 2019), https://data.europa.eu/doi/10.2826/69418.

Some existing tools are being improved:

3.I Skill development and firm upgrading to sustain the competitiveness of manufacturing sector29

SkillUp contributed to research on skills in manufacturing sectors in European advanced economies in the following aspects:

Theory. SkillUp provides a systematic view of new trends in manufacturing and services for Industry 4.0. SkillUp develops a new conceptual framework in terms of the types of workers of today and tomorrow. It connected so-far distant works of literature on the global value chain with learning and skills development in relation to upskilling and upgrading in advanced economies. The research defined a systemic, interdisciplinary view of fragmented literature on the global reorganisation of production activities in the manufacturing industries in advanced economies.

Empirics. SkillUp provides rigorous research and evidence-based findings on which skills are needed for todays and tomorrow's jobs.

Methods. SkillUp tackles the limitations of standard methods by using new methodologies by allowing methods that accept the equifinality of different combinations, and possible redundancy of elements.

3.J Making our workforce fit for the factory of the future: FIT4FoF30 31

The increased introduction of digital technologies into manufacturing is leading to increased automation. Estimates indicate that the potential for automation in predictable physical work is at 33% followed by 22% in data collection and 11% in data processing.

The increased globalisation in manufacturing also introduces requirements in terms of teamwork, intercultural and language capabilities, the need to deal with shorter production cycles and changes in demographics requiring workers to stay active for longer.

Europe faces considerable challenges in addressing future skills needs. From the perspective of the workforce, the issues are increasingly complex where current training and educational solutions are discrete and lack interconnections and are largely dissociated from work activities.

[29] Cordis, Periodic Reporting for period 1 - SkillUp (Skill development and firm upgrading to sustain the competitiveness of the EU manufacturing sector) | H2020 | CORDIS | European Commission », HORIZON 2020, 17 septembre 2017, https://cordis.europa.eu/project/id/660022/reporting.

[30] Cordis, «Co-designed training for factory of the future jobs | FIT4FoF Project | Results in brief | H2020 | CORDIS | European Commission», Cordis, 31 décembre 2021, https://cordis.europa.eu/article/id/436472-co-designed-training-for-factory-of-the-future-jobs.

[31] Cordis, «Making our Workforce Fit for the Factory of the Future | FIT4FoF Project | Fact Sheet | H2020 | CORDIS | European Commission», Cordis, 31 décembre 2021, https://cordis.europa.eu/project/id/820701.

Growing gaps in knowledge and know-how make it increasingly challenging to adapt, work proactively and contribute to innovations.

FIT4FoF aims at addressing a range of these issues by analysing current skills initiatives, better understanding how to address workers' needs, analysing technology trends across six industrial areas of robotics, additive manufacturing, mechatronics/machine automation, data analytics, cybersecurity and human-machine interaction, to define new job profiles, which will inform education and training requirements.

FIT4FoF develops a new education and training framework, which places workers (women and men) at the centre of a co-design and development process that recognises and addresses their skills needs.

By applying educational approaches based on Communities of Practice, FIT4FoF empowers workers to be drivers of the design, development and delivery of their own upskilling programmes.

FIT4FoF develops Alliances of Communities of Practice to broaden the approach across Europe, creating replication strategies enabling educational/training design and development practices to be transferred between regional communities across Europe.

FIT4FoF focuses on engaging workers in the design of upskilling programmes for the manufacturing sector. Their partners identified a catalogue of 117 emerging new job profiles, developed a repository of existing upskilling initiatives and captured this within a novel Upskilling Analysis Tool to support the rapid analysis of the upskilling needs.

To answer these needs, FIT4FoF places workers at the centre of a collaborative process using co-design, to change the dynamic between employers and educators in a manner that enables the voice of the employee/learner to be amplified.

As an easy-to-use process, it becomes possible for companies, clusters, and other stakeholders to design and execute their own upskilling programs using the project toolkit to adapt to industrial context, language, culture and needs.

4.A Considering a greenfield manufacturing investment?32

As every industry faces unique market forces, global manufacturing is experiencing four paradigm shifts: enhanced market competition, supply chain and workforce disruption, evolving customer tastes, and new sustainability expectations. Turn these challenges into opportunities by developing greenfield manufacturing sites with smart factory solutions.

[32]Deloitte, «Greenfield Manufacturing », Deloitte, Deloitte United States, s. d., https://www2.deloitte.com/us/en/pages/operations/articles/greenfield-manufacturing.html.

4.B Why manufacturing is setting the bar for climate-related disclosures33

Most manufacturing companies score highly for coverage of the Task Force on Climate-related Financial Disclosures (TCFD) recommendations. Most companies are beginning to provide information on their approach to incorporating scenario planning as part of their climate strategy development.

4.C French mechanical industry supports the future european aerospace research towards Green aviation34

Aeronautics must respond to three challenges – environmental, economic and societal – that require and justify an unprecedented R&T effort.

This sector is strongly committed to the energy transition and the reduction of its environmental impacts. In response to market expectations, the manufacturing tool must evolve in technicality and productivity to reduce acquisition and operating costs while preserving margins. The Supply Chain, especially SMEs, must continue to develop its skills in a highly competitive environment.

4.D SmartEnergy project: Accelerate the energy transition35

This MINALOGIC Innovation cluster project aims at companies in the world of Smart Energy: to develop innovative solutions at the crossroads between digital and energy, and to support energy efficiency and performance, energy and ecological transition, intelligent distribution of energy, Smart Grids, etc.

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[33]Mathew EY, «Manufacturing Sets Bar for Climate-Related Disclosures», EY, 1 juin 2020, https://www.ey.com/en_ie/climate-change-sustainability-services/why-manufacturing-is-setting-the-bar-for-climate-related-disclosures.

[34]Cetim, «French Mechanical Industry Supports the Future European Aerospace Research towards Green Aviation - Cetim Engineering %», *Cetim Engineering* (blog), 18 décembre 2020, https://www.cetim-engineering.com/french-mechanical-industry-supports-the-future-european-aerospace-research-towards-green-aviation/.

[35]Minalogic, SmartEnergy. Accélérez la transition énergétique », Minalogic, 21 avril 2020, https://www.minalogic.com/smartenergy-accelerez-la-transition-energetique/.

New tools being developed:

DTAM[36]: A new EU project to facilitate digital transformation in advanced manufacturing. DTAM creates an Integral Training Curriculum for EU technicians to deploy and manage digital tools in Smart Manufacturing.

4.E i E T4.0 report on Industry4.0 for Ecological transition37

This European ERASMUS project aims to present Industry 4.0 technologies to help Ecological Transition.

5. Circular economy38

The focus is based on digital technologies' potential to enable circular manufacturing, and policy and other enablers for circular manufacturing.

The circular economy paradigm is becoming increasingly relevant as more and more companies realise the real value and profitability of this new, more sustainable way of doing business. The circular economy relies on several strategies that extend the product life cycle through reusing, recycling, remanufacturing, and redesigning circular products and materials, intending to reduce waste. This report identifies key drivers to the circular economy, which include global initiatives such as the UN Sustainable Development Goals and other policy developments, innovation, collaboration across stakeholders, and business drivers. However, challenges need to be addressed such as the uptake of new business models, adequate standards and laws, and financial incentives, among others. Nevertheless, the benefits for manufacturers are profound, such as increased economic opportunities for manufacturers, a reduction in waste, the creation of more and better jobs, and a contribution to alleviating climate change.

Digital technologies are an important catalyst to achieve circularity in manufacturing value chains. Digitally enabled circular manufacturing supports three key objectives: resource efficiency, waste reduction, and reduced emissions. As outlined in the Report, digital technologies can support the transition to circular manufacturing at the firm level - which includes product development, production, and new business models - as well as at the network level.

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[36]«DTAM: A New EU Project to Facilitate the Digital Transformation in Advanced Manufacturing - European Forum for Vocational Education & Training», 18 janvier 2021, https://efvet.org/dtam-a-new-eu-project-to-facilitate-the-digital-transformation-in-advanced-manufacturing/.

[37]«Project iET 4.0», iet 4.0, s. d., https://iet40.eu/.

[38]WMF, «Report 2021: Digitally Enabled Circular Manufacturing», World Manufacturing Foundation, 1 juillet 2021, https://worldmanufacturing.org/report/report-2021-digitally-enabled-circular-manufacturing/.

The transition to circular manufacturing is a priority for many governments globally. Regional and national strategies to promote circularity vary in ambition, approach, and the emphasis put on the enabling role of digital technologies. The Report identifies key enablers for the circular manufacturing transition. Enablers at the consumer level include environmental awareness, increasing trust and transparency in relation to service providers, convenience and accessibility of sustainable products, and digital literacy. At the company level, enablers include demand for sustainable products, digital technologies, and circular skills, among others. At the value chain level, there is a need to improve data sharing, enhance infrastructure and networks, and standardisation of requirements.

3.2.3.5 Conclusions

Following the review of sources, and exploration of various new programmes already in place to tackle the challenges of the future, the below five statements capture the future 'mega trends' for Advanced Manufacturing:

1. **Companies and SMEs will be more and more connected and there will be more IA inside technological processes.**

   Companies working in Advanced Manufacturing are and will become more and more connected, using more and more 4.0 Technologies, with a significant introduction of Artificial Intelligence for Predictive Maintenance (See sub-topic on Predictive Maintenance). There will be more connections within and between companies. Current and future training courses need to take into account this technological mega-trend.

2. **Cybersecurity will spread everywhere.**

   Cyber threads will be more and more present because of the interconnectedness of companies, and the strong developments in AI and digital tools. Cybersecurity will be strategic (see specific sub-topic). Current and future training courses need to take into account this technological mega-trend.

3. **Human will be at the centre of Advanced Manufacturing.**

   In Europe, Industry 4.0 has been introducing AI and digital tools, within and between companies for more than 15 years. More recently, due to developments in several countries, human is becoming a real subject in the heart of Industry 4.0, to the point that some people use the new concept of ‘Industry 5.0.’ But it might be more a 4.1 evolution of Industry 4.0.

4. **Advanced Manufacturing will become greener, and energy transition will develop in Advanced Manufacturing.**

   One of the new evolutions of Industry 4.0, and Advanced Manufacturing, is the strong commitment to an Energy Transition, to accompany the Ecological Transition.

   This evolution could be considered Industry 4.2 (if Industry 4.1 is the Human-centred evolution). Consecutively, Industry 4.0 is becoming more Human-centred and greener. Current and future training courses need to consider these industry evolutions.

5. **Circular economy will be introduced at each step in Advanced Manufacturing.**

   Finally, another upcoming evolution of the Industry 4.0 is that of the introduction of circular economy within Advanced Manufacturing.

   We could this in the 4.3 evolution of the industry. Current and future training courses need to consider this industry evolution.

3.3 MEGA TRENDS IN MANUFACTURING & INSIGHTS FOR VET IN THE BASQUE COUNTRY

3.3.1 Introduction

This sub-report aims to provide a comprehensive analysis of the current state of advanced manufacturing in the Basque Country, with a focus on the role of vocational education and training (VET) in developing the skills necessary for this sector. The sub-report identifies the Advanced Manufacturing sector as one key strategic area for the Basque Country's economy and highlights the importance of collaboration between companies, the VET system and governments in fostering innovation and transmitting ideas to the industrial network. Additionally, the sub-report offers reflections for VET teachers, VET students and heads of VET centres.

3.3.2 Contextualisation

The Basque Country has established itself as a key player in the European advanced manufacturing sector, with machine-tool and advanced aeronautical manufacturing being identified as the strategic areas for its economy over the last few decades.

In order to maintain and strengthen its position in this sector, the Basque government has made a strong commitment to vocational education and training (VET), having recognized the crucial role that it plays in developing the skills necessary for this industry.

3.3.3 Objectives / Research Question / Problem Statement

Advanced Manufacturing is a critical sector for the Basque Country's economy, with increasing demand for skilled workers in areas such as robotics, additive manufacturing, and automation. However, the VET system faces challenges in keeping pace with these rapid technological changes and providing students with the skills and competencies needed for successful careers in Advanced Manufacturing.

This report aims to answer the research question, "How can the Basque Country's VET system better prepare students for careers in Advanced Manufacturing?" To achieve this goal, the report has the following objectives:

- Identify the skills and competencies needed for a career in Advanced Manufacturing, based on a review of industry trends and job requirements.
- Assess the current state of VET programs in the Basque Country and their alignment with industry needs, using a combination of surveys, interviews, and case studies.
- Analyse successful models of VET programs in other regions or countries and identify best practices that can be applied in the Basque Country.
- Provide recommendations for VET teachers, heads of VET centres, and VET students to enhance the quality and relevance of VET programs in the field of Advanced Manufacturing.

The problem statement for this report is that there is a skills gap between the skills taught in VET programs in the Basque Country and the needs of industry in the field of Advanced Manufacturing. Despite the importance of this sector to the Basque Country's economy, students are not being adequately prepared for careers in this field, leading to limited job opportunities and a lack of competitiveness for the region.

The scope of this sub-report is focused on Basque Country's VET system and its alignment with the needs of the Advanced Manufacturing sector. The report draws on a range of sources, including academic literature, industry reports, and other sources from stakeholders in the VET and Advanced Manufacturing sectors. By providing insights and recommendations, this report aims to contribute to the ongoing efforts to improve the quality and relevance of VET programs in the Basque Country and enhance the competitiveness of the Advanced Manufacturing sector.

3.3.4 Findings

The results are presented starting from the European and national approach down to the level of Basque VET. It shows what is happening in the advanced manufacturing ecosystem in terms of trends, how this may affect Basque VET and how the challenges are being met.

- **European and national approach**
- Strategic response of the Basque Country
- How Basque VET is affected.

European and national approach

The development of new technologies and processes is crucial for the success of the manufacturing industry in Europe.[39] Digitalisation, automation and sustainability are identified as key areas for innovation.

Collaboration is essential to drive progress in the manufacturing industry. It, therefore, underlines the importance of cooperation between stakeholders, including researchers, businesses and policymakers, to ensure that innovation efforts are coordinated and effective.

The human factor is becoming increasingly important in advanced manufacturing. The need to focus on human-centred manufacturing is highlighted, which involves designing manufacturing systems that are safe, ergonomic, and adaptable to the needs of workers. This includes areas such as human-robot collaboration and the development of skills for the workforce of the future.

Advanced manufacturing represents an opportunity for Spain to increase productivity, competitiveness, and innovation, and attract new investment[40].

Spain has a strong industrial base, particularly in the automotive and aerospace sectors, and has the potential to develop new capabilities in areas such as robotics, additive manufacturing, and smart factories.

To realize the full potential of advanced manufacturing, Spain needs to invest in research and development, digital skills, and collaboration between industry, academia, and government, and create an ecosystem that supports innovation and entrepreneurship.

The digitalization and automation of the manufacturing process are transforming the labour market, requiring workers to develop new skills and competencies to succeed in the jobs of the future[41].

Vocational education and training (VET) programs play a critical role in preparing workers for the jobs of the future by providing them with the necessary skills and competencies to adapt to the changing technological landscape.

There is a need for collaboration between VET schools and industry stakeholders to ensure that VET programs align with the needs of the labour market and that students are equipped with the skills and knowledge needed to succeed in Industry 4.0-related fields.

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[39]«Plataforma Tecnológica Española de Fabricación Avanzada: AGENDA DE PRIORIDADES ESTRATÉGICAS DE I+D+i», *MANU-KET*, 2022, https://www.manufacturing-ket.com/wp-content/uploads/2022/02/MANU-KET-AGENDA-PRIORIDADES-ESTRATEGICAS-de-IDi.pdf.

[40]«Claves e inversiones estratégicas para una España 5.0», *PricewaterhouseCoopers*, 2021, 98.

[41]«informe-completo-2021.pdf», consulté le 3 mai 2023, https://www.observatoriofp.com/downloads/2021/informe-completo-2021.pdf.

The nature of work is changing[42] in the Industry 4.0 era, with an increasing emphasis on digital and technological skills, problem-solving skills, and soft skills such as communication and collaboration.

To prepare VET students for the jobs of the future, VET teachers and heads of VET schools must adapt their teaching methodologies and content to the changing nature of work and incorporate new teaching strategies, such as project-based learning and work-based learning.

To succeed in the Industry 4.0 era, VET students must be proactive in their learning, seek out opportunities for continuous learning and upskilling, gain practical, hands-on experience through internships and other experiential learning opportunities, and be flexible and adaptable in their career paths.

Strategic response of the Basque Country

Advanced manufacturing has been identified as a key area of strategic focus for the Basque Country, to become a world reference in this field by 2030[43].

To achieve this goal, it outlines a series of actions to be carried out, including the promotion of innovation and digitalisation in manufacturing processes, the development of new materials and technologies, and the creation of new business models.

It also highlights the importance of collaboration between companies, research centres and public institutions to boost innovation and competitiveness in advanced manufacturing.

In the Basque Country, the 6th Basque Vocational Training Plan[44] aims to adapt vocational education and training to the technological and organisational changes brought about by Industry 4.0. This includes promoting the development of digital skills, the use of emerging technologies and the adoption of flexible and innovative training methods.

The plan aims to strengthen collaboration between the vocational education and training system and the industrial sector to ensure that the skills and competencies acquired by learners respond to the needs of the labour market. This includes promoting the involvement of enterprises in the design and delivery of training programmes and establishing partnerships between vocational education and training institutions and enterprises.

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[42]«cambios-en-los-perfiles-profesionales97650.pdf», consulté le 3 mai 2023, https://www.caixabankdualiza.es/recursos/doc/portal/2022/06/23/cambios-en-los-perfiles-profesionales97650.pdf.

[43]«pcti-euskadi-2030-604a5a6f761c1.pdf», 2021, https://www.innobasque.eus/uploads/attachment_files/pcti-euskadi-2030-604a5a6f761c1.pdf.

[44]6PLAN_FP_cas_2022.pdf, 2022, https://www.euskadi.eus/contenidos/informacion/lh_euskal_plana/es_def/adjuntos/6PLAN_FP_cas_2022.pdf.

The plan recognises the importance of advanced manufacturing as a key sector for the economic and social development of the Basque Country. In this sense, the plan aims to support the development of advanced manufacturing through vocational training, promoting the acquisition of the necessary skills and competencies for the digitalisation and automation of industrial processes, and supporting companies in their transition towards Industry 4.0.

How Basque VET is affected

Advanced manufacturing technologies, such as additive manufacturing, robotics, and nanotechnology, are transforming the manufacturing sector and creating new opportunities for vocational training[45].

Vocational training programs must be updated to include training on advanced manufacturing technologies in order to prepare workers for the jobs of the future.

There is a growing trend towards the use of digital technologies in manufacturing, such as 3D printing, robotics, and automation. These technologies are enabling manufacturers to produce more complex and customized products, while also improving efficiency and reducing costs.

Industry 4.0 is a new industrial revolution[46] that involves the integration of advanced technologies such as cyber-physical systems, the Internet of Things, big data, and automation into the manufacturing process. This requires a workforce that is familiar with these concepts and technologies and has the skills and competencies needed to work with them.

Advanced manufacturing techniques such as additive manufacturing (3D printing) and robotics are becoming more widespread in Industry 4.0, leading to increased efficiency and productivity. VET programs need to adapt their curricula to provide students with hands-on experience with these techniques to better prepare them for the changing demands of the industry.

Educational institutions and industry partners need to collaborate to develop training programs and apprenticeships that align with the needs of the local workforce. VET students can benefit from internships and apprenticeships that provide them with real-world experience and help them develop industry-specific skills.

[45]MikelAlbizu Echevarria et Miren Estensoro Garcia, « EL ROL DE LA FORMACIÓN PROFESIONAL EN LOS SERVICIOS AVANZADOS », *Orkestra*, 2020, https://api.observatoriofp.com:8443/documents/20123/51081/48_El-rol-de-la-formaci%C3%B3n-profesional-en-los-servicios-avanzados.pdf.

[46]«RevistaTecnologica2021_Art11.pdf», 2021, http://www.redicces.org.sv/jspui/bitstream/10972/4419/1/RevistaTecnologica2021_Art11.pdf.

3.3.5 Conclusions

General conclusions

From a general perspective, there is a need for collaboration, investment, and education to advance the industry and prepare the workforce for future jobs.

The manufacturing industry faces challenges such as competition in a global market, changing technologies, and the need for human-centred manufacturing. To address these challenges, stakeholders must work together, develop new technologies and processes, and prioritize vocational education and training programs to prepare workers for the changing landscape of Industry 4.0.

In Spain, investment in research and development, digital skills, and collaboration between industry, academia, and government is needed to enhance competitiveness, productivity, and innovation in areas such as robotics, additive manufacturing, and smart factories.

Vocational education and training programs must adapt their teaching methodologies and content to the changing nature of work, provide practical, hands-on experience, and encourage flexibility and adaptability in career paths. By investing in collaboration and education, the manufacturing industry can thrive, and workers can stay competitive in the rapidly evolving job market.

In the Basque Country, in order to improve competitiveness, productivity and innovation, a policy to invest in research and development, digital skills and collaboration between industry, academia and the administration is in place.

The Basque Government has launched several initiatives such as the Basque Digital Innovation Hub and the Advanced Manufacturing Training Center to develop new skills in areas such as robotics, additive manufacturing and smart factories.

These initiatives are designed to provide practical experience for vocational education and training students and to align VET programmes with the needs of the labour market.

The Basque Government also encourages collaboration between industry and VET schools to develop new technologies and processes and ensure that VET students are prepared for the changing landscape of Industry 4.0.

Overall, the initiatives implemented in the Basque Country serve as a model for the advancement of the manufacturing industry and the preparation of the workforce for the jobs of the future.

Conclusions for the VET community

For VET teachers

As Industry 4.0 advances, the manufacturing industry is changing rapidly, requiring workers to develop new skills and competencies to keep up with technological advancements. As a VET teacher, it's important to understand the changing nature of work and the skills required for the jobs of the future.

One of the key findings related to advanced manufacturing is the importance of collaboration between stakeholders in the industry, including VET schools, industry partners, and the government. VET teachers can play a critical role in preparing students for careers in advanced manufacturing by adapting their curricula to align with the needs of the labour market and collaborating with industry partners to provide students with practical, hands-on experience.

Another important finding is the need for workers to be flexible and adaptable in their career paths, continuously learning and upskilling to stay relevant in the rapidly evolving job market. As a VET teacher, it's important to encourage students to be proactive in their learning, seek out opportunities for continuous learning and upskilling, and gain practical experience.

Finally, it is important to highlight the importance of vocational programmes in preparing workers for the changing landscape of Advanced Manufacturing and ensuring employability. As VET teachers, it is important to adapt teaching methods and content to the changing nature of work and to incorporate new teaching strategies to prepare students for the jobs of the future.

In summary, as a VET teacher, it's crucial to stay up to date with the latest trends and advancements in advanced manufacturing and collaborate with industry partners to provide students with the necessary skills and competencies.

For VET students

Industry 4.0 is changing the nature of work and requiring a new set of skills and competencies from workers, including those who receive vocational education and training (VET). This means that students need to be proactive in their learning, seeking out opportunities for continuous learning and upskilling, gaining practical, hands-on experience, and being flexible and adaptable in their career path.

Collaboration between VET schools and industry stakeholders is crucial in ensuring that VET programs align with the needs of the labour market. This means that students should be aware of the trends and needs of the industry and try to gain exposure to real-world projects or internships whenever possible.

Finally, preparing for the jobs of the future requires a combination of technical skills and soft skills, such as communication, problem-solving, and teamwork. Students must focus on developing both sets of skills, through formal training and practical experience, to ensure their employability in Industry 4.0-related fields.

Overall, the key message for VET students interested in advanced manufacturing is to be proactive, collaborative, and focused on developing a well-rounded set of skills to succeed in the rapidly evolving job market. This includes seeking out opportunities for continuous learning and upskilling, gaining practical, hands-on experience, and being flexible and adaptable in their career paths. Additionally, it's essential for VET students to develop competencies beyond technical skills, such as problem-solving, critical thinking, communication, and teamwork, which are highly valued in the industry. By taking an active approach to their learning and development, VET students can position themselves for success in the competitive and dynamic field of advanced manufacturing.

For heads of VET centres

The advanced manufacturing industry is rapidly evolving, and it is crucial for VET centres to keep up with these changes to effectively prepare their students for the workforce. To do so, it is important for heads of VET centres to stay informed about the latest trends and advancements in the field and to collaborate with industry partners to ensure that their programs align with industry needs.

One of the key challenges facing VET centres is the need to strike a balance between traditional manufacturing skills and new, emerging technologies. This requires a willingness to adapt and change curricula to incorporate new techniques and tools while also maintaining a strong foundation in the fundamentals.

In addition, it is important for VET centres to focus on developing a well-rounded set of skills in their students, including soft skills like communication, problem-solving, and critical thinking, as well as technical skills. This will help ensure that graduates are prepared for the demands of the advanced manufacturing workplace and are able to adapt to new challenges as they arise.

Overall, heads of VET centres play a critical role in preparing the next generation of workers for the advanced manufacturing industry. By staying informed, collaborating with industry partners, and focusing on a well-rounded education, they can help ensure that their students are well-prepared to succeed in this rapidly evolving field.

3.4 LEARNING ANALYTICS

3.4.1 Introduction

Learning analytics refers to the collection, analysis, and interpretation of data generated from educational activities and environments. It involves using technology and data analysis techniques to gain insights into learning processes, behaviours, and outcomes. Learning Analytics is positioned at the intersection of Learning, Analytics, and Human-Centred Design, and encompasses areas such as educational research, learning and assessment sciences, educational technology, statistics, visualization, computer/data sciences, artificial intelligence, usability, participatory design, and sociotechnical systems thinking.[47] The primary goal of learning analytics is to enhance and optimize learning experiences and outcomes.

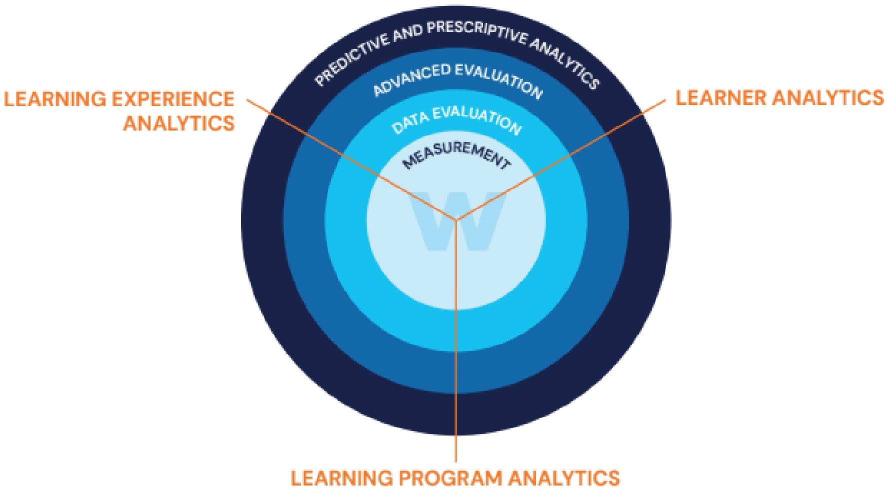

Figure 5: About Learning Analytics, Source: watershed LRS

By collecting and analysing data from various sources, such as learning management systems, online platforms, and educational tools, learning analytics aims to provide valuable information to educators, administrators, and learners themselves. This information can be used to make informed decisions, improve instructional strategies, identify areas of improvement, and personalize learning experiences.

[47] «What Is Learning Analytics?», *Society for Learning Analytics Research (SoLAR)* (blog), s. d., https://www.solaresearch.org/about/what-is-learning-analytics/.

Learning analytics empowers the workforce in advanced manufacturing by addressing skills gaps, enabling personalized training, promoting continuous learning, supporting predictive workforce planning, optimizing performance management, and facilitating knowledge sharing. Through the evidence-based approach, organisations can make more informed decisions, leading to better learning outcomes.[48] Leveraging data and analytics ensures that the industry remains competitive and that employees have the necessary skills to thrive in the dynamic field of advanced manufacturing.

Figure 6: Typical answers from LE.AN. Source. Learning Technology Hub

[48] Dirk Ifenthaler, «Learning Analytics for School and System Management» (Paris: OCDE, 27 octobre 2021), https://doi.org/10.1787/d535b828-en.

3.4.2 Contextualisation

In the context of advanced manufacturing, learning analytics can be used in several ways:

- **Skills assessment and training:** Learning analytics can be employed to assess the skills of employees in advanced manufacturing. By analysing data on performance, training outcomes, and job requirements, organizations can identify skill gaps and develop targeted training programs to address them. Learning analytics can track the progress and effectiveness of training initiatives, ensuring that employees acquire the necessary skills and knowledge to excel in their roles.
- **Performance monitoring and optimization:** Learning analytics enables organizations to monitor and analyse employee performance in advanced manufacturing. By collecting and analysing data on productivity, quality metrics, and other performance indicators, organizations can identify areas for improvement and provide targeted feedback and coaching. This data-driven approach helps optimize individual and team performance, leading to increased efficiency and quality in manufacturing processes.
- **Predictive analytics for workforce planning:** Learning analytics can be used for predictive analytics in workforce planning for advanced manufacturing. By analysing historical data on employee performance, training outcomes, and industry trends, organizations can forecast future workforce needs. This helps in planning for skill requirements, identifying potential skill gaps, and ensuring the availability of a capable workforce to meet the evolving demands of advanced manufacturing.
- **Adaptive training and personalized learning:** Learning analytics can support adaptive training approaches in advanced manufacturing. By analysing data on individual employee performance, learning preferences, and skill levels, organizations can personalize training programs to meet the specific needs of each employee. This ensures that training is efficient and targeted, maximizing learning outcomes and skill development.
- **Process improvement and optimization:** Learning analytics can be utilized to identify bottlenecks, inefficiencies, and areas for improvement in manufacturing processes. By analysing data on employee performance, process metrics, and quality indicators, organizations can gain insights into areas that can be optimized. This data-driven approach helps in streamlining processes, reducing waste, and improving overall operational efficiency in advanced manufacturing.
- **Knowledge sharing and collaboration:** Learning analytics can facilitate knowledge sharing and collaboration among employees in advanced manufacturing. By analysing

data on employee interactions, knowledge acquisition, and expertise, organizations can identify opportunities for collaboration, identify subject matter experts, and foster a culture of knowledge exchange. This promotes innovation, problem-solving, and continuous learning within the workforce.

By leveraging learning analytics in advanced manufacturing, organizations can optimize workforce skills, enhance performance, improve process efficiency, and foster a culture of continuous learning and improvement. Ultimately, learning analytics helps drive innovation, productivity, and competitiveness in the field of advanced manufacturing.[49]

3.4.2.1 How is Learning Analytics Used?

Learning analytics typically involves the following steps:

- **Data collection:** Gathering data from different sources, including student assessments, interactions with digital resources, online discussions, and more.
- **Data analysis:** Applying statistical and computational techniques to examine the collected data and identify patterns, trends, and correlations.
- **Interpretation and visualization:** Interpreting the analysed data and presenting it in a meaningful way through visualizations, dashboards, and reports.
- **Actionable insights:** Extracting insights from the analysed data and using them to inform decision-making and improve learning experiences.

Understand and predict user behaviour

Learning analytics helps understand and predict user behaviour by analysing data patterns. It uncovers insights into how users engage with learning materials and platforms. Examining factors such as learning paths, content preferences, and engagement levels, it deepens understanding of user interactions. Learning analytics also identifies patterns in activity sequences, time spent, and frequency of engagement. This knowledge enables tailored learning experiences and predicts user performance. Historical data analysis, including completion rates and assessment scores, allows for forecasting performance and timely interventions. Learning analytics enhances understanding of user behaviour, enabling personalized and effective learning experiences.[50]

[49] Ibid.

[50] Graduate Programs Staff, «What Is Learning Analytics & How Can It Be Used?», Graduate Blog, 18 février 2020, https://graduate.northeastern.edu/resources/learning-analytics/.

Personalise and improve courses

By analysing data on individual learner performance, preferences, and behaviour, learning analytics provides insights to customize course content and delivery. It helps identify gaps in knowledge, areas of difficulty, and preferred learning styles for each learner. This information enables instructors to tailor instructional strategies, resources, and assessments to meet individual needs. By continuously monitoring learner progress, learning analytics facilitates timely interventions and adjustments, ultimately enhancing the effectiveness and relevance of courses, leading to improved learning outcomes.[51]

Enable early intervention and support

Through ongoing monitoring and analysis, learning analytics helps track learner progress and provides insights to optimize intervention strategies. This proactive approach helps ensure timely support, leading to improved learner outcomes and a more inclusive and effective learning environment.[52]

3.4.2.2 Learning Analytics Data Sources

Depending on the type of organisation, learners and learning outcome about advanced manufacturing, specific data sources for learning analytics could be:

- **Learning management systems (LMS):** LMS platforms capture data on learner interactions within advanced manufacturing training programs. This includes information such as course enrolment, completion rates, time spent on activities, assessment scores, and participation in discussion forums. LMS data provides insights into learner engagement, progress, and performance within the structured learning environment.
- **Simulation and Virtual reality systems:** Simulations and VR systems used in advanced manufacturing training generate data on user interactions and performance. This includes metrics like task completion time, accuracy, decision-making processes, and user feedback. Learning analytics can analyse this data to assess learner

[51]«How can learning analytics help you design more effective courses?», s. d., https://www.linkedin.com/advice/3/how-can-learning-analytics-help-you-design.

[52]OctopusBI, «5 Ways Learning Analytics Helps Schools Predict Students at Risk», OctopusBI, 10 novembre 2021, https://octopusbi.com/5-ways-learning-analytics-helps-schools-predict-risk-and-manage-early-intervention/.

proficiency, identify areas for improvement, and provide personalized feedback within the simulated environments.

- **Sensor data and Internet of Things (IoT):** In advanced manufacturing, sensors and IoT devices capture real-time data on equipment performance, process parameters, and product quality. Learning analytics can integrate with these data sources to track learner interactions with sensor-equipped machinery, analyse performance metrics, and provide insights on skill development and operational understanding.
- **Workforce performance data:** Performance data from the advanced manufacturing workforce, including productivity levels, quality metrics, and operational efficiency, can be valuable for learning analytics. By analysing this data, learning analytics can identify skill gaps and training needs, assess the impact of training initiatives on workforce performance, and align learning programs with the specific requirements of the advanced manufacturing industry.
- **Learning content and courseware:** Learning analytics can analyse data from the content and courseware used in advanced manufacturing training programs. This includes data on content utilization, completion rates, learner interactions with specific learning resources (e.g., videos, simulations, quizzes), and feedback provided by learners. Analysing this data helps identify the effectiveness of learning materials, areas where content can be improved or adapted, and the impact of different resources on learner engagement and comprehension.[53] [54]

3.4.2.3 Learning Analytics Methodologies

Learning analytics methodologies encompass a range of approaches to analyse and derive insights from educational data. These include descriptive analytics, which examine historical data to understand patterns and trends; predictive analytics, which use data to forecast future outcomes and learner performance; and prescriptive analytics, which recommend actions and interventions based on data analysis. Additionally, learning analytics methodologies may involve data mining,

[53]Jim Yupangco, «What Sources Of Learning Analytics Should You Be Collecting?», eLearning Industry, 3 juillet 2017, https://elearningindustry.com/sources-of-learning-analytics-should-collecting.

[54]Jeanette Samuelsen, Weiqin Chen, et Barbara Wasson, «Integrating multiple data sources for learning analytics—review of literature», *Research and Practice in Technology Enhanced Learning* 14, nº 1 (28 août 2019): 11, https://doi.org/10.1186/s41039-019-0105-4.

machine learning algorithms, visualization techniques, and statistical analysis to uncover meaningful patterns and inform decision-making in education and training contexts.[55] [56] [57]

3.4.2.4 Learning Analytics Tools

To conduct learning analytics, organisations are reliant on an arsenal of tools that help them collect and sort the data. Therefore, choosing the most suitable and effective set of tools is a vital step in ensuring your learning analytics strategy is a success.

Various factors come into play when determining which learning analytics tools one will need. Some aspects to consider are the sector you work in and which learning tools you already have at your disposal. Since many learning management systems include learning analytics features, this is something that should be considered.

Since some tools are specifically designed for education and some are specifically designed for corporate settings, you'll want to make sure you're selecting a tool that is appropriate to your learners and learning objectives.

Tools for educational institutes

When it comes to choosing an appropriate tool for schools, universities and educational institutes, you'll want to ensure the system is able to effectively identify at-risk students so that support and early intervention can be provided.

Within education, it is typically the teachers, instructors and advisors who are responsible for monitoring student success. Therefore, the tool should ideally include a user-friendly dashboard with data visualisations.

Some examples of learning analytics tools that are designed for education are Intellischool Albitros and Blackboard Predict. There are also various Moodle plugins with learning analytics capabilities. [58]

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[55] Andy Nguyen, Lesley Gardner, et Don Sheridan, *A Design Methodology for Learning Analytics Information Systems: Informing Learning Analytics Development with Learning Design*, 2020, http://hdl.handle.net/10125/63753.

[56] «Learning Analytics: The Ultimate Guide | DLI Blog», Digital Learning Institute, 6 septembre 2022, https://www.digitallearninginstitute.com/blog/learning-analytics-the-ultimate-guide/.

[57] «Unleashing the Types of Analytics: Categories and Applications», ProjectPro, s. d., https://www.projectpro.io/article/types-of-analytics-descriptive-predictive-prescriptive-analytics/209.

[58] Ifenthaler, «Learning Analytics for School and System Management».

Tools for corporate training

When choosing learning analytics tools for corporate training or L&D, it's crucial to align the tools and features with the business and learning objectives. For example, whether your focus is on employee onboarding, leadership development or upskilling, you may need specific types of learning analytics strategies and tools.

It is also important to ensure that the tool is user-friendly. While some L&D teams may have a specialised Learning Analyst, or Training Analyst within their team, this is not always the case. Therefore, choosing tools that enable you to make the most use of the data without advanced data analysis skills is also an important factor.

One example of an enterprise learning analytics tool is Learning Pool. Their reporting and analytics solution includes customised dashboards with data visualisations and AI-powered predictive analytics. A further example of a corporate learning platform with analytics features is 360learning, which uses AI to create personalised learning experiences.[59]

3.4.2.5 Learning Analytics: Proposal for Real-World Application

Learning Analytics is a service built on a set of tools, that can be part of a platform such as LCAMP. The service would aim to help individuals (or account owners) understand and follow their educational needs and progress.

The user would be able to access their current educational status (skills and/or competencies), their desired educational goals and their desired vocational goals (jobs).

Learning analytics, utilizing tools such as GAP analysis, learning pathways and Course recommendation, can help steer the user towards their educational or vocational goals and help them monitor their progress.

Without such a service and with the exponentially growing number of required new skills, new types of vocations and a plethora of courses of various quality levels, it will be near impossible for individuals, let alone companies, to navigate the space of required learning, that would allow them to adapt to new Advanced Manufacturing requirements.

[59] CommLab India Bloggers, «How to Optimize Corporate Training Courses with Learning Analytics?», *Rapid ELearning Blogs – CommLab India* (blog), 30 juin 2022, https://blog.commlabindia.com/elearning-design/learning-analytics-effective-corporate-training.

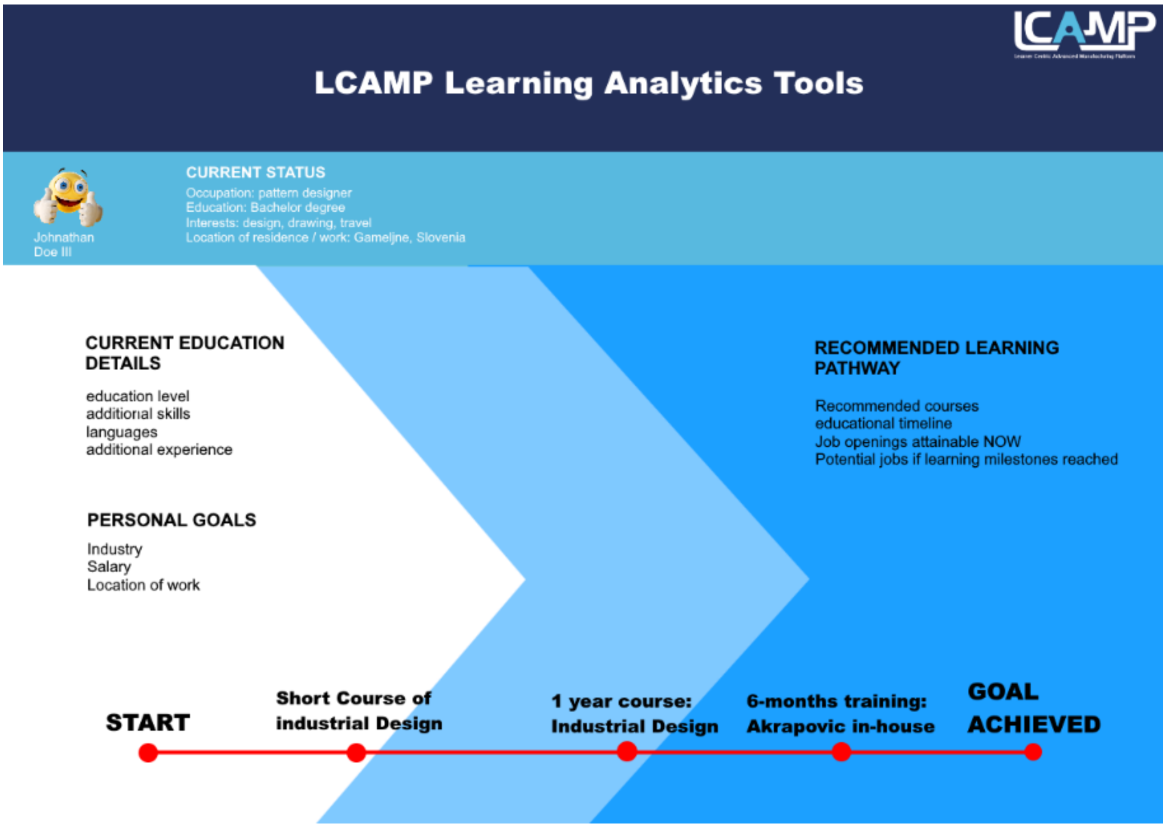

Figure 7: Early idea for a learning pathway overview

The tools would ultimately combine the services of a customized HR and educational advisory and concierge – it would help identify interesting jobs, analyse for skills/competencies gaps, recommend the correct courses to take and ultimately propose a timeline with viable courses.[60]

[60]«12 Learning Analytics Software | EdApp Microlearning», 7 mars 2023, https://www.edapp.com/blog/learning-analytics-software/.

3.4.2.6 Combining Learning Analytics with an Observatory Tool

The observatory tool aims to gather information on the Advanced Manufacturing trends and statistics. Such information can be of use for individuals either trying to learn more about Advanced Manufacturing or trying to learn specific data about a certain section within Advanced Manufacturing, to help them decide which vocational path to take, perhaps even whether or not to change their career paths.

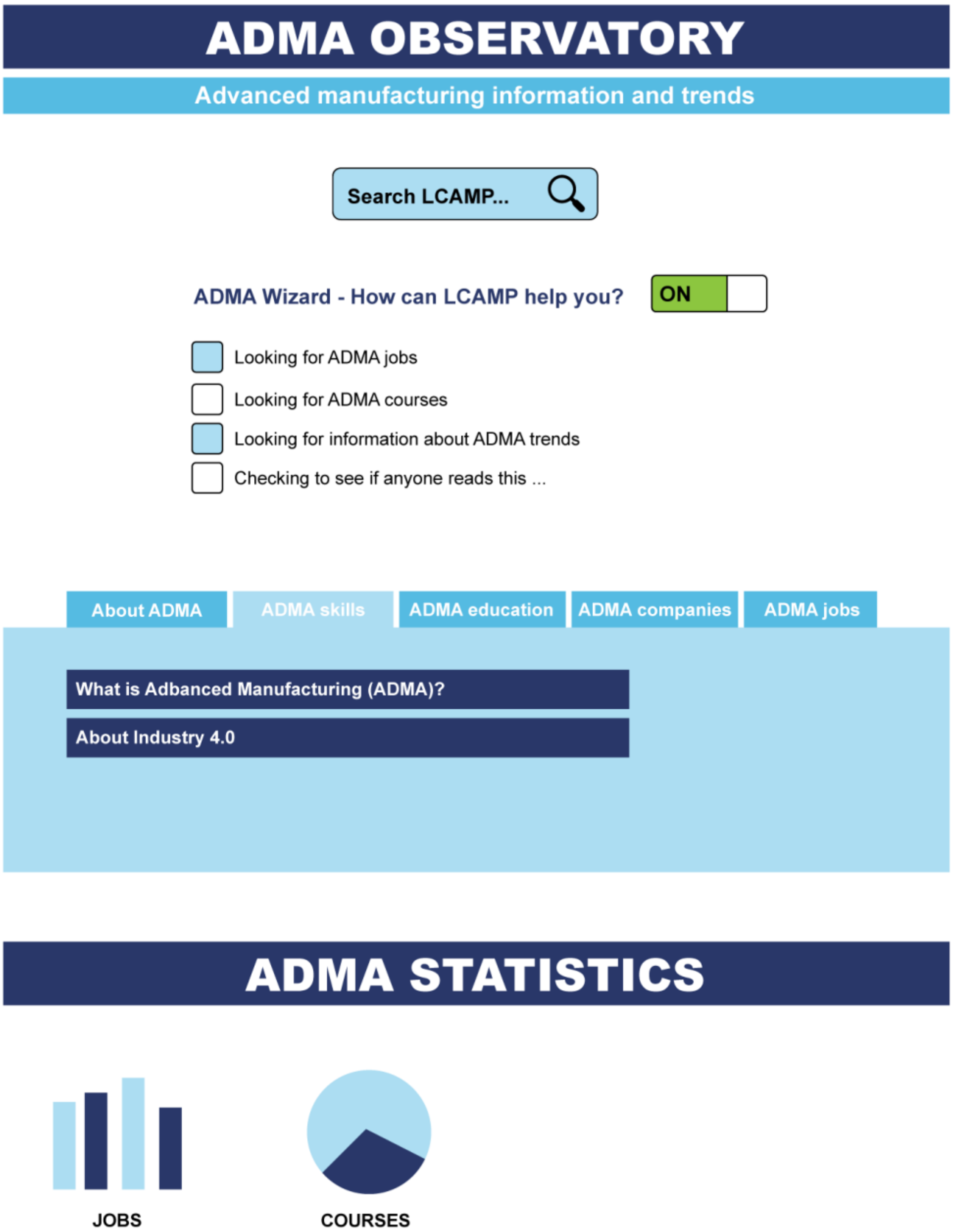

Figure 8: Idea for an Advanced Manufacturing observatory subpage

3.4.3 Objectives / Research Question / Problem Statement

3.4.3.1 Objectives

The ability to develop new skills and competencies is a central concept of lifelong learning. Research to date has largely focused on the processes and support individuals require to engage in upskilling, re-learning or training. However, there has been limited attention examining the types of support that are necessary to assist a learner's transition from “old” workplace contexts to “new”. Professionals often undergo significant restructuring of their knowledge, skills, and identities as they transition between career roles, industries, and sectors. Domains such as learning analytics (LA) have the potential to support learners as they use the analysis of fine-grained data collected from education technologies.

However, in order to support transitions throughout lifelong learning, LA needs fundamentally new analytical and methodological approaches that differ from existing methodologies and tools used in classical education. To enable insights, research needs to capture and explain variability, dynamics, and causal interactions between different levels of individual development, at varying time scales.[61]

3.4.3.2 Research Question

What measures can VETs and SMEs take to implement the benefits of Learning Analytics while avoiding the challenges that come with it?

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[61]Sandra Nunn et al., «Learning Analytics Methods, Benefits, and Challenges in Higher Education: A Systematic Literature Review», *Online Learning* 20, nº 2 (10 janvier 2016), https://doi.org/10.24059/olj.v20i2.790.

3.4.3.3 Problem Statement

Most important aspects of Learning Analytics that are key to helping VETs and universities to meet contemporary demands and future possibilities ARE NOT without their challenges.

- Placing the learning analytics strategy in practice can be a treacherous road.
- Cross-unit collaboration is essential, with continuous feedback from academics.
- Fail fast strategies work only when proper communication strategies are in place.
- Out-of-the-box solutions will most likely not serve the needs of academics and L&T research.
- Data pipelines need to be simplified and allow connectivity with sandboxes.[62]

Challenges of learning analytics: Although there are numerous practical uses and benefits that come along with leveraging learning analytics, it is not without challenges. Below we address some of the main challenges associated with learning analytics and how organisations can overcome them.[63]

Integrating large amounts of data: Learning analytics often involves working with large amounts of data from varying sources. Some of the challenges that come along with working with large amounts of data include safely storing the data and effectively integrating it. These are two logistical challenges that organisations should keep in mind when planning their learning analytics strategy.[64]

Lack of analytical skills: Although technology can collect large amounts of data, it is of little use without the skills required to understand and interpret the data in meaningful ways. Therefore, one challenge of learning analytics is attracting and retaining talent with the analytical skills required to effectively work with learning analytics.[65]

Data security: Since Learning Analytics deals with user data, ensuring data is properly handled and stored can be a challenge. It's crucial that students consent to their data being collected and that the data is anonymised when possible. It's also a good idea to provide employees with training on data protection in order to minimise the risk of data breaches.[66]

[62] Ibid.
[63] Ibid.
[64] Ibid.
[65] Ibid.
[66] Ibid.

3.4.4 Findings

Learning Analytics is a necessary set of tools and methodologies to help the industry catch up with newest technologies by offering faster and more custom learning pathways. However, in order for it to achieve the objectives, it has to be set up correctly in such a way, that it avoids the Negative impacts and maximizes the positive impacts.in such a way, that it avoids the Negative impacts and maximizes the positive impacts.

3.4.4.1 Negative Impacts

1. Increased reliance on technology can lead to decreased face-to-face interactions with colleagues, resulting in a lack of collaboration and cohesiveness.
2. Potential to create an ‘us vs. them’ dynamic in the workplace, wherein ‘data-driven’ employees feel superior to those who lack the skills to work with the technology.
3. Data-driven decisions may lead to a focus on short-term objectives and neglect of long-term goals.
4. Analytics can create false assumptions and cause decision makers to base decisions on incorrect data.
5. Data may be incomplete or outdated; analysis of such data can lead to incorrect conclusions.
6. Data privacy and security is a concern, as companies need to ensure they are collecting and managing data responsibly.
7. Over-reliance on analytics can lead to “analysis paralysis”, where too much time is spent analysing data and not enough time is spent taking action.
8. Data-driven decisions may lead to a lack of creativity and innovation.
9. Analytics can lead to a “one-size-fits-all” approach to learning, which may not be suitable for all employees.
10. Companies may be tempted to make decisions based on data without taking into account the perspectives of employees.[67] [68] [69]

[67] Yi-Shan Tsai et Dragan Gasevic, «Learning analytics in higher education --- challenges and policies: a review of eight learning analytics policies», in *Proceedings of the Seventh International Learning Analytics & Knowledge Conference*, LAK '17 (New York, NY, USA: Association for Computing Machinery, 2017), 233-42, https://doi.org/10.1145/3027385.3027400.

[68] Madeth May, Sébastien Iksal, et Claus A. Usener, «The Side Effect of Learning Analytics: An Empirical Study on e-Learning Technologies and User Privacy», in *Computers Supported Education*, éd. par Gennaro Costagliola et al., Communications in Computer and Information Science (Cham: Springer International Publishing, 2017), 279-95, https://doi.org/10.1007/978-3-319-63184-4_15.

[69] Neil Selwyn, «What's the Problem with Learning Analytics?», *Journal of Learning Analytics* 6, nº 3 (13 décembre 2019): 11-19, https://doi.org/10.18608/jla.2019.63.3.

3.4.4.2 Positive Impacts

1. Learning Analytics can provide meaningful insights into employees' learning patterns and needs, allowing companies to tailor learning experiences to individual employees.
2. Companies can use analytics to identify areas of improvement and develop strategies for addressing them.
3. Analytics can help to identify employees who are struggling with certain skills and allow companies to provide additional support.
4. Analytics can provide a holistic view of the employee experience, allowing companies to track progress and measure employee performance.
5. Companies can use analytics to identify areas where employees have mastered particular skills and adjust training accordingly.
6. Learning Analytics can help to identify employees who have the potential to take on new roles and responsibilities.
7. Companies can use analytics to identify the most effective training methods and use them to improve the overall learning experience.
8. Analytics can provide insights into employees' engagement with learning content, helping companies to develop and adjust courses to ensure they are engaging and effective.
9. Learning Analytics can help to identify potential gaps in an organization's skillset and can be used to develop training programs to address those gaps.
10. Analytics can provide valuable data to help companies assess the effectiveness of their training programs and make necessary adjustments.[70]

[70] «Understanding How Learning Analytics is Driving Positive Strides in Higher Education», s. d., https://www.impactio.com/blog/understanding-how-learning-analytics-is-driving-positive-strides-in-higher-education.

3.4.4.3 Ways to Avoid the Negative Impacts of Learning Analytics

1. Lack of privacy: Companies must ensure that employee data is securely stored and that individuals are aware of how their data is being used. This could be done through periodic privacy notifications, as well as training staff on data protection and privacy best practices.
2. Data manipulation: Companies must ensure that data is not manipulated in any way, and that the analytics are used to support learning goals, not to manipulate outcomes. Companies should also have internal checks and balances in place to monitor the use of data and detect any irregularities.
3. Data overload: Companies must be aware of the potential to overwhelm employees with data and must be proactive in providing contextual guidance and support to help make sense of the data.
4. Stereotyping: Companies must ensure that the data collected is not used to perpetuate stereotypes or target individuals based on their race, gender, or any other distinguishing characteristics.
5. Unfair comparison: Companies must ensure that analytics are not used to make unfair comparisons between individuals, but rather to provide guidance for improving learning outcomes.
6. Overreliance: Companies should be aware of the potential for overreliance on analytics and should not replace traditional learning methods with analytics.
7. Data bias: Companies should be aware of the potential for data bias and should take steps to ensure that data is collected and analysed in an objective and unbiased manner.
8. Lack of trust: Companies should be mindful of the potential for mistrust when using analytics and should ensure that employees are informed of how the data is being used and how their privacy is being respected.
9. Unethical use: Companies should be aware of the potential for unethical use of data and should ensure that all data is used ethically and responsibly.
10. Unsustainable: Companies should be aware of the potential for analytics to become unsustainable and should ensure that analytics are used in a sustainable way that does not overburden employees or the organization.[71]

[71] Oleksandra Poquet et al., «Transitions through Lifelong Learning: Implications for Learning Analytics», *Computers and Education: Artificial Intelligence* 2 (1 janvier 2021): 100039, https://doi.org/10.1016/j.caeai.2021.100039.

3.4.5 Conclusions

Without Learning Analytics, assessing the current knowledge, competence and skill levels, creating custom learning pathways and monitoring and adapting it to the progress of individuals and groups is almost impossible. It proved to be crucial to implement an adequately fast learning curve in response to the coming Advanced Manufacturing challenges, where SMEs need to find new or re-educate existing employees with new skills and competences.

At the very least, both VETs and SMEs should either create Learning Pathways with Learning Analytics or cooperate with companies that can provide those services to them.

The most important measures to be taken in order to ensure success of Learning Analytics is to do the following:

1. Encourage and facilitate face-to-face interactions between colleagues and emphasize collaboration. This can be done using video conferencing, virtual meetings, and other technology-mediated communication methods.
2. Provide training and resources to ensure all employees have the necessary skills to work with technology.
3. Ensure that decisions are based on long-term goals as well as short-term objectives.
4. Analyse data carefully and question any assumptions that may be made.
5. Ensure that data is up-to-date and accurate, and that data privacy and security measures are in place.
6. Ensure that data is used to drive action and not just to analyse.
7. Ensure that creativity and innovation are encouraged and rewarded.
8. Provide training and resources to tailor learning to each employee's individual needs.
9. Ensure that employee perspectives are taken into account when making decisions.
10. Ensure that data-driven employees do not create an 'us vs. them' dynamic and that all employees are treated equally regardless of their software and technology skills.

3.5 INDUSTRY STANDARTS IN DIGITALISATION (GREEN & DIGITAL): METAL FORMING

Title	Description	Geographical scope	Sectorial scope	URL
Cetim	Mechanical expertise centre	French	Multisector	https://www.cetim.fr/

Table 1: Sources Metal forming

3.5.1 Introduction

Metal forming is the fashioning of metal parts through various means. As part of the metalworking sector, it is essential to the manufacturing sector and thus VETs, students, and professionals working in that sector.

Metal forming implies a mechanical deformation through various processes: Compressive forming (rolling, extrusion, forging, etc.), tensile forming (stretching, expanding, recessing), and combined forming (spinning, deep drawing, etc.). Metal forming jobs are one of the oldest that exist, especially in the metal sector.

However, there are few training centres for metal forming and even fewer students.[72] This sector also knows little automatization.

The goal is to understand how advanced manufacturing impacts the metal forming sector and what future trends can be expected in it. What is the state of advanced manufacturing in metal forming? How is advanced manufacturing expected to change the metal forming sector (its equipment, its competencies, its jobs)?

[72] Cécile Maillard, «Face à la pénurie de compétences, les entreprises doivent bousculer leurs méthodes», *L'Usine Nouvelle*, 16 janvier 2023, https://www.usinenouvelle.com/article/face-a-la-penurie-de-competences-les-entreprises-doivent-bousculer-leurs-methodes.N2086576.

3.5.2 Findings

It is difficult to find any article about innovations in metal forming.

Metal forming includes different processes and machines. Today many metal-forming machines are using digital technologies. However, these are not always connected. Connected machines are the major trend that will affect the metal-forming sector for the years to come.

There are many advantages to connected digital machines: it is faster, more precise, and more convenient and it allows better management of the parts, such as detecting flaws, being able to make changes, and being able to easily reuse a part's program on a different machine. This means less material is wasted due to errors or changes.

Electric rollers are a type of connected equipment that can rapidly detect flaws during the manufacturing process. It can also detect them before the process through simulation. Furthermore, the precision of the roller is also helpful to avoid flaws. Finally, as it is electric, it consumes less energy than non-electric rollers. On the European market, the Italian manufacturing Davi Promau sells the CNC iRoll eXtreme for instance.[73]

Other types of connected equipment in metal forming available on the market are press brakes and their wireless foot pedals.[74]

There are two recent techniques in metal forming: Incremental forming and hydroforming.

Incremental forming is a recent technique using CAO consisting of deforming locally a sheet to gradually shape it.[75] This technique, used mostly for small series aims to reduce its cycle times, is to diversify its applications and improve the performance of the final products.[76] The cost of this manufacturing technique can vary greatly depending for instance on the size and complexity of the part. It is however usually much lower than with other techniques. For instance, a car's bonnet was made for 12 000 euros. According to the research centre Ocas, that is 2 to 3 times lower than with traditional methods.[77]

[73]'Dossier de Veille - Nouveautés Pour Les Métiers de La Mise En Forme Des Tôles - Euroblech 2022', Cetim, 22 November 2022, https://www.cetim.fr/mecatheque/Veille-technologique/dossier-de-veille-nouveautes-pour-les-metiers-de-la-mise-en-forme-des-toles-euroblech-2022; *Web-Conférence : Les Dernières Innovations Dans Le Domaine Du Travail Des Métaux En Feuilles*, 2022, https://www.youtube.com/watch?v=dgjdJNgAxV0.

[74]«Dossier de Veille - Nouveautés pour les métiers de la mise en forme des tôles - Euroblech 2022».
Web-conférence.

[75]«Formage incrémental», Cetim, 7 février 2012, https://www.cetim.fr/mecatheque/Veille-technologique/Formage-incremental.

[76]«Note de veille - Le découpage-emboutissage à Esaform 2018», Cetim, 5 octobre 2018, https://www.cetim.fr/mecatheque/Veille-technologique/Note-de-veille-Le-decoupage-emboutissage-a-Esaform-2018.

[77]« e formage incrémental réalise des prototypes en acier», *L'Usine Nouvelle*, 12 octobre 2006, https://www.usinenouvelle.com/article/le-formage-incremental-realise-des-prototypes-en-acier.N53515.

Hydroforming is another technique consisting in deforming thin parts using a fluid under high pressure.[78]

Efforts to set up and adapt training courses must be maintained, but the major challenge is to guarantee trainings and certifications that integrate the evolution of techniques in order to facilitate the adaptation of people.

If processes are now well known and well established, the evolution of the technological means used, and their interweaving require an adaptation of the people in charge of their implementation and of the training made available to them. And finally, as for all technologies related to Industry 4.0, the major challenge is to guarantee training and certifications that integrate the evolution of techniques in order to facilitate the adaptation of people to new techniques and thus help companies to offer the right job to the right person, for the good and interest of all.

3.5.3 Conclusion

1. The development of connected metal forming equipment is the main trend of the sector.
2. The main advantages of connected equipment are to manufacture at a lower cost and to recognize flaws in manufacturing faster.
3. Incremental forming and hydroforming are newer techniques of this sector that are expected to grow.

[78] «Procédés de formage - Synthèse en version française et anglaise», Cetim, 6 septembre 2017, https://www.cetim.fr/mecatheque/Resultats-d-actions-collectives/Procedes-de-formage-Synthese-en-version-francaise-et-anglaise.

3.6 DIGITIZATION OF MANUFACTURING PROCESSES

Adapting to increasingly digital market environments and levering digital technologies to improve operations and drive new customer value are important goals for nearly all contemporary businesses. This is the reason why companies are beginning to make the necessary changes to adapt their organisation to a digital environment. Organisations are beginning to progress digitally, and are more likely to experiment and iterate. Their abilities to do so are key for companies to respond to digital disruption.

Established companies must figure out how to experiment more to compete in the future, as well as keep attracting the best talent to fill jobs that rely on digitization.

3.6.1 Introduction

The Digital Transformation, initiated through the fourth industrial revolution, continues to be unstoppable in the machine tool sector and is allowing new intelligence to be incorporated into machines and generating new digital business models based on digital services that are in turn, generating new value propositions, innovative income generation models and new configurations of the digital value network. The efforts made by Basque companies and institutions to adopt the fourth industrial revolution have made it possible to position machine tools from the Basque country as state of the art, strengthening their position in the market, and growing their business and employment figures in recent years. It is a reality that digitization is increasingly present in our companies. That is why to face the advances that are being presented, we must equip students with the knowledge of these technologies.

Data science is a well-developed discipline. Even though it has gained great prominence in recent years, it is a concept coined in the 60s of the previous century. Since the birth of the 4.0 paradigm, many companies have conducted initiatives to collect data in their workshops and plants, analyse the data using advanced techniques, and use it for decision-making or to generate new or better ways of working.

However, both experts and large consultancies agree that horizontal integration in the value chain is a pending issue in the industry. The Industry 4.0 platform itself, a forerunner of the industry 4.0 concept, includes in one of its latest publications on Asset Administration Shell, from October 2020, the importance of exchanging information between partners in 4.0 value chains. It has even held monographic Webinars addressing how added value can be generated through collaboration between companies on topics such as Condition Monitoring of machines and components.

3.6.2 Technology Trends

3.6.2.1 Sensoring of Manufacturing Processes

A global deployment of 5G technology, in which data can be transmitted anywhere in the world without latency, eliminates the need for distributed edge computing, enabling lower costs for data storage and management on servers in the cloud. However, such a global deployment may take many years and a gradual 5G network deployment scenario must involve Edge Computing modules that use 5G technology locally on a machine or in a factory, and the design of these modules needs to be done in such a way that the transition to global 5G is gradual and non-traumatic. Therefore, there is a challenge to integrate new 5G sensors into Edge Computing modules, support the highest bandwidth or number of locally connected devices and ease the transition to a future global 5G network.

Assuming a higher number of connections as a higher bandwidth in an edge computing module could be realised with more powerful and expensive hardware, but a more economical solution is the inclusion of intelligence in the edge computing module so that the configuration of the bandwidths of each signal and the storage capacity is adaptively set by an artificial intelligence module. The challenge in this area will be to adapt the telecommunication network to the characteristics of the processes being controlled or monitored.

In the following, the most representative state-of-the-art advanced solutions for machine condition monitoring in the manufacturing machine sector are presented by international reference manufacturers:

Makino's Health Maximizer™ (MHmax™)[79] is a solution for predictive and proactive monitoring of machine health, using integrated sensors and software monitoring to help predict failures before they occur. The system includes the monitoring of four critical subsystems of the machine: the spindle is monitored through vibrations recorded by an integrated high frequency accelerometer; in the cooling system all lines are monitored; the hydraulic circuit is analysed for pressure and temperature; finally, for the tool change system, the actual physical position of the spindle is monitored and compared with the theoretical one. The system generates warnings and alarms in case of health incidents of the monitored components.

The development of MHmax™ is based on data recorded during fifteen years of customer support in different production scenarios, from which the main causes and alarm symptoms of unplanned machine stoppages were identified.

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[79] *Predictive and Proactive Machine Health Technology - MHmax*, 2019, https://www.youtube.com/watch?v=VSkTMQw_Ubg.

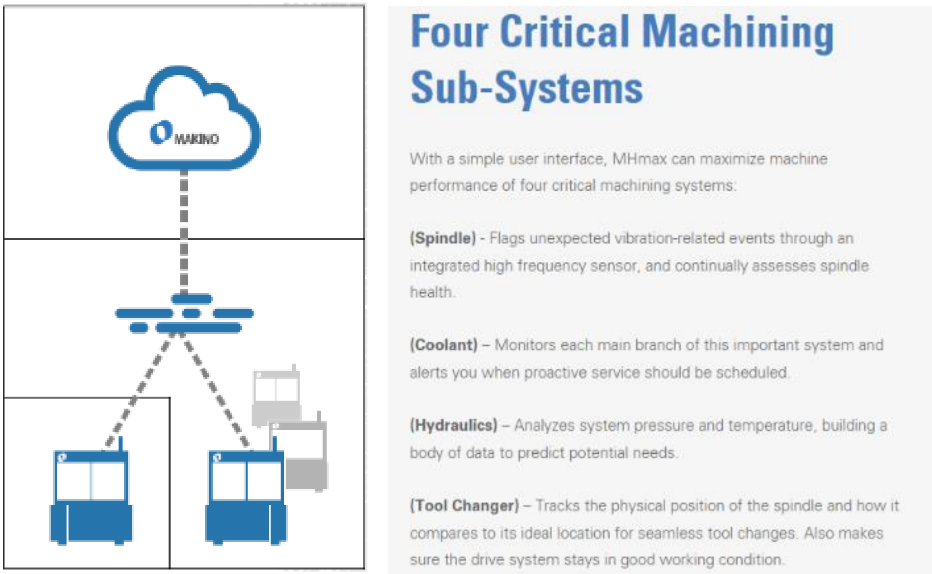

Figure 9: Health Maximizer™ (MHmax™) of Makino[80]

Makino offers three levels of machine connectivity for the MHmax: With no external connection, the information provided by the system remains in the machine control; With plant-level connectivity, allowing access to system information from any connected machine with permissions; With connection to the external cloud and the ability to transmit information to Makino's technical team who provide technical support and help in deciding proactive actions.

Okuma presents a solution integrated into the machine control for artificial intelligence diagnosis of the condition of the main spindle and linear axes[81]. It provides self-diagnosis of the bearing health status of these components through AI analysis of vibration recorded in specific motion cycles. The condition of the components is displayed on the machine control using traffic light colour coding, and the degree of normality is also provided as a numerical value.

[80] *Predictive and Proactive Machine Health Technology - MHmax.*

[81] «The Next-Generation Intelligent CNC OSP Suite [OSP-P300A] | Technology & Solutions Okuma Smart Factory», OKUMA CORPORATION, s. d., https://www.okuma.co.jp/english/smart-factory/osp-suite/index.html.

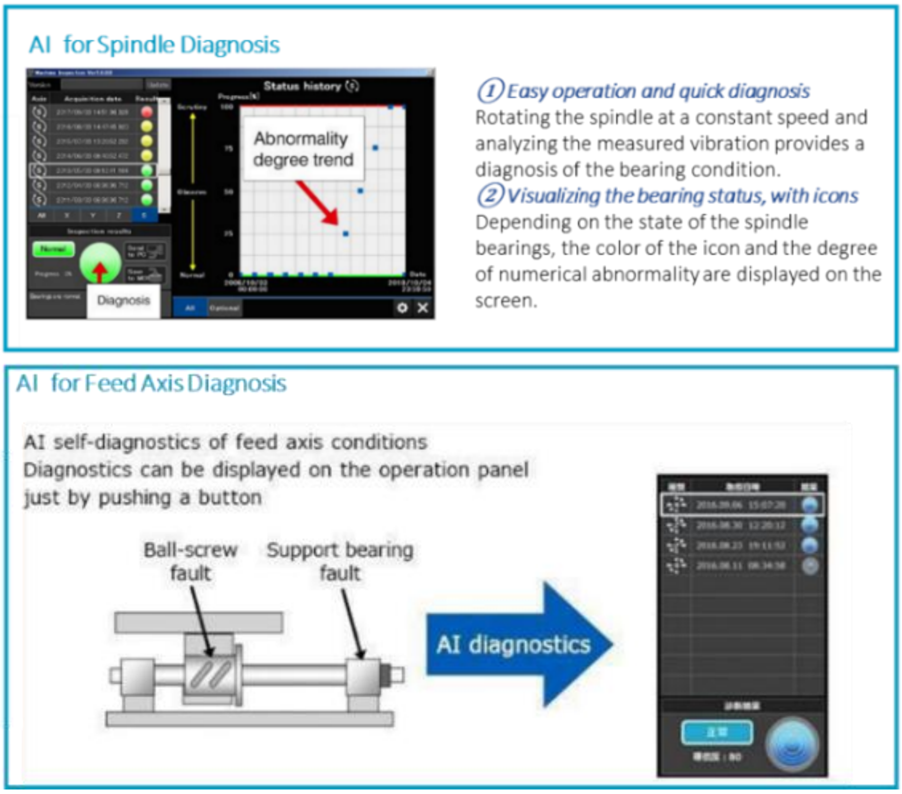

Figure 10: Diagnosis of the electro spindle and linear axes through Okuma´s AI[82]

Regarding the condition of machine geometric accuracy, Okuma has developed the Thermo-Friendly Concept[83], a control solution powered by temperature sensors distributed in the machine, to compensate for oscillations caused by temperature and achieve high dimensional stability in long-term continuous machine use. In addition to achieving high accuracy, the system saves time and costs, as machine warm-up and manual adjustment of thermal conditions are eliminated.

[82]«The Next-Generation Intelligent CNC OSP Suite [OSP-P300A] | Technology & Solutions Okuma Smart Factory».

[83]*Okuma's Intelligent Technology - Thermo-Friendly Concept*, 2015, https://www.youtube.com/watch?v=3er2OHlq9Bc.

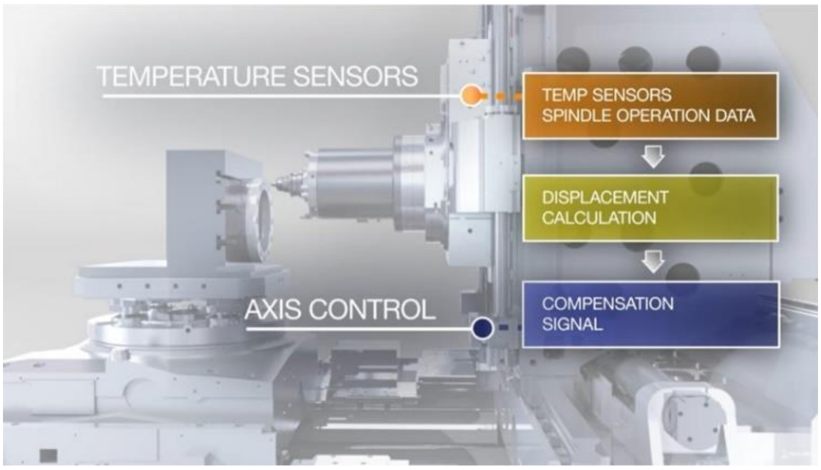

Figure 11: Thermo-Friendly Concept of Okuma[84]

In the same field of precision machine condition, Okuma's 5-Axis Auto Tuning function[85] is a solution to compensate for geometrical errors that occur during the manufacture and assembly of machines and during the life of the machine due to wear and ageing. The application detects the actual machine geometry through a touch probe and established measurement procedure, and compensates for errors through a calibration function, improving the dimensional quality of machined parts.

Figure 12: 5-Axis Auto Tuning of Okuma[86]

Mazak has developed the Spindle Analytics application[87], which analyses the status of the electro spindle by monitoring its temperature, vibrations and displacements, to prevent problems and reduce production stoppages. In addition, Mazak offers its customers the service of remotely monitoring the performance of the machine, to alert the customer of possible problems and provide technical assistance.

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[84] *Okuma's Intelligent Technology - Thermo-Friendly Concept*.

[85] *Okuma's Intelligent Technology - 5-Axis Auto Tuning System*, 2015, https://www.youtube.com/watch?v=CcGqxaFnI5M.

[86] *Okuma's Intelligent Technology - 5-Axis Auto Tuning System*.

[87] «Artificial Intelligence Makes Spindle Health Monitoring a Reality», 2019, https://www.mazakusa.com/news-events/blog/artificial-intelligence-makes-spindle-health-monitoring-a-reality/.

Figure 13: Spindle Analytics of Mazak [88]

The Condition Analyzer function of DMG MORI[89] [90] monitors the condition of certain machine components by analysing the data recorded by sensors. The results are provided both on the machine control as well as on PC, tablet, or smartphone devices. The aim is to reduce unexpected machine downtime through preventive maintenance. In addition, it allows the quality of the manufactured parts to be improved thanks to the possibility of optimising processes based on the information recorded by the sensors.

The components included in the supervision are: The electro spindle, of which the unbalance, the condition of the bearings and the vibration level are monitored through an integrated accelerometer, the thermal expansion which is automatically detected and compensated, the clamping force of the tool with predefined measurement cycles and an external sensor type power check and the lubrication through automatic lubrication cycles; the cooling system to ensure that the flow rate is adequate for proper cooling; the pneumatic system to detect possible leaks.

[88]«Artificial Intelligence Makes Spindle Health Monitoring a Reality».

[89]«Monitoring», s. d., https://es.dmgmori.cm/productos/digitization/integrated-digitization/monitoring.

[90]«DMG MORI France - Machines-outils CNC pour toutes les applications de l'enlèvement de matière», 2023, https://fr.dmgmori.com/.

Figure 14. Condition Analyzer of DMG MORI[91] [92]

DMG MORI introduces the concept of the geometric fingerprint, or characteristic fingerprint of the machine's geometric accuracy condition. Its Volumetric Calibration System (VCS) application[93] is a solution for automated periodic checking of the machine's volumetric positioning accuracy, with the implementation of a contact inspection probe and a set measurement cycle that runs through the entire working volume. In addition to determining accuracy, the VCS solution allows for compensation of position and angle errors through machine control.

[91]«Monitoring».

[92]«DMG MORI France - Machines-outils CNC pour toutes les applications de l’enlèvement de matière».

[93]Ibid

Figure 15: Volumetric Calibration System (VCS) of DMG MORI[94]

DMG MORI also offers its customers a remote technical assistance service, NETservice[95], which includes a 5G WIFI camera to transmit images of the machine in streaming, with the high-resolution rate, flexible connectivity, speed and security offered by 5G technology.

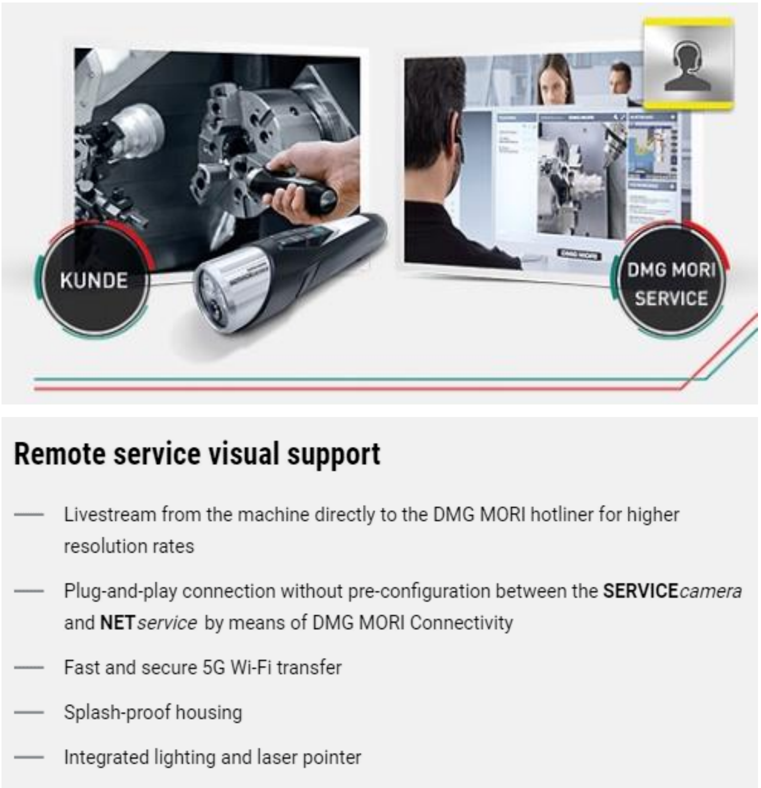

Figure 16: NETservice of DMG MORI[96]

[94]«DMG MORI France - Machines-outils CNC pour toutes les applications de l'enlèvement de matière».

[95]«Service», s. d., https://es.dmgmori.com/productos/digitization/integrated-digitization/service.

[96]«Service».

Hermle's Wear Diagnosis System[97] includes the analysis of the feed behaviour and frequency spectrum of linear and rotary axes, the evaluation of relevant data from sensors integrated in the machine, the calculation of the vibrations of the electro spindle, the monitoring of the machine's accuracy and the monitoring of the temperatures of the drive motors. Associated with this machine condition monitoring system, Hermle offers its customers the service of analysis and diagnosis of all these data by a qualified technician.

Siemens' approach to machine condition monitoring, Analyze MyMachine/Condition[98], combines high-frequency computing at the edge with long-term trajectory monitoring in the cloud. Its solution establishes a series of dedicated tests for the acquisition of certain control parameters under controlled machine condition conditions, parameters that are indicative of the machine health status. Among others, it includes obtaining the squareness error, friction or backlash of the machine axes. The analysis of the data consists of comparing the current values with those recorded at the time of installation of the machine, with the machine in perfect condition. The initial values form the so-called fingerprint of the machine and represent the normal reference values.

The purpose of this functionality is to perform a periodic diagnosis of the machine's condition to establish corrective actions. It enables early detection of problems and increases machine availability and opens up the possibility of new remote diagnostic services from the machine manufacturer to the customer.

In the scientific literature there are numerous research references on the condition of machine components, those related to rotating components being especially notable, such as ball screws or bearings, in which solutions for predictive maintenance of components based on the monitoring of machine control signals and integrated sensors, mostly accelerometers, are analysed[99] [100].

However, there are fewer bibliographical references related to the condition of the machine as a whole, since this is a more recent field of research:

The research work described in[101] proposes predictive machine maintenance based on Manufacturing Error Based Maintenance (MEBM), specifically by monitoring the machining

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[97]KMS GmbH & Co KG http://www.kms-wirkt.de, « Maschinenfabrik Berthold Hermle AG - Módulos digitales », Text, Maschinenfabrik Berthold Hermle AG (Maschinenfabrik Berthold Hermle AG, 23 mai 2023), https://www.hermle.de/es/centros_de_mecanizado/m%C3%B3dulos_digitales.

[98]«Siemens Machine Tool Days 2020 | Press | Company | Siemens», 2020, https://press.siemens.com/global/en/event/siemens-machine-tool-days-2020.

[99]Li Zhang et al., «A Deep Learning-Based Recognition Method for Degradation Monitoring of Ball Screw with Multi-Sensor Data Fusion», *Microelectronics Reliability* 75 (1 août 2017): 215-22, https://doi.org/10.1016/j.microrel.2017.03.038.

[100]María Navarro Carmona, «Diagnóstico de fallos en rodamientos», 2016, https://ingemecanica.com/tutorialsemanal/objetos/tutorial215.pdf.

[101]Shengyu Shi et al., «Manufacturing-error-based maintenance for high-precision machine tools | SpringerLink», 2017, https://link.springer.com/article/10.1007/s00170-017-1070-y.

backlash through machine control parameters. Also, a methodology for automated machine condition monitoring based on internal machine control parameters, without the need for external sensors, is described in[102]. It is based on periodic comparison of machine axis parameters with reference values. The research work described in [103] proposes the development of a predictive maintenance system for a milling machine based on web-services, with data acquisition from the CNC-PLC of the machine and statistical analysis of the variables. It introduces the concept of the no-load check cycle. Two research works[104] [105] propose the analysis of the health of the machine's spindle and linear axes through the analysis of electrical signals. They propose the use of an eMaintenance web platform to benefit from the exploitation of information from many machines. It introduces the concept of machine fingerprinting during the execution of a check cycle. The research work described in Industrial Applications of Machine Learning[106] discusses the industrial applications of Machine Learning and presents a use case on the predictive maintenance of a machine head, based on its fingerprint. The publication by Galar and Kumar (2017)[107] presents eMaintenance as a potential service of machine data access, explains how to use sensor-based tools and control data to increase the efficiency of diagnosis, prognosis and decision making in maintenance, and describes methods to solve the challenges of massive data recording and processing.

In the field of EDM and additive manufacturing, machine condition has not been as high a priority as process control, because machines suffer less than with start-up processes. However, a recent work[108] stands out in which the condition of some of the consumables of a wire EDM machine (filters, resins, contacts) is monitored by adapting new sensors to predict their useful life.

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[102] A. Verl et al., «Sensorless Automated Condition Monitoring for the Control of the Predictive Maintenance of Machine Tools», *CIRP Annals* 58, nº 1 (2009): 375-78, https://doi.org/10.1016/j.cirp.2009.03.039.

[103] Luca Fumagalli et Marco Macchi, Integrating Maintenance within the Production Process through a Flexible E-Maintenance Platform», *IFAC-PapersOnLine*, 15th IFAC Symposium onInformation Control Problems inManufacturing, 48, nº 3 (1 janvier 2015): 1457-62, https://doi.org/10.1016/j.ifacol.2015.06.292.

[104] Susana Ferreiro et al., «Industry 4.0: Predictive Intelligent Maintenance for Production Equipment», 2016, https://www.researchgate.net/publication/317066007_Industry_40_Predictive_Intelligent_Maintenance_for_Production_Equipment.

[105] Augustin Prado et al., «Health and Performances Machine Tool Monitoring Architecture» (International Workshop and Congress on eMaintenance : 17/06/2014 - 18/06/2014, Luleå tekniska universitet, 2014), 139-44, https://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-40402.

[106] Pedro Larranaga et al., *Industrial Applications of Machine Learning*, 2018, https://doi.org/10.1201/9781351128384.

[107] Diego Galar & Uday Kumar, *eMaintenance: Essential Electronic Tools for Efficiency*, 1st éd. (USA: Academic Press, Inc., 2017), https://dl.acm.org/doi/book/10.5555/3161422.

[108] G. Wälder et al., «Smart Wire EDM Machine», *Procedia CIRP*, 19th CIRP Conference on Electro Physical and Chemical Machining, 23-27 April 2017, Bilbao, Spain, 68 (1 janvier 2018): 109-14, https://doi.org/10.1016/j.procir.2017.12.032.

3.6.2.2 Data Collection, Analysis of Data

Over the last 5 years and in the context of Industry 4.0, almost all manufacturing companies have, to a greater or lesser extent, undertaken actions aimed at integrating functionalities based on digital technologies. Today, there are many solutions available on the market for the acquisition and recording of machine data on which to build new services and new functionalities. Both machine manufacturers and component manufacturers have incorporated sensors into their products to increase the nature and type of data from machines and the processes they run and have developed and incorporated functionalities based on this data.

The application of AI techniques in manufacturing has made it possible to formalise complex multivariate knowledge of machine and process conditions. These tools enhance the work of the operator, which also increases his value as a technician.

Continuous learning based on the experiences of machine use is a reality that is applied to strategies for continuous process improvement.

The worker is provided with many more tools for assistance, diagnosis, and optimisation, and can focus his efforts on increasing the value of the component and freeing himself from tasks that may not have a direct impact on production. It is also a fact that the incorporation of new technicians can be accelerated in a more efficient way. In short, more reliability, workers who see their jobs valued, increased overall machine safety and an impact on overall well-being.

The massive generation of data through the IIoT and is giving Artificial Intelligence (AI) a huge boost in the industrial sector. Artificial Intelligence currently offers tremendous potential for industry, making production more efficient, more flexible and, above all, more reliable.

An important lever in favour of AI deployment in industry has been the advent of high computing power as an asset available to all. This capability makes it possible to disentangle knowledge from massive ingestions of sensor data and new sources of unstructured data (images, text, video, etc.). All these new functionalities are a perfect fit in a sector with such varied needs as advanced manufacturing.

As stated in the European Communication Artificial Intelligence for Europe, Artificial Intelligence refers to systems that display intelligent behaviour by analysing their environment and take actions with some degree of autonomy to achieve specific objectives. AI does not refer to a single technology, but refers to a set of different approaches, methods and technologies that demonstrate behaviour in different contexts. AI-based systems can be solely software-based, acting in the virtual world, or embedded in hardware devices. Machine Learning can be considered as a branch of AI and is defined as "the set of methods that can automatically detect patterns in a data set and use them to predict future data, or to make other types of decisions in uncertain environments". In turn, Deep Learning is a branch of Machine Learning that, defined in its most basic aspect, can be explained as a probability system that allows computational models that are composed of multiple layers of processing to learn about data with multiple levels of abstraction.

Currently, there are multiple machine learning techniques in the advanced manufacturing environment, depending on the type of information (structured or unstructured information) and the learning paradigm used. The choice of the technique to be applied depends, among others, on the objective of the model to be built, as well as on the type of information available. Furthermore, it seems that the solution is probably not the use of a single technique for each of the problems, but rather combinations of several techniques. For intelligent environments, this has been the approach that has been adopted.

One of the main advantages of AI is optimisation based on prescriptive analysis based on decision models. The use of machine learning for autonomous machine decision-making is one of the main goals of AI today. To date, developments have mainly focused on descriptive analytics and predictive maintenance tasks. Several of the techniques used in industry in this field are outlined below:

- **Fuzzy logic:** for symbolic knowledge management and process diagnosis; this is a reasoning system based on logical expressions describing the membership of fuzzy or fuzzy sets. The diagnosis of the system is based on fuzzy rules and the detection of events of interest from fuzzy rules and fuzzy sets, defined from the available data. Its main utility is to manage easily interpretable symbolic knowledge, very close to natural language. It is compatible with automatic rule generation systems and can be useful for detecting faults or symptoms of future faults (corrective and predictive maintenance). This method allows predictive maintenance to be carried out if the input data used refers to the state of health of the system. Regarding its application in data diagnosis and prognosis, this article[109] presents a diagnostic method based on fuzzy logic applied to the manufacturing sector. They show better results in noisy data than standard models. In the work carried out by Rocha et al, 2020[110], diagnosis and fault detection is performed with the aim of reducing the number of false positives generated in an engine.

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[109]Tung-Hsu (Tony) Hou et Chun-Chi Huang, «Application of Fuzzy Logic and Variable Precision Rough Set Approach in a Remote Monitoring Manufacturing Process for Diagnosis Rule Induction», *Journal of Intelligent Manufacturing* 15, nº 3 (1 juin 2004): 395-408, https://doi.org/10.1023/B:JIMS.0000026576.00445.d8.

[110]Erick Rocha et al., «A fuzzy type-2 fault detection methodology to minimize false alarm rate in induction motor monitoring applications», *Applied Soft Computing*, 1 mai 2020, 106373, https://doi.org/10.1016/j.asoc.2020.106373.

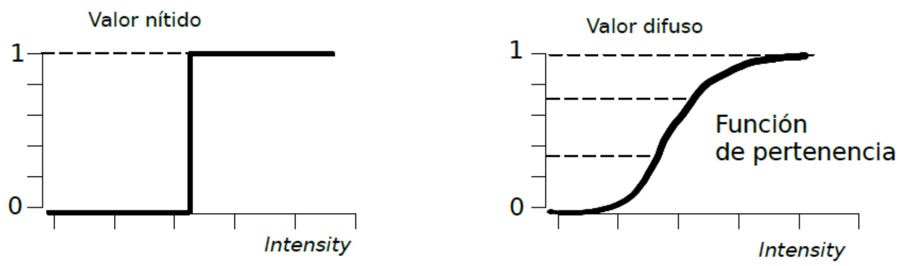

Figure 17: Classic Logic vs Fuzzy Logic[111]

- **Artificial neural networks:** for the characterisation of non-linear behaviour in industrial processes; these models are non-linear multivariate mathematical models that use iterative procedures with the aim of minimising a certain error function and thus classifying the observations. Their main disadvantage is their "black box" nature, i.e., the difficulty in interpreting the results and the limitation in incorporating the physical sense of the element or process. This technique has been used many times for fault classification and diagnosis. For example, some research[112] uses neural networks for fault detection in industrial rotating equipment. Others[113] present a new methodology based on neural networks for failure mode detection applied to rotating machinery. In unbalanced data, the methodology presented shows substantial improvements over traditional techniques applied in this field. Zhou et al., 2020[114], present a robust convolutional neural network capable of performing real-time diagnosis for gas turbines. And Chen at al., 2020[115] have diagnosed bearing failures using convolutional neural networks.

[111]Azzam Sleit, Maha Saadeh, et Wesam Almobaideen, «A Two-Phase Fuzzy System for Edge Detection», 2016, https://www.researchgate.net/publication/311068958_A_Two-Phase_Fuzzy_System_for_Edge_Detection.

[112]Xianzhen Xu et al., «Application of neural network algorithm in fault diagnosis of mechanical intelligence», *Mechanical Systems and Signal Processing* 141 (1 juillet 2020): 106625, https://doi.org/10.1016/j.ymssp.2020.106625.

[113]Quan Zhou et al., «A Novel Method Based on Nonlinear Auto-Regression Neural Network and Convolutional Neural Network for Imbalanced Fault Diagnosis of Rotating Machinery», *Measurement* 161 (1 septembre 2020): 107880, https://doi.org/10.1016/j.measurement.2020.107880.

[114]Dengji Zhou et al., «Fault Diagnosis of Gas Turbine Based on Partly Interpretable Convolutional Neural Networks», *Energy* 200 (1 juin 2020): 117467, https://doi.org/10.1016/j.energy.2020.117467.

[115]Zhuyun Chen et al., «A Deep Learning Method for Bearing Fault Diagnosis Based on Cyclic Spectral Coherence and Convolutional Neural Networks», *Mechanical Systems and Signal Processing* 140 (1 juin 2020): 106683, https://doi.org/10.1016/j.ymssp.2020.106683.

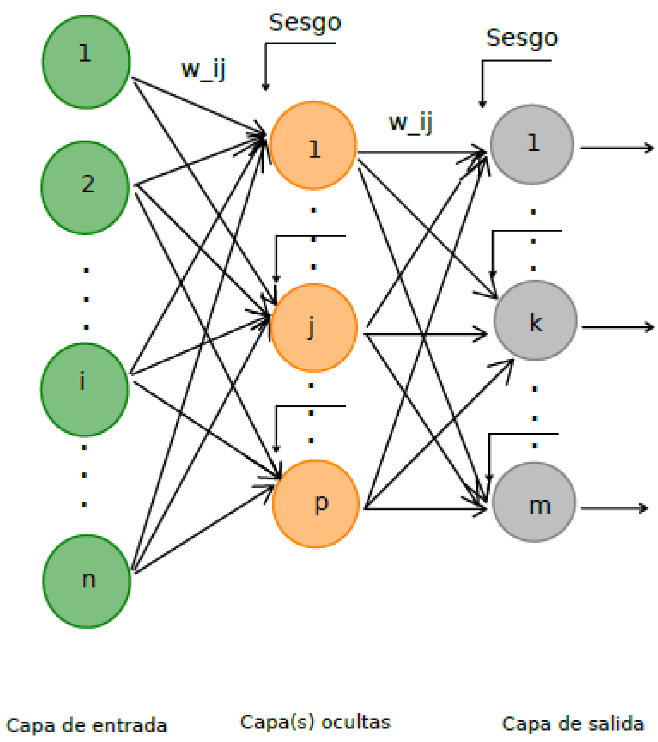

Figure 18: Structure of neural network[116]

- **Support vector machine or SVM:** these are classification models that try to solve the difficulties that complex data samples can pose, where relationships need not be linear. In other words, the aim is to classify observations into various groups or classes, but these are not separable via a hyperplane in the dimensional space defined by the data. The goal is to find the hyperplane that separates the classes and that is most distant from the observations of the classes simultaneously. SVMs have been widely used in the field of failure mode classification. This study[117] presents a comparison of several techniques for failure diagnosis in a centrifugal pump including the SVM model. The results show a higher capability of SVM using a smaller number of features. Another work[118] proposes a new methodology based on SVM for the detection and identification of multiple bearing failure modes. The results obtain high accuracy for different operating conditions.

[116] Amin Hedayati, Moein Hedayati, et Morteza Esfandyari, «Stock Market Index Prediction Using Artificial Neural Network», SSRN Scholarly Paper (Rochester, NY, 17 juillet 2017), https://papers.ssrn.com/abstract=3004032.

[117] Maamar Ali Saud ALTobi et al., «Fault Diagnosis of a Centrifugal Pump Using MLP-GABP and SVM with CWT», *Engineering Science and Technology, an International Journal* 22, nº 3 (1 juin 2019): 854-61, https://doi.org/10.1016/j.jestch.2019.01.005.

[118] Xiaoan Yan et Minping Jia, «A Novel Optimized SVM Classification Algorithm with Multi-Domain Feature and Its Application to Fault Diagnosis of Rolling Bearing», *Neurocomputing* 313 (3 novembre 2018): 47-64, https://doi.org/10.1016/j.neucom.2018.05.002.

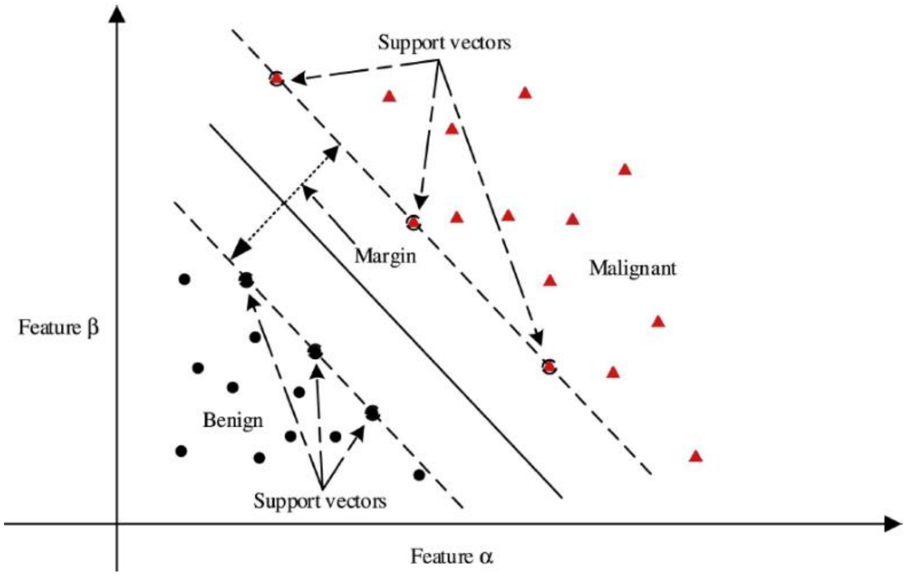

Figure 19: Illustrative image of the operation of SVM for linear cases[119]

- **Clustering techniques:** these clustering techniques are unsupervised techniques that group data according to their similarity. In the field of diagnosis, clustering techniques make it possible to detect the state of health of a system at a given moment based on a history of data that has been previously trained. The classification of a piece of data is established by its belonging to a specific grouping. These techniques are frequently used today in the field of maintenance, especially for the diagnostic part. This study[120] presents a fault diagnosis for real data associated with rotating machinery. The results obtained are really good in the exploration of these faults for unsupervised data. This work[121] performs an approach for on-line fault diagnosis based on clustering and fuzzy logic techniques. This approach incorporates a machine learning mechanism that allows excellent results to be obtained.

[119]Haifeng Wang et al., «A Support Vector Machine-Based Ensemble Algorithm for Breast Cancer Diagnosis», *European Journal of Operational Research* 267, nº 2 (1 juin 2018): 687-99, https://doi.org/10.1016/j.ejor.2017.12.001.

[120]Xiang Li, Xu Li, et Hui Ma, «Deep Representation Clustering-Based Fault Diagnosis Method with Unsupervised Data Applied to Rotating Machinery», *Mechanical Systems and Signal Processing* 143 (1 septembre 2020): 106825, https://doi.org/10.1016/j.ymssp.2020.106825.

[121]Adrián Rodríguez-Ramos, Antônio José da Silva Neto, et Orestes Llanes-Santiago, «An Approach to Fault Diagnosis with Online Detection of Novel Faults Using Fuzzy Clustering Tools», *Expert Systems with Applications* 113 (15 décembre 2018): 200-212, https://doi.org/10.1016/j.eswa.2018.06.055.

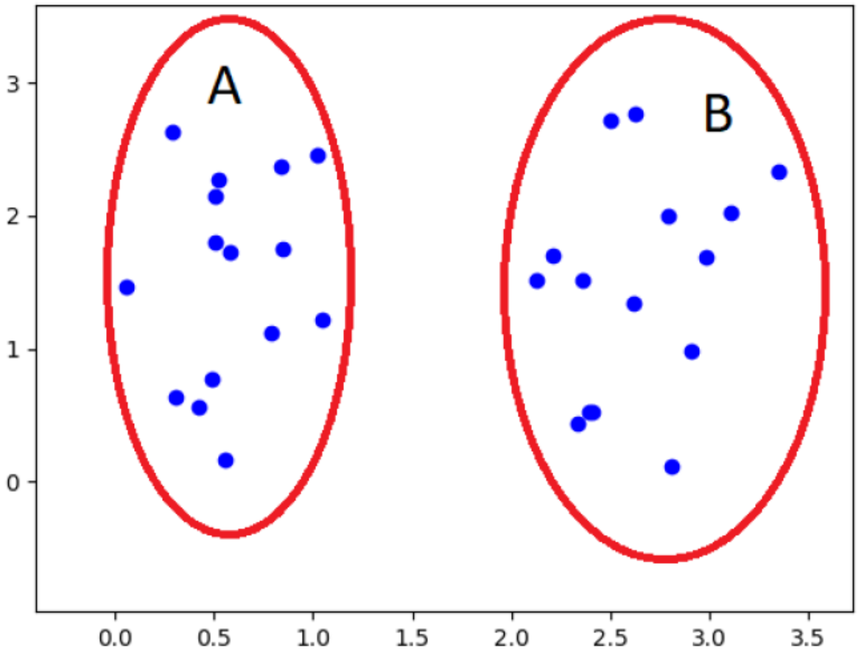

Figure 20: Clustering of 2 Dimensional signals[122]

- **Hidden Markov model (HMM):** is a concept developed within the theory of probability and statistics that establishes a strong dependence between an event and a previous state. This type of technique is used for irreversible repetitive systems of long duration, where the evolution in the states of the chain allows establishing a distance to the event under study. This work[123] performs bearing fault detection and demonstrates its superiority over conventional methods. This work[124] also generates a fault detection model applying Markov models based on the data acquired from the fluids of the machinery associated with the process.
- **ARIMA:** these are statistical models that use variations and regressions of data to detect patterns and predict future values over time. It is a dynamic time series model, i.e., future estimates are explained by previously collected data. For prognostics, it allows the prediction of future values based on the latest available data in an adaptive way, which provides an immense potential in those systems with a small margin of error such as the prediction of tool wear in fast mechanical processes. This technique

[122]Amit Saxena et al., «A Review of Clustering Techniques and Developments», *Neurocomputing* 267 (6 décembre 2017): 664-81, https://doi.org/10.1016/j.neucom.2017.06.053.

[123]Zefang Li et al., «Data-Driven Bearing Fault Identification Using Improved Hidden Markov Model and Self-Organizing Map», *Computers & Industrial Engineering* 116 (1 février 2018): 37-46, https://doi.org/10.1016/j.cie.2017.12.002.

[124]Pasquale Arpaia et al., «Fault Detection on Fluid Machinery using Hidden Markov Models», *Measurement* 151 (1 octobre 2019): 107126, https://doi.org/10.1016/j.measurement.2019.107126.

has become important in time series prediction. This work[125] shows the estimation of remaining tool life for the turning of a part in the automotive sector.

- **Gaussian regressive processes (GPR):** is a collection of random variables that satisfy that any physical subset of the collection has a Gaussian distribution. It can be likened to an infinite-dimensional multivariate Gaussian distribution. Within this distribution, prior knowledge about the function space can be incorporated through the selection of the mean and covariance functions. This study[126] generates a surface roughness prediction model for compacted graphite cast iron using GPR. The results show that the shear rate significantly affects the surface roughness. This study[127] presents an application of the GPR method for the prediction of the RUL (remaining useful life) of low-speed bearings based on acoustic emission signals. The results show very low errors in low-speed bearings.
- **Survival methods:** these techniques are part of studies in which the objective is to study the times until an event of interest occurs. Once this event is fixed, the time until the event occurs is observed, which in maintenance is known as time to failure (TTF), and the study focuses on modelling this time. This type of analysis aims at modelling the survival function and the risk function of the event. This study[128] presents a predictive maintenance model using the Cox model. The data used has been real data in which the proposed method has improved the existing one. This study[129] applies the survival model for the estimation of the RUL in a turning system.
- **Decision trees and extensions:** for the inference of diagnostic rules and detection of malfunctioning symptoms in industrial assets; this method consists of using efficient and easily interpretable classification and regression algorithms that divide the problem search space into tree models. It is a classifier whose interpretability is reduced in tree rules and has high computational efficiency. This method allows mixing continuous and

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[125]Alberto Jimenez-Cortadi et al., «Predictive Maintenance on the Machining Process and Machine Tool», *Applied Sciences* 10, nº 1 (janvier 2020): 224, https://doi.org/10.3390/app10010224.

[126]Juan Lu et al., «Effect of Machining Parameters on Surface Roughness for Compacted Graphite Cast Iron by Analyzing Covariance Function of Gaussian Process Regression», *Measurement* 157 (1 juin 2020): 107578, https://doi.org/10.1016/j.measurement.2020.107578.

[127]S. A. Aye et P. S. Heyns, «An Integrated Gaussian Process Regression for Prediction of Remaining Useful Life of Slow Speed Bearings Based on Acoustic Emission», *Mechanical Systems and Signal Processing* 84 (1 février 2017): 485-98, https://doi.org/10.1016/j.ymssp.2016.07.039.

[128]Chong Chen et al., «Predictive Maintenance Using Cox Proportional Hazard Deep Learning», *Advanced Engineering Informatics* 44 (1 avril 2020): 101054, https://doi.org/10.1016/j.aei.2020.101054.

[129]Lucas Equeter et al., *Estimate of Cutting Tool Lifetime through Cox Proportional Hazards Model*, 2016, https://doi.org/10.13140/RG.2.2.15305.13927.

categorical data, and there are multiple extensions with state-of-the-art performance such as Random Forest, AdaBoost, etc.

- **Novelty detection:** this type of Machine Learning algorithms from the world of robotics have become widespread in industrial realities where training with anomalous cases is not an option. This type of algorithm is an evolution of anomaly detection with the difference of being able to label these anomalies as they happen, to learn as they go along. Novelty Detection has been largely driven by applications in nuclear energy and aerospace technologies. In addition, such algorithms can learn from data streams, so that they can process them as they arrive, in some cases, and depending on the underlying algorithm, they can work in real time. Another fundamental characteristic is its capacity to detect and measure the degradation of the system being measured, which is very interesting for different types of industrial applications where the remaining useful life of the different components is to be measured.

Regarding process optimisation algorithms, genetic algorithms, inspired by the theory of evolution, make it possible to find optimal solutions to a problem. These algorithms try to optimise an objective function by recombining and mutating the existing population of solutions. The use of evolutionary methods in optimisation problems has introduced important improvements with respect to traditional methods in various domains and applications: mathematics, industry, applied engineering, etc. It allows ad-hoc solutions to be defined, establishing complex relationships between variables, constraints, and objectives[130].

Industrially, Artificial Intelligence appears especially in Asian manufacturers. The Japanese machine tool manufacturer Okuma has integrated a set of applications called Intelligent Technologies into the numerical controls of its machines, including the "Machining Navi" application. Among other things, this application recommends optimal spindle speeds to avoid vibrations during machining and increase productivity. The system leverages Okuma's advanced OSP control and sensors to monitor vibrations[131].

Siemens' "Analyze MyMachine/Condition" application[132] uses AI-based statistical models to analyse and ensure the quality and stability of the workpiece process, and improve productivity while saving resources, by analysing machine data acquired at high frequency.

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[130]Zuntong Wang, Zhanqiang Liu, et Xing Ai, «Case Representation and Similarity in High-Speed Machining», *International Journal of Machine Tools and Manufacture* 43, nº 13 (1 octobre 2003): 1347-53, https://doi.org/10.1016/S0890-6955(03)00152-4.

[131]«Intelligent Technology // OKUMA Europe GmbH», Okuma Europe GmbH, s. d., https://www.okuma.eu/es/tecnologia/corte/intelligent-technology/.

[132]«Analyze MyMachine /Condition», s. d., https://documentation.mindsphere.io/resources/html/Analyze-MyMachine-condition-opman/en-US/114549568779.html.

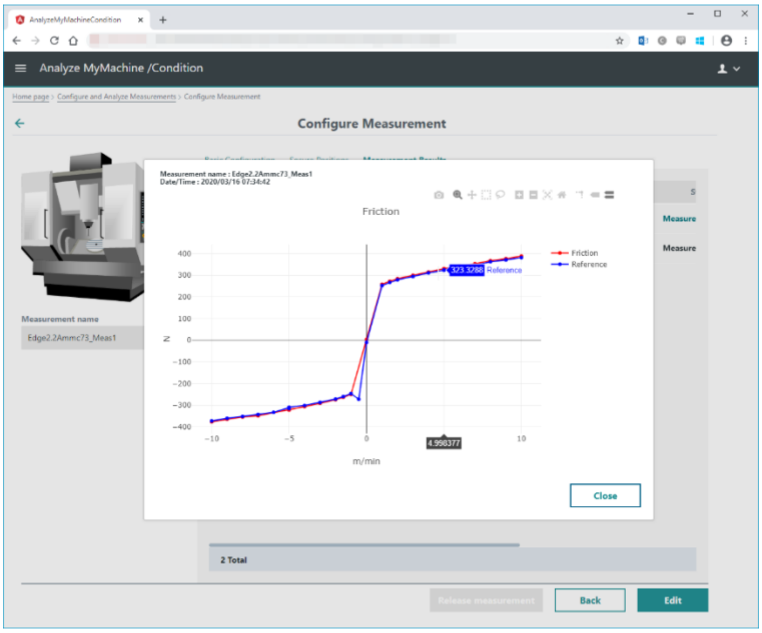

Figure 21: "Analyze MyMachine/Condition" application of Siemens[133]

In turn, DMG MORI focuses on the optimisation and acceleration of procurement and manufacturing processes based on Artificial Intelligence: from quotation and order entry, through job preparation and CAM programming, to machine planning. The core of the software solution is Artificial Intelligence, which analyses the geometry of each component in a matter of seconds based on machine learning algorithms and human knowledge. The result is a concrete work plan and the manufacturing price of the component. With each component, the AI 'learns', optimising its algorithms independently and continuously. One example is the "Machine Vibration Control" application, which aims to assist the user in the operational phase of the machine by means of tools that range from monitoring the parameters of the machining processes to the automatic and intelligent correction of the different geometric errors and deviations detected from the programmed trajectories[134].

Makino, for its part, has developed the "MHmax" software based on Machine Learning techniques for predictive machine status monitoring which, by means of automatic learning of the sensors integrated in the machine, predicts problems before they occur, taking measures to avoid unplanned downtime[135].

[133] «Analyze MyMachine /Condition».

[134] «CELOS Machine & Manufacturing», s. d., https://es.dmgmori.com/productos/digitization/celos.

[135] «Makino Health Maximizer (MHmax) Tutorial | Makino», s. d., https://www.makino.com/en-us/digital-makino/mhmax/mhmax-tutorial.

Figure 22: "MHmax" Software of Makino to determine the spindle status[136]

Finally, Mazak has incorporated the term "AI powered" into its machines. Two Machine Learning applications are worth highlighting, a CAM assistant for turning that is able to learn from operator corrections, and an application that records vibration levels in operation in order to create a pattern of positions and cutting conditions where machine vibrations are generated in order to assist the operator in controlling cutting conditions[137].

Figure 23: "Smooth AI Spindle" system of Mazak138

In the EDM environment, a review of the most recent scientific literature shows the increasing trend towards intelligent manufacturing systems, with autonomy to detect/collect data, control the erosion process, diagnose faults and "learn" to improve their performance using AI techniques. An example in the field of wire EDM is the application of AI techniques, such as unsupervised

[136]«Makino Health Maximizer (MHmax) Tutorial | Makino».

[137]«Smooth Ai», s. d., https://www.mazakeu.com/smooth-ai/.

[138]«Smooth Ai».

learning algorithms, to process machine signals and detect deviations in part accuracy[139] [140]. Another example is the work done by Giusti et al. This work[141] based on a convolutional neural network (CNN) that, given as input a small image of the surface (thanks to a machine vision system) returns the roughness value. In the specific case of "Fasthole" penetration machines, many of the works focus on the detection of the "break out" or exit of the hole based on the machine data and the detected patterns[142]. Finally, one of the Keynotes of the most prestigious conference on EDM, ISEM XX (Conference on Electro Physical and Chemical Machining), held in early 2021, mentions how the use of enabling technologies such as the Internet, 5G, IoT, Edge Computing or AI are overcoming the frontier of technical limitations for the development of modern smart manufacturing systems[143].

GF Machining Solutions is one of the leading manufacturers of EDM machines in the use of AI for process control and improvement. During MATLAB Expo 2019 it presented a Keynote showcasing some applications where AI algorithms could be useful. For example, the application of neural networks to detect anomalies in the process in advance and correct them (Zero Defect Manufacturing) or the optimisation of the Fasthole process for turbine blades. This process is notable for the large number of variables involved, and GF proposes the application of stochastic optimisation algorithms to find the optimum of the process.

GF. MITSUBISHI Electric has applied its wireless communication system for automatic optimisation thanks to AI called Maisart (Mitsubishi Electric's AI creates the State-of-the-art in Technology) in its SV12P die sinking EDM machine. This technology monitors the process and thanks to AI adapts it to obtain better results such as an ultra-fine finish, faster machining speed

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[139] J. Wang et al., «Artificial Intelligence for Advanced Non-Conventional Machining Processes», *Procedia Manufacturing*, 8th Manufacturing Engineering Society International Conference, MESIC 2019, 19-21 June 2019, Madrid, Spain, 41 (1 janvier 2019): 453-59, https://doi.org/10.1016/j.promfg.2019.09.032.

[140] Jun Wang et al., «Unsupervised Machine Learning for Advanced Tolerance Monitoring of Wire Electrical Discharge Machining of Disc Turbine Fir-Tree Slots», *Sensors* 18 (8 octobre 2018): 3359, https://doi.org/10.3390/s18103359.

[141] Alessandro Giusti et al., « Image-Based Measurement of Material Roughness Using Machine Learning Techniques», *Procedia CIRP*, 20th CIRP CONFERENCE ON ELECTRO PHYSICAL AND CHEMICAL MACHINING, 95 (1 janvier 2020): 377-82, https://doi.org/10.1016/j.procir.2020.02.292.

[142] Wei Liang et al., «Feasibility Research on Break-out Detection Using Audio Signal in Drilling Film Cooling Holes by EDM», *Procedia CIRP*, 20th CIRP CONFERENCE ON ELECTRO PHYSICAL AND CHEMICAL MACHINING, 95 (1 janvier 2020): 566-71, https://doi.org/10.1016/j.procir.2020.02.271.

[143] Wansheng Zhao et al., «Reconstructing CNC Platform for EDM Machines towards Smart Manufacturing», *Procedia CIRP*, 20th CIRP CONFERENCE ON ELECTRO PHYSICAL AND CHEMICAL MACHINING, 95 (1 janvier 2020): 161-77, https://doi.org/10.1016/j.procir.2020.03.134.

or less wear on the electrodes when working with PCD and CBN type materials. In addition, they promise to predict erosion times more accurately, traditionally a difficult task[144].

With respect to Machine Vision, it can be defined as a field of Artificial Intelligence that, by using the appropriate techniques, allows obtaining, processing, and analysing any type of special information obtained through digital images. Artificial Vision is made up of a set of processes aimed at carrying out image analysis. These processes are image capture, information storage, processing and interpretation of the results.

Machine vision excels at quantitative measurement of a structured scene due to its speed, accuracy, and repeatability. For example, on a production line, a machine vision system can inspect hundreds, or even thousands, of objects per minute. A Machine Vision system built around the right camera resolution and optics can easily inspect details of objects too small to be seen by the human eye. Some of the applications of Machine Vision in industry are as follows:

Industrially, in recent years there has been a growing number of companies that have installed automated systems in their workshops using Machine Vision. For example, one of the problems of DMG MORI's customers who use automation systems is stopping the machine due to faults caused by chips generated during machining. The "AI Chip Removal" function developed by DMG MORI analyses the state of chip accumulation using Machine Vision and Machine Learning techniques and removes the chip automatically to reduce problems and help maximise the production output of automation systems[145].

Figure 24: "AI Chip Removal" application from DMG MORI for the removal of chips by Artificial Vision[146]

[144]«Electroerosionadora Mitsubishi SV12P con tecnología de inteligencia artificial», 31 décembre 2020, https://www.mms-mexico.com/productos/electroerosionadora-mitsubishi-sv12p-con-tecnologia-de-inteligencia-artificial.

[145]«"AI Chip Removal" Developed for Automatic Removal of Chips Generated during Machining | News/topics | DMG MORI», s. d., https://www.dmgmori.co.jp/en/trend/detail/id=5484.

[146]«"AI Chip Removal" Developed for Automatic Removal of Chips Generated during Machining | News/topics | DMG MORI».

Siemens offers a wide range of Edge applications for a variety of use cases. Its "Analyze MyWorkpiece/Vision" application analyses the quality of the workpiece using a camera image and AI-based software to increase machine tool productivity. The application can determine the correct position of the workpiece in the machining area and can also monitor tool wear throughout its life[147].

Figure 25: "Analyze MyWorkpiece/Monitor" for the analysis by Artificial Vision[148]

Regarding the maintenance of machine components, researchers at the Karlsruhe Institute of Technology (KIT) have developed a system for fully automated monitoring of ball screws in machine tools. A camera integrated directly into the disc nut generates images that artificial intelligence continuously monitors for signs of wear, which helps to reduce machine downtime using machine vision[149].

[147]«Analyse MyWorkpiece /Toolpath», fw_Routing, siemens.com Global Website, s. d., https://www.siemens.com/global/en/markets/machinebuilding/machine-tools/cnc4you/fokus-digitalisierung/analyse-myworkpiece-tp.html.

[148]Ibid

[149]Tobias Schlagenhauf et al., «Integration of machine vision in ball screw drives – Integrated system for condition monitoring of ball screw drives», *wt Werkstattstechnik online* 109 (1 août 2019): 605-10, https://doi.org/10.37544/1436-4980-2019-07-08-95.

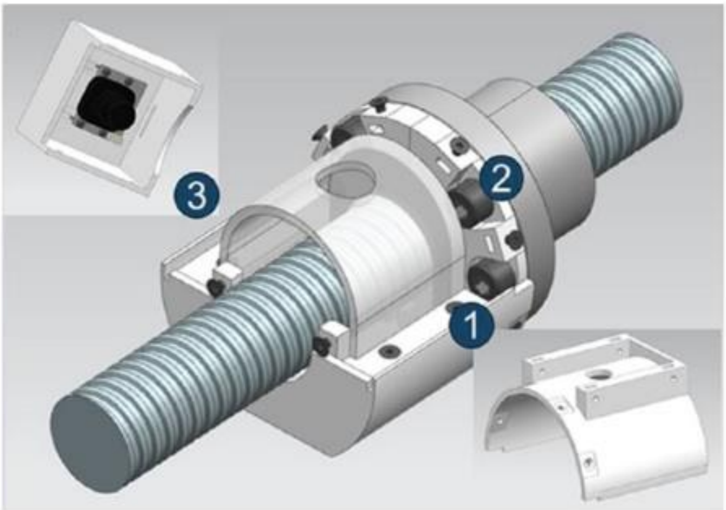

Figure 26: Artificial Vision for intelligent monitoring of the ball screw (KIT)[150]

The Makino i-Assist robot features a host of advanced functions for manufacturing parts using machine vision. For example, it finds its own way to the machine it needs to feed, avoiding any obstacles, picks up parts even if they are not in the correct position, and loads tools into a pre-setting machine.

Figure 27: Robot i-Assist by Artificial Vision of Makinol

[150] Ibid

3.6.2.3 Multitask and Hybrid Machines, Flexible Systems

The industrial capacity of the Basque Country is undoubtedly one of the most important in Spain, and it is also one of the most advanced regions in Europe. Within Basque industry, it is worth highlighting the machine tool sector, which is widely consolidated and is considered strategic for the Basque Country, not only because of the volume it represents, but also because of the pull effect it generates on the entire Basque economy. The Basque machine tool sector is characterised by its high competitiveness, continuous innovation, and high rate of internationalisation, with more than 90% of its sales being exported to all corners of the world.

One fact that reflects the importance of the machine tool sector in the Basque Country is that, with Spain being the third largest exporter of machine tools in Europe and the ninth largest in the world, 90% of its machine tool companies are in the Basque Country. It is therefore clear that the Basque Country is one of the most important machine tool regions in the world and where most technology and added value is being generated.

Due to the great depth and importance of the machine tool sector in the Basque Country, there are numerous entities and administrations that continually propose common actions related to new activities for the sector.

More efficient and flexible processes and their effect in terms of productivity gains.

- **Predictive maintenance of machinery**

The state of the machine condition will be diagnosed continuously and unattended at the customer's site without interfering with production. Normality patterns and supervised learning of the machine's condition will allow the parameters of the machine and its systems to be adapted to the state of the machine and its cabin at any given moment. Continuous modification of the tuning parameters will ensure optimal operating conditions and prolong the service life of the machines.

- **Second best**

The learning of the process executed during the manufacturing of the first part will allow the learning and formulation of prescriptions to improve the manufacturing of the second part according to objective functions selected by the machine operator: reduce times to increase productivity, reduce vibrations and deflections in the tool to improve precision and surface quality, eliminate impacts on the tool and keep the load on the cutting edge constant, reduce the flow of the input material in areas of overgrowth or similar.

- **Continuous dynamic adjustment of the machines**

As opposed to an adjustment for a fixed weight and inertia that impairs the dynamics in case of reduced part weight and inertia by finding a compromise solution for any weight and inertia, the continuous adjustment of the machine dynamics will increase the process speed and substantially reduce process times. Parts can undergo drastic weight changes through processing: weight reduction in start-up processes of up to 90% and weight increase in additive processes (up to 100%).

3.6.2.4 Automation of Processes

As with machine condition monitoring and optimisation, including the condition of major components and geometric accuracy, access to machine control and integrated sensor data opens a world of possibilities related to the condition of the manufacturing processes carried out on the machine. Access to data enables the development of advanced functions aimed at optimising process quality and productivity.

Recently, the most advanced machine manufacturers have been incorporating functionalities for monitoring the condition of the processes carried out on their machines and functionalities for self-adjustment of process control parameters, giving rise to adaptive processes that seek to optimise quality and productivity, as well as facilitating the work of machine operators.

Some of the advanced solutions for process condition monitoring, representative of the state of the art in the manufacturing machine sector, are presented below:

As a standard the machines are delivered with the drive parameters set to the highest foreseeable part weight. The Load Adaptive Control (LAC) functions from Heidenhain[151], Intelligent Load Control (ILC) from Siemens[152] and Servonavi from Okuma[153] adapt the settings of the machine axis control according to the weight of the workpiece to be machined. This allows the machine dynamics to be optimised for each workpiece, resulting in shorter process times and greater precision. The adjustment is made possible by the automated calculation of the workpiece weight by means of control parameters recorded in a specific axis movement.

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[151] «DynamicPrecision.pdf», Heidenhain, 2013, https://www.heidenhain.us/lp/controls/DynamicPrecision.pdf.

[152] «Siemens Machine Tool Days - October 14th, 2020», siemens.com Global Website, 2020, https://new.siemens.com/global/en/company/fairs-events/events/machine-tool-days.html.

[153] *Okuma's Intelligent Technology - SERVONAVI*, 2016, https://www.youtube.com/watch?v=k4bHmpFui-Y.

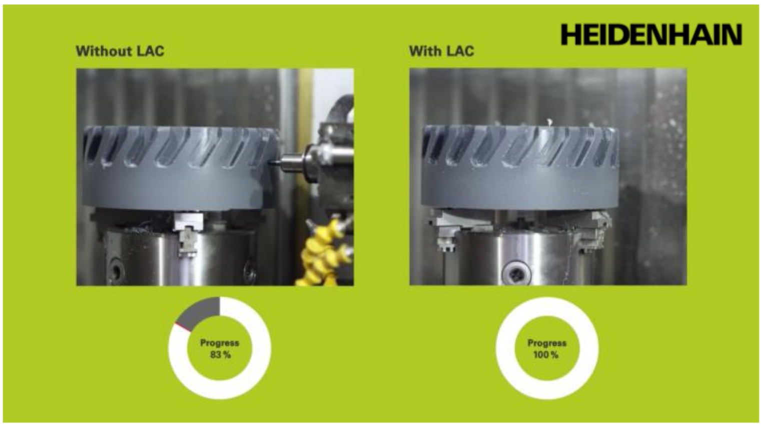


Figure 28: Load Adaptive control of Heidenhain [154]

During the high-performance machining process, the high forces generated by the tool can cause vibrations in the machine structure (chatter). In extreme situations, this can lead to damage to the tool, workpiece, or machine. DMG MORI, Heidenhain, Mazak, Okuma and Soraluce offer intelligent control solutions to reduce these vibrations.

DMG MORI's Machine Vibration Control (MVC) function[155] registers vibrations during machining by means of an accelerometer integrated in the electro spindle and detects whether chatter is occurring, in which case the system algorithm proposes new cutting conditions that avoid vibrations. More productive cutting conditions are obtained with less vibration, it provides automatic suggestions of suitable process parameters and allows the vibration status to be monitored by means of different indicators that serve as guidance for the machine operators.

Heidenhain has developed the Active Chatter Control (ACC) function[156], which calculates a compensation signal based on the number of inserts in the tool and the spindle speed, thus reducing vibrations. This makes it possible to achieve higher feed rates, feed rates and process times, which helps to increase productivity and reduce costs.

[154]«DynamicPrecision.pdf».

[155]«DMG MORI France - Machines-outils CNC pour toutes les applications de l'enlèvement de matière».

[156]DR JOHANNES HEIDENHAIN GmbH, «Dynamic Efficiency», s. d., https://www.heidenhain.us/lp/controls/DynamicEfficiency.pdf.

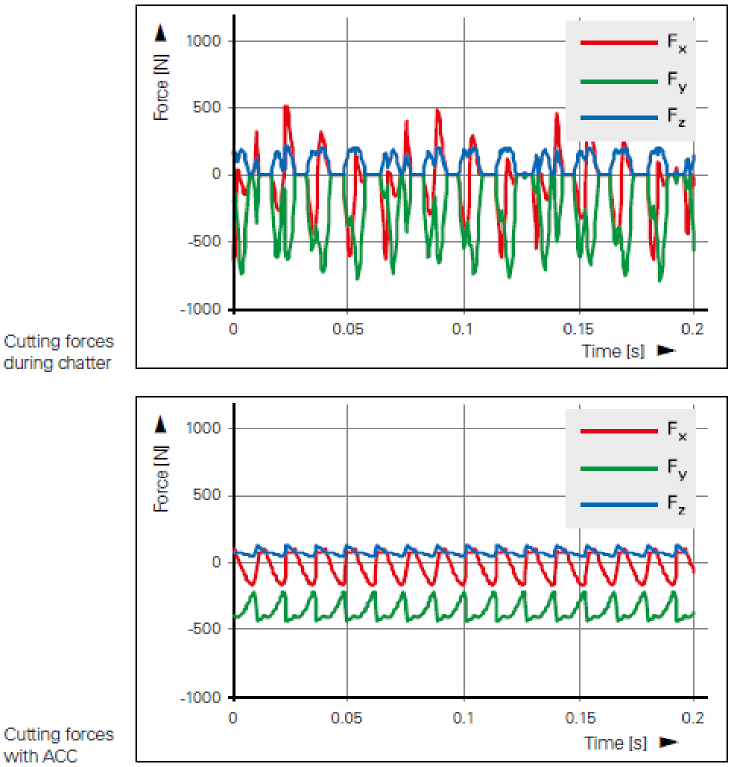


Figure 29: Active Chatter Control (ACC) of Heidenhain[157]

Mazak's chatter control solution, Smooth AI Spindle[158], detects when chatter is occurring during machining, and using AI techniques searches for optimal machining conditions to reduce or eliminate chatter to improve part quality and enable increased productivity.

Okuma's Machining Navi system[159] uses accelerometers to monitor the vibrations of the electro spindle during the cutting process. If necessary, the intelligent control application recommends or automatically adapts the spindle speed, improving machining surface quality and process times.

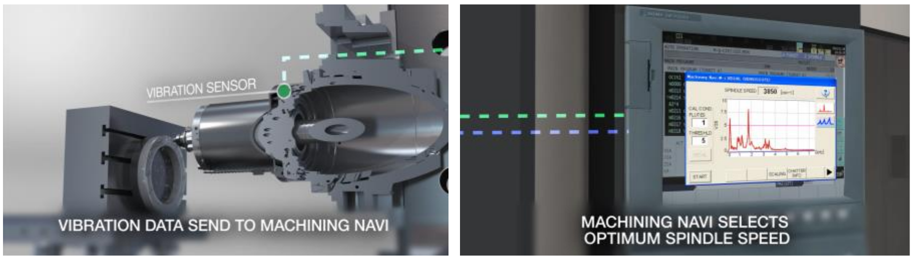


Figure 30: Machining Navi of Okuma[160]

[157] GmbH.

[158] *Smooth AI Spindle : Automatic compensation by AI*, 2018, https://www.youtube.com/watch?v=K0pjVRsS2hI.

[159] *Okuma's Intelligent Technology - Machining Navi*, 2016, https://www.youtube.com/watch?v=wXfsKomM_tE.

[160] *Okuma's Intelligent Technology - Machining Navi*.

DMG MORI presents Machine Protection Control (MPC)[161], a solution that prevents tool breakage and protects the machine against damage caused by overloads and collisions during machining. With an accelerometer integrated in the machine head, the vibrations produced during machining are recorded and compared live with the reference values for the respective process, values that were obtained in a teaching or learning cycle. The solution monitors the vibrations continuously and generates alarms and machine stops when set thresholds are exceeded.

DMG MORI also offers a complementary solution for the prevention of damage due to tool breakage or overloading, which does not require external sensors as it is based on the machine's internal control parameters. Easy Tool Monitoring 2.0162 consists of an advanced evaluation algorithm with self-learning capability of load limits and efficient control after the first workpiece.

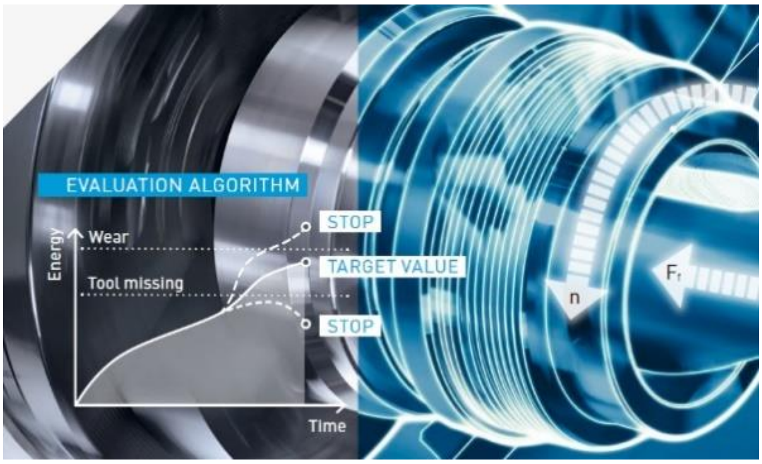


Figure 31: Easy Tool Monitoring 2.0 of DMG MORI[163]

Another solution from the same manufacturer, DMG MORI, is the Tool Control Center[164] for force and bending detection of the cutting head, with sensors integrated in the nose of the electro spindle and wireless data transfer by induction from the rotor to the stator. It allows detection of chips in the bearing and tool taper, monitoring of the tensile force, in-process control of the cutting tool cutting edge by symmetrical tracking of the bending moment per cutting edge, and monitoring of the bending moment by history graph. It provides tool and workpiece protection and optimises tool life.

[161]«DMG MORI France - Machines-outils CNC pour toutes les applications de l'enlèvement de matière».

[162]Ibid

[163]Ibid

[164]Ibid

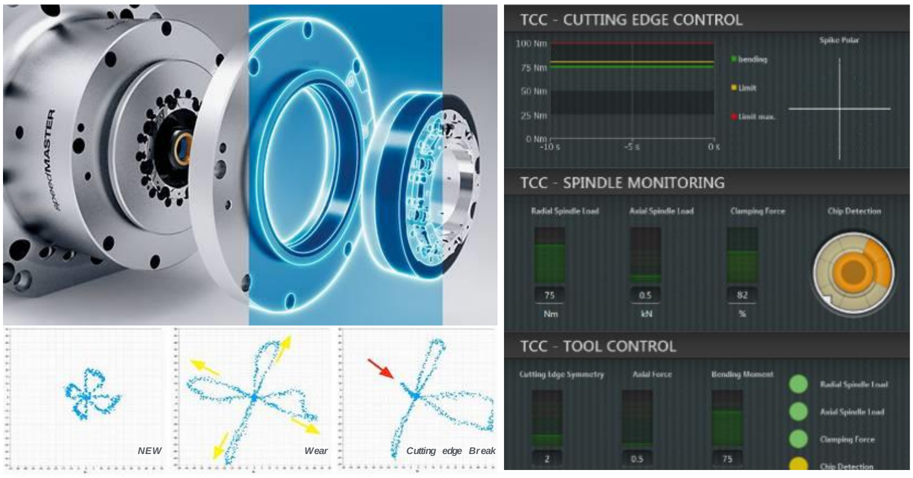


Figure 32: Tool Control Center of DMG MORI[165]

Along the same lines of cutting tool protection, Okuma incorporates Dynamic Tool Load Control in its machines, with the aim of reducing cutting tool wear, achieving stable machining for difficult-to-cut materials. Okuma's Dynamic Tool Load Control[166] compensates for tool deflection by varying the feed rate. Deflection is measured, ensuring a constant load during machining. It increases tool life, improves the quality of machined parts, and reduces downtime for tool changes.

To protect the machine against excessive power values and optimise productivity, Heidenhain offers the Adaptive Feed Control function[167]. The feed rate in machining operations is usually set depending on the material to be machined, the tool and the depth of cut. If the cutting conditions change during the process, e.g., due to fluctuations in the depth of cut, tool wear or variations in the hardness of the material, the feed rate is usually not changed, so that the process is not optimised because the values are usually set for the worst-case scenario. The AFC function adapts and optimises the machining feed rate in real time, depending on the spindle power. The function continuously compares the momentary power of the process with the reference values and varies the feed rate to keep the power at the reference values. In this way, it increases the productivity of the process while protecting the machine from exceeding excessive power values.

To avoid collisions between tool and workpiece during machining, Okuma's Collision Avoidance System (CAS)[168] installed in the machine control monitors the cutting process through a virtual application (with 3D models of the machines, workpieces, and tools) that measures the exact shape of the material milliseconds before the machining operation. Potential collisions are detected in time for the control to stop the machine before they occur. It protects the machine,

[165] Ibid

[166] *Okuma's Intelligent Technology - SERVONAVI*.

[167] GmbH, «Dynamic Efficiency».

[168] *Okuma's Intelligent Technology - Collision Avoidance System*, 2015, https://www.youtube.com/watch?v=ViONSkhC3SU.

workpiece and tools against collisions and greatly reduces machining setup time as it can also be used in the manual mode of the control.

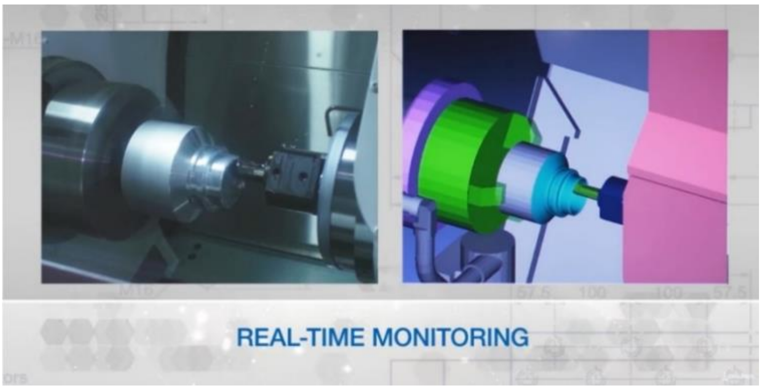


Figure 33: Collision Avoidance System (CAS) of Okuma[169]

In turn, Siemens proposes a solution that integrates a vision camera that monitors the machining process and protects the machine and workpiece from collisions through artificial intelligence[170].

Figure 34: Solution to avoid collisions with Artificial Vision of Siemens[171]

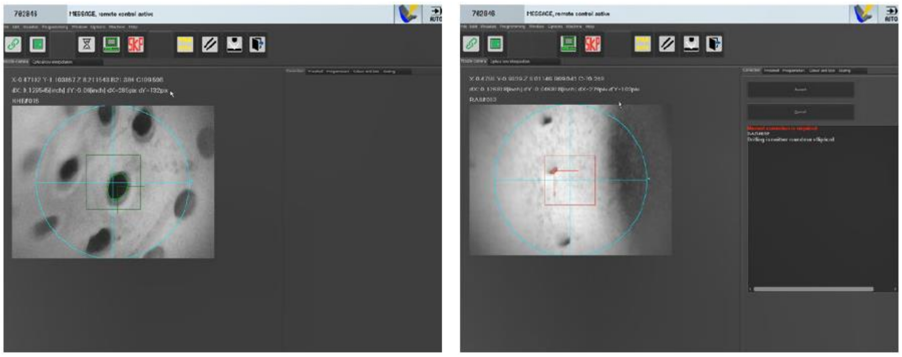
Another example of solutions based on machine vision is DMG MORI's Automatic Hole Detection (ADH)[172], for recognition of reference holes in the part (features), comparison with the virtual part and automated translation of the part program on the machine. It reduces the work of positioning and adjusting the part prior to machining, eliminating errors, and reducing process times.

[169] *Okuma's Intelligent Technology - Collision Avoidance System*.

[170] «Siemens Machine Tool Days - October 14th, 2020».

[171] Ibid

[172] «DMG MORI France - Machines-outils CNC pour toutes les applications de l'enlèvement de matière».



Automatic detection and position compensation of round and elliptical drill holes

Possibility for manual correction of hardly detectable or partially closed drill holes

Figure 35. Automatic Hole Detection (ADH) of DMG MORI[173]

Taking a particular look at EDM, this process requires a great deal of variable control to achieve a stable cut, which has forced machine manufacturers to develop digital generators capable of controlling and acting on individual discharges. The control of discharges influences the achievement of priority objectives such as increasing removal rates or improving the surface integrity of the parts, but also opens an opportunity to adapt the process to specific part characteristics or working conditions, such as detecting part cutting thickness, avoiding wire breakage, predicting wear, estimating component life, etc. If this is combined with the information acquired from the CNC itself and the use of new sensors on the machine, its environment or the part itself, it is possible to acquire enough information from the process to apply techniques with predictive and decision-making capabilities.

Thanks to this, manufacturers of EDM machines have begun to integrate intelligent systems into the machines to facilitate the user's work. GF Machining Solutions has integrated the optional Spark Track system into its wire EDM machines[174]. Although the principle of this system has been known for more than 30 years, it could not be implemented until now due to the absence of the necessary electronics for signal processing. GF integrates state-of-the-art sensors in its machines that detect in real time where each discharge occurs along the wire and its intensity, and then process all this data and generate application modules to better control the cutting process. The processing is done using FPGAs (Field Programmable Gate Arrays), programmable devices to extract from the electrical signals the most significant characteristics for the process in real time.

The first module presented is the Intelligent Spark Protection System (ISPS), which prevents wire breakage thanks to constant monitoring of discharges in variable-section parts and adaptive control of process parameters. This results in an increase in performance. In addition to this

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[173]«DMG MORI France - Machines-outils CNC pour toutes les applications de l’enlèvement de matière».

[174]«ISPS - Intelligent Spark Protection System», GF Machining Solutions Sales Switzerland SA - Suisse, s. d., https://www.gfms.com/fr-ch/machines/edm/wire-cutting/intelligent-spark-protection-system.html.

module, according to GF, the Spark Track system opens the way for further innovation in wire EDM and the implementation of research carried out more than 30 years ago thanks to the capabilities of new sensors, the processing speed of signal acquisition and processing systems and the application of AI algorithms[175].

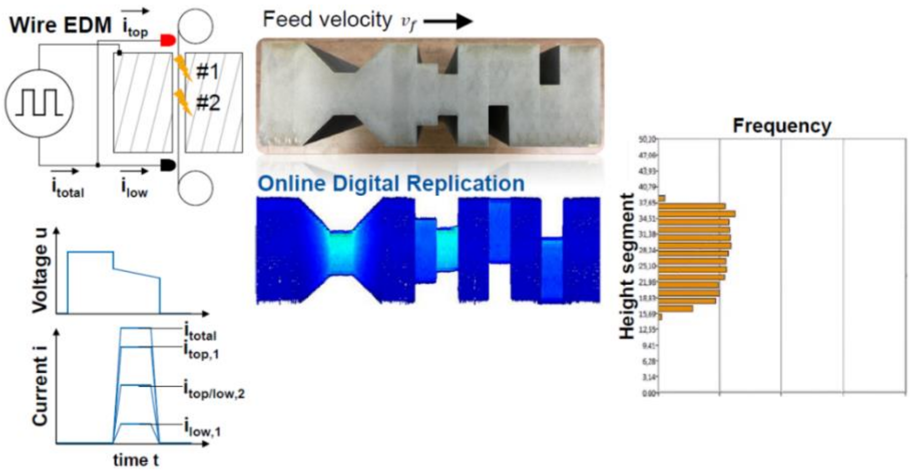

Figure 36: SparkTrack system of GF Machining Solutions[176]

Other manufacturers, such as Makino, have recently presented a paper showing the development of a system for online analysis of machine signals in wire EDM using FPGAs for process performance control[177]. They also mention that the developed control system can be implemented in other applications such as wire breakage control.

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[175] M. Boccadoro, R. D'Amario, et M. Baumeler, «Towards a Better Controlled EDM: Industrial Applications of a Discharge Location Sensor in an Industrial Wire Electrical Discharge Machine», *Procedia CIRP*, 20th CIRP CONFERENCE ON ELECTRO PHYSICAL AND CHEMICAL MACHINING, 95 (1 janvier 2020): 600-604, https://doi.org/10.1016/j.procir.2020.02.266.

[176] Boccadoro, D'Amario, et Baumeler.

[177] Ugur Küpper, Tim Herrig, et D. Welling, «Evaluation of the Process Performance in Wire EDM Based on an Online Process Monitoring System», *Procedia CIRP* 95 (2 février 2021): 360-65, https://doi.org/10.1016/j.procir.2020.02.325.

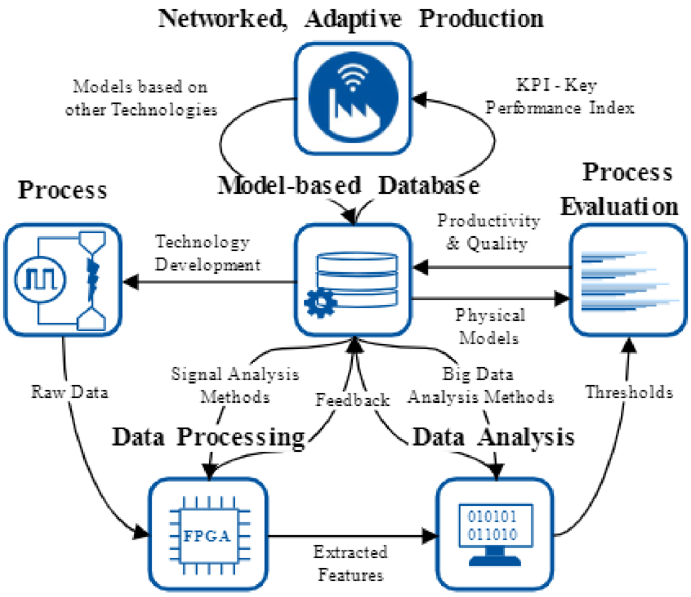

Figure 37: Process data analysis system of Makino[178]

In the field of additive manufacturing, in order to obtain a reliable and efficient industrial input process, it is of vital importance to monitor the process by acquiring internal signals.

An example of this is the DMG MORI AM-Evaluator[179] solution for data logging of the additive manufacturing process. It provides a detailed analysis of relevant process data, in 3D model format, as well as in time graphs. It allows comparisons of different processes to be made for user support, enabling processes to be optimised and quality to be improved. Data logging also provides traceability of the manufacturing of each part.

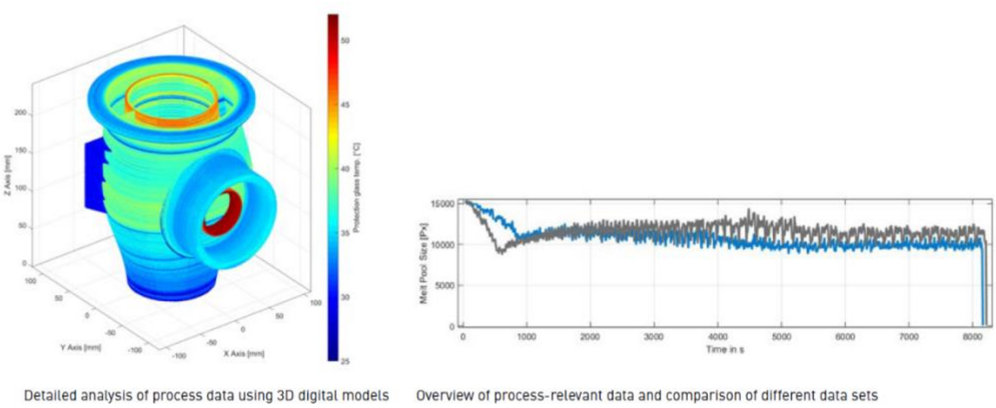

Figure 38: AM-Evaluator of DMG MORI[180]

[178] Küpper, Herrig, et Welling.

[179] «DMG MORI France - Machines-outils CNC pour toutes les applications de l'enlèvement de matière».

[180] «DMG MORI France - Machines-outils CNC pour toutes les applications de l'enlèvement de matière».

3.6.2.5 Additive Manufacturing

In Additive Manufacturing it is also necessary to include closed loop control systems within the process that act on the main parameters (power, powder feed and flow/wire feed, etc.) adapting automatically according to the data recorded during the process. Recent studies in additive technologies have incorporated process monitoring and control systems in machines dedicated to additive manufacturing and have developed control algorithms to diagnose the process during input. This is essential to ensure the quality of the parts and to prevent errors such as pores, non-fusion zones, or deformations. The inclusion of these systems implies integrating more systems into the process that interact with the rest of the machine and with the casting paths.

More specifically, regarding Laser Cladding technology, the most frequent monitoring parameters in the state of the art are the geometry of the molten bath, defects in the structure (porosities and cracks), height of the deposited material or simply temperature[181]. Most efforts have focused on monitoring temperature, molten bath size and deposited layer height in addition to the subsequent dimensional control of the deposited geometry.

The following is a description of the work focused on monitoring and controlling the main process parameters in additive manufacturing by Laser Cladding, which are the molten bath, the layer height, powder flow and the final delivered geometry:

- **Melting bath:** Temperature is a relevant parameter that affects the metallurgical structure[182] and the dimensional accuracy of the input material. As material is added, the substrate heats up, so if you continue to add material in the same area, the process will reach higher temperatures. This will increase the molten pool and dilution causing dimensional differences, differences in structure and mechanical characteristics in the different layers of input material. It will also increase the fluidity of the input material and may cause loss of shape and, if the temperature reached is too high, evaporation of material as in a laser cutting process.
  The control of the temperature and size of the molten bath is done by reducing the power in a closed control during the process. Control of the molten bath can be done with a CMOS camera and a closed-loop control algorithm controlling the dilution and hardness of the coatings by keeping the values constant[183]. The temperature is

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[181] Adrita Dass et Atieh Moridi, «State of the Art in Directed Energy Deposition: From Additive Manufacturing to Materials Design», *Coatings* 9 (29 juin 2019): 418, https://doi.org/10.3390/coatings9070418.

[182] Mohammad H. Farshidianfar, Amir Khajepouhor, et Adrian Gerlich, «Real-Time Monitoring and Prediction of Martensite Formation and Hardening Depth during Laser Heat Treatment», *Surface and Coatings Technology* 315 (15 avril 2017): 326-34, https://doi.org/10.1016/j.surfcoat.2017.02.055.

[183] J. T. Hofman et al., «A Camera Based Feedback Control Strategy for the Laser Cladding Process», *Journal of Materials Processing Technology* 212, nº 11 (1 novembre 2012): 2455-62, https://doi.org/10.1016/j.jmatprotec.2012.06.027.

controlled by pyrometers or thermographic cameras. However, measurements in this process are characterised by the noise caused by the injected powder[184], making it difficult to obtain a clean reading of the temperature and geometry of the molten bath.

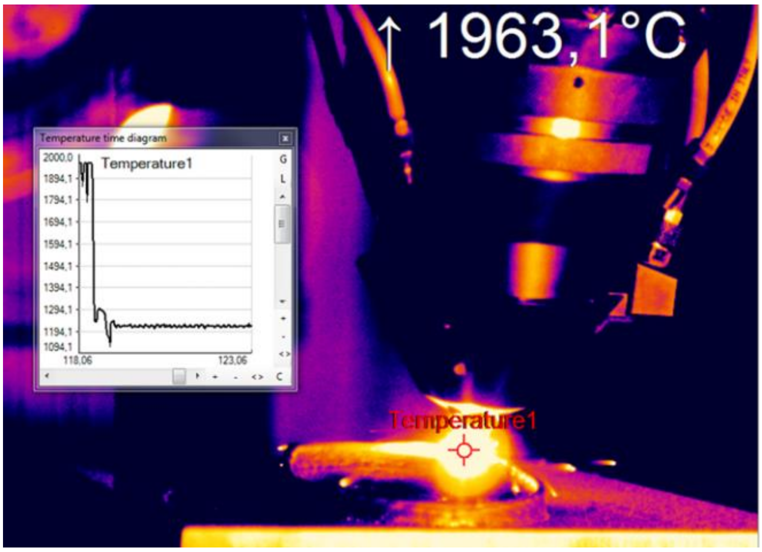

Figure 39: Image of temperature measurement with a thermal camera.

However, alterations in the mean noise amplitude have been related to process instabilities such as damage to the laser head protective lens[185] or oxidation and dilution problems[186]. Aligning the chamber coaxially is strongly recommended as the lateral arrangement, although simpler, can lead to measurement errors.

This type of control improves the profile of the deposited material by reducing its waviness and therefore stabilises the cutting forces to which the tool is subjected in subsequent machining. It also makes it possible to monitor defects such as lack of fusion or porosity[187]. However, it is not clear what effect power control has on the efficiency of the process and whether the deposited layer height remains constant using this type of control.

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[184] Ahmad Mozaffari et al., «Optimal Design of Laser Solid Freeform Fabrication System and Real-Time Prediction of Melt Pool Geometry Using Intelligent Evolutionary Algorithms», *Applied Soft Computing*, Hybrid evolutionary systems for manufacturing processes, 13, nº 3 (1 mars 2013): 1505-19, https://doi.org/10.1016/j.asoc.2012.05.031.

[185] Pedro Ramiro et al., «Characteristics of Fe-Based Powder Coatings Fabricated by Laser Metal Deposition with Annular and Four Stream Nozzles», *Procedia CIRP*, 10th CIRP Conference on Photonic Technologies [LANE 2018], 74 (1 janvier 2018): 201-5, https://doi.org/10.1016/j.procir.2018.08.094.

[186] Guijun Bi et al., «Identification and Qualification of Temperature Signal for Monitoring and Control in Laser Cladding», *Optics and Lasers in Engineering* 44, nº 12 (1 décembre 2006): 1348-59, https://doi.org/10.1016/j.optlaseng.2006.01.009.

[187] Zhong Yang Chua, Il Hyuk Ahn, et Seung Ki Moon, «Process Monitoring and Inspection Systems in Metal Additive Manufacturing: Status and Applications», *International Journal of Precision Engineering and Manufacturing-Green Technology* 4, nº 2 (1 avril 2017): 235-45, https://doi.org/10.1007/s40684-017-0029-7.

Power control is critical in thin substrate coating applications such as pipelines for the petrochemical sector. In such cases the temperature rise with process time is excessive and leads to severe damage to the substrate. An example of this control is the CLAMIR system for the control of coatings manufactured by DED [New Infrared Technologies].

- **Layer height:** Controlling the height of the applied layer is also critical. If the deposited layer grows less than calculated, after several layers the deposition distance between the laser head and the substrate will be greater, causing a poor deposition process and generating a dimensionally defective structure[188].

This layer control can be performed during the deposition process by triangulating a coaxial laser beam of a different wavelength than the deposition laser[189] and varying the deposition rate[190] so that the layer grows as much as required. Height control can also be performed by stopping the process between layers, obtaining the actual input geometry using structured light and adapting the trajectories to the differences with the programmed geometry[191].

It is important to point out that both the laser height control and the control of the molten bath and temperature are carried out coaxially. This fact, together with the fact that they influence different process parameters, can cause space problems to integrate all the necessary sensors and incompatibilities in the control strategies if they are not developed as a joint control.

The height control developed within the European PARADDISE project by Siemens using a Precitec sensor based on interferometry [Siemens, Height control] for the laser beam process is a clear example[192].

- **Powder flow:** One of the problems with monitoring the flow in laser sputtering processes is the low powder flow rate (between 5 and 20 g-min-1) compared to other processes such as thermal spraying. Monitoring systems based on the weight of gravimetric feeders are often not effective in generating a uniform flow in these cases and this can result in a deposition process with significant variations in the amount of

[188]Andrew J. Pinkerton et Lin Li, «The Significance of Deposition Point Standoff Variations in Multiple-Layer Coaxial Laser Cladding (Coaxial Cladding Standoff Effects)», *International Journal of Machine Tools and Manufacture* 44, nº 6 (1 mai 2004): 573-84, https://doi.org/10.1016/j.ijmachtools.2004.01.001.

[189]Simone Donadello et al., «Monitoring of Laser Metal Deposition Height by Means of Coaxial Laser Triangulation», *Optics and Lasers in Engineering* 112 (1 janvier 2019): 136-44, https://doi.org/10.1016/j.optlaseng.2018.09.012.

[190]«Additive Manufacturing: New Process Improves Speed and Reliability», fw_Inspiring, siemens.com Global Website, s. d., https://www.siemens.com/global/en/company/stories/research-technologies/additivemanufacturing/additive-manufacturing-laser-metal-deposition.html.

[191] Iker Garmendia et al., «Structured Light-Based Height Control for Laser Metal Deposition», *Journal of Manufacturing Processes* 42 (1 juin 2019): 20-27, https://doi.org/10.1016/j.jmapro.2019.04.018.

[192]«ADDITIVE MANUFACTURING APPARATUS AND METHOD - US20210039167», 2020, https://patentscope.wipo.int/search/es/detail.jsf?docId=US317629321.

material deposited[193]. This is why, to monitor the powder flow in the laser deposition process, optical sensors are often used in the flow path due to the direct impact that the powder in the flow has on the intensity of the light that can be detected [MEDICOAT, Flow Watch]. A photoresistor transforms this light intensity into a voltage that allows the flow to be monitored and to act directly on the powder feeder depending on the signal generating a closed-loop control.

As the flow is carried several meters to the injectors in the die, a control system with short response times is complicated, so these control systems are used to ensure a stable flow during the process. Powder characteristics such as size, density or surface area have a direct effect not only on the flow provided by the feeder but also on the response of the sensor.

- **Verification of the geometry obtained:** The low dimensional accuracy of the process coupled with the uncertainty of the final geometry obtained inspects prior to the machining stage necessary. In repair and coating applications there is also an uncertainty of the initial substrate geometry so the substrate must also be inspected before the additive process.

This inspection stage is more critical in hybrid additive manufacturing + machining as its main advantage is to incorporate both processes without the need to move the part. This eliminates errors associated with geometry manipulation and mismatch. However, for this solution to be fully realised, an in-situ measurement system must also be incorporated.

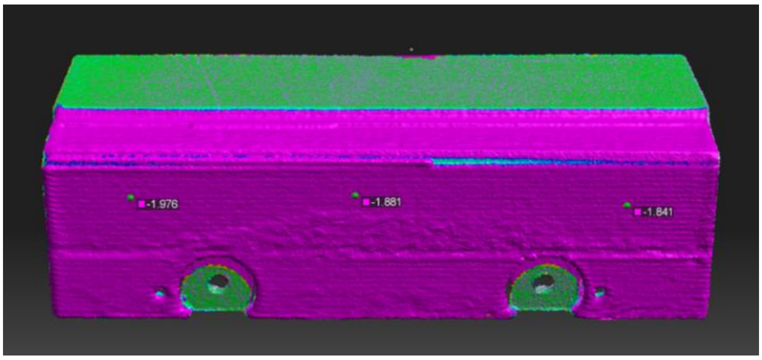

Figure 40: Measurement of a coating applied by laser using structured light.

[193] Vishnu Thayalan et Robert G. Landers, «Regulation of Powder Mass Flow Rate in Gravity-Fed Powder Feeder Systems», *Journal of Manufacturing Processes* 8, nº 2 (1 janvier 2006): 121-32, https://doi.org/10.1016/S1526-6125(06)80007-1.

Although various methods have been studied in other additive technologies[194], not many alternatives have been studied for laser cladding processes. Siemens has incorporated into its NX software the inspection of additive parts using a stylus to validate quality[195] and other work has focused on 3D laser scanning[196] or structured light measurement systems[197] integrated into the machine itself.

In the case of **WAAM - Wire Arc Additive Manufacturing technology**, the main process parameters to be controlled are the signal intensity, voltage, wire feed, speed of the moving system, etc.

The following figure shows the monitoring of the energy used during the WAAM process in the manufacture of a single aeronautical hardware and in the manufacture of three aeronautical hardware in matrix form.

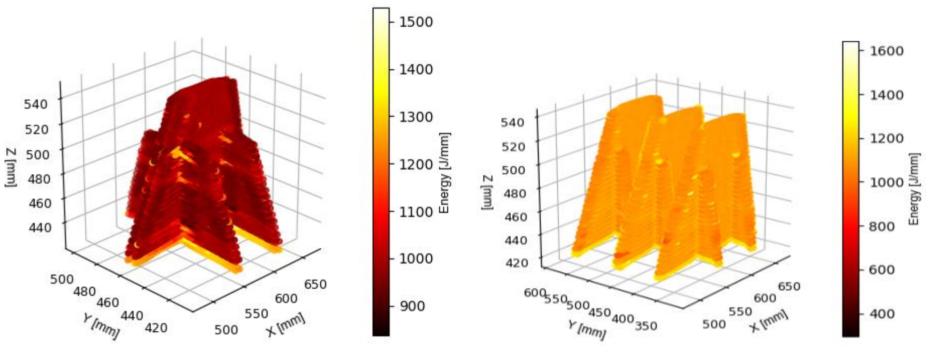

Figure 41: Monitored energy during the manufacture of a single aeronautical fitting (left) and during the manufacture of three matrix-shaped aeronautical fittings (right).

[194] Magdalena Cortina et al., «Latest Developments in Industrial Hybrid Machine Tools That Combine Additive and Subtractive Operations», *Materials* 11, nº 12 (décembre 2018): 2583, https://doi.org/10.3390/ma11122583.

[195] «Tecnomatix Digital Manufacturing Software | Siemens Software», Siemens Digital Industries Software, s. d., https://plm.sw.siemens.com/en-US/tecnomatix/.

[196] Yuan Liu, Thomas Bobek, et Fritz Klocke, «Laser Path Calculation Method on Triangulated Mesh for Repair Process on Turbine Parts», *Computer-Aided Design* 66 (1 septembre 2015): 73-81, https://doi.org/10.1016/j.cad.2015.04.009.

[197] Amaia Alberdi et al., «Egituraturiko argiaren aplikazioak fabrikazio hibridoaren bidez pieza metalikoak ekoizteko», *EKAIA EHUko Zientzia eta Teknologia aldizkaria*, 2 avril 2019, https://doi.org/10.1387/ekaia.19829.

On the other hand, elements such as vision systems, geometric lasers, pyrometers, etc. have sometimes been integrated:

- **Visual control systems:** Several studies have shown that to reduce defects in the parts, the most important thing is to control the width and height of the wall, and for this, on-line monitoring of the melt pool is an essential part of the control. In these cases, visual control systems are commonly used for this application[198] [199] [200].
- **Geometric laser:** Another control strategy for WAAM processes is often the scanning of each layer after deposition with a geometric laser. This provides three-dimensional information of the deposited weld beads in the form of a point cloud and allows the deviation in the height and width of each layer to be monitored and the parameters of the next layer to be adjusted to compensate for this[201].
- **Oxygen level gauges:** Oxygen level gauges are used for materials that require an enclosed space with a controlled atmosphere for deposition to ensure the quality of the manufacturing atmosphere[202].
- **Pyrometers:** Another control method is the monitoring of the melting pool temperature by means of pyrometers[203], since, in the WAAM process, temperature is a fundamental parameter due to the complicated thermal history of the parts manufactured by this method.

As an example, at Chalmers University they are working on WAAM technology using a robot and a table with an additional rotation for LMD technology. The most characteristic feature of their system is that it focuses on an exhaustive monitoring of the process, with up to three cameras in the head, as can be seen in the figure below[204]. In addition, the latest version of the system

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[198] Zengxi Pan et al., «Arc Welding Processes for Additive Manufacturing: A Review», in *Transactions on Intelligent Welding Manufacturing*, éd. par Shanben Chen, Yuming Zhang, et Zhili Feng, Transactions on Intelligent Welding Manufacturing (Singapore: Springer, 2018), 3-24, https://doi.org/10.1007/978-981-10-5355-9_1.

[199] Y. M. Zhang, H. S. Song, et G. Saeed, «Observation of a Dynamic Specular Weld Pool Surface», *Measurement Science and Technology* 17, nº 6 (mai 2006): L9, https://doi.org/10.1088/0957-0233/17/6/L02.

[200] Jun Xiong et al., «Vision-Sensing and Bead Width Control of a Single-Bead Multi-Layer Part: Material and Energy Savings in GMAW-Based Rapid Manufacturing», *Journal of Cleaner Production* 41 (1 février 2013): 82-88, https://doi.org/10.1016/j.jclepro.2012.10.009.

[201] Almir Heralić, Anna-Karin Christiansson, et Bengt Lennartson, «Height Control of Laser Metal-Wire Deposition Based on Iterative Learning Control and 3D Scanning», *Optics and Lasers in Engineering* 50, nº 9 (1 septembre 2012): 1230-41, https://doi.org/10.1016/j.optlaseng.2012.03.016.

[202] T. Artaza et al., «Design and Integration of WAAM Technology and in Situ Monitoring System in a Gantry Machine», *Procedia Manufacturing*, Manufacturing Engineering Society International Conference 2017, MESIC 2017, 28-30 June 2017, Vigo (Pontevedra), Spain, 13 (1 janvier 2017): 778-85, https://doi.org/10.1016/j.promfg.2017.09.184.

[203] Artaza et al.

[204] Almir Heralic, «Monitoring and Control of Robotized Laser Metal-Wire Deposition», 2012, 82, https://www.semanticscholar.org/paper/Monitoring-and-Control-of-Robotized-Laser-Heralic/76527b9a6ea6a1c8256e1b23884d991de56759e0.

incorporates a laser scanner mounted on a protective housing. In the latest version of the system, a laser scanner mounted on a protective housing has been incorporated.

3.6.3 Conclusion

A global deployment of 5G technology, eliminates the need for distributed edge computing, enabling lower costs for data mining and management on servers in the cloud. 5G enables better communication and supports the maturity levels in digital transitions of companies.

3.7 TECHNOLOGY TRENDS IN ROBOTICS

The field of robotics will have a large influence on future trends in advanced manufacturing. In these different areas we are observing different trends

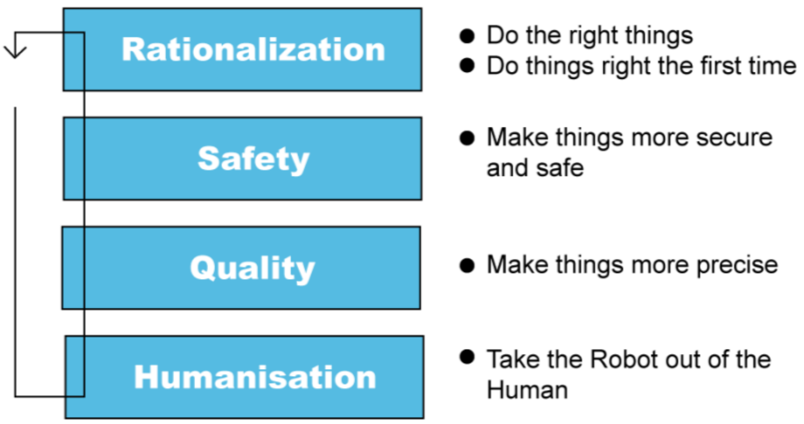

Figure 42: Trends of robotics

The future trends in robotics differ depending on the different fields of use:

- Industrial Robots
  - Serial Robots, Parallel Robots, Mobile industrial Robots, Cobots
- Service & Entertainment Robots
  - Programmable systems,
  - Autonomous Systems
- Entertainment Robots
  - Toys, Humanoid Robots, Marketing Robots, Art Robots, …

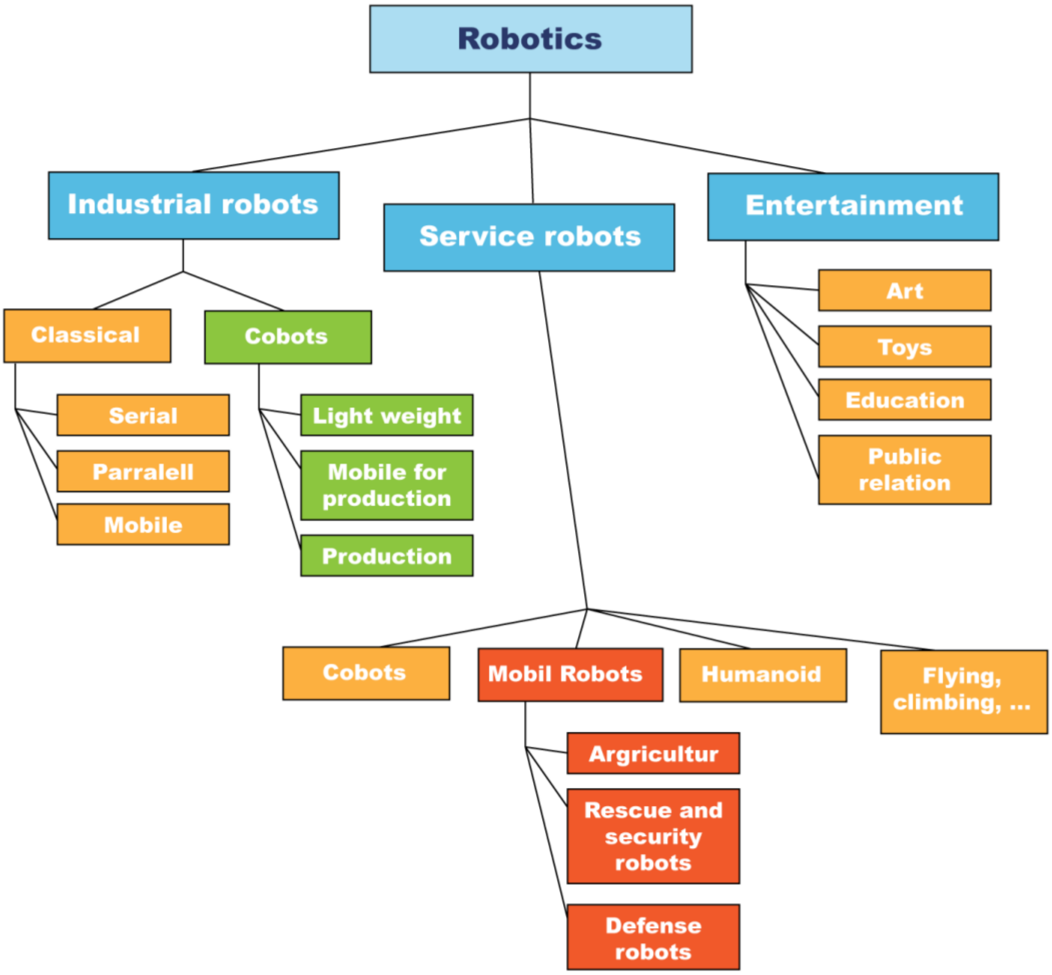

Figure 43: Areas and Trends of robotics

3.7.1 Introduction

Robotics is becoming increasingly relevant for vocational education and training (VET) because of the growing demand for workers with skills in this field. As automation and artificial intelligence continue to transform many industries, there is a need for workers who can design, program, operate, and maintain robots and other automated systems.

Moreover, the use of robotics is becoming more prevalent in various industries, such as manufacturing, healthcare, agriculture, and logistics. These industries need skilled workers who can integrate robotics technology into their work processes and optimize their efficiency.

VET institutions can provide students with the necessary skills and knowledge to work with robots and automated systems. This can include programming, troubleshooting, and maintenance of these systems. Robotics training can also help students develop important skills such as problem-solving, critical thinking, and teamwork, which are essential in many workplaces.

The relevance of robotics in VET is driven by the need for skilled workers in industries that are increasingly using automation and robotics technology. Robotics training can provide students with the skills and knowledge they need to succeed in these fields and help them develop important transferrable skills.

Robotic technology is highly relevant for vocational education and training (VET) for several reasons:

- **Job opportunities:** Robotics is becoming an increasingly important field in the modern workforce, with more and more companies seeking individuals with expertise in robotics. VET programs that offer training in robotics provide students with the skills and knowledge needed to succeed in this growing field, making them more employable.
- **Industry demand:** Many industries, such as manufacturing, logistics, and healthcare, are starting to adopt robotics to automate tasks, improve efficiency, and reduce costs. By teaching students about robotics, VET programs can help meet the industry demand for skilled workers in this area.
- **Hands-on learning:** Robotics offers a highly interactive and hands-on learning experience, which can be engaging and motivating for students. This type of learning allows students to apply theoretical concepts in a practical setting, which can help deepen their understanding and develop their problem-solving skills.
- **Future-proofing skills:** As robotics becomes more prevalent in various industries, it is important for VET programs to incorporate this technology into their curricula. By doing so, VET programs can help future-proof students' skills, ensuring that they are equipped with the knowledge and competencies needed to succeed in a rapidly changing job market.

Overall, robotics is highly relevant for VET because it offers students the opportunity to gain valuable skills and knowledge that can increase their employability and future-proof their career prospects.

Robotics is a multidisciplinary field that covers a wide range of applications and industries. Here are some of the main fields that robotics covers:

F1 - Trends: This field focuses on the latest trends and innovations in robotics, including new technologies, emerging applications, and market trends. It involves tracking and analysing developments in the robotics industry and predicting future directions and opportunities.

F2 - Impact on jobs: This field focuses on the impact that robotics is having on the workforce, including changes to job roles, job displacement, and new job opportunities. It involves analysing the effects of automation and robotics on different industries and occupations and identifying strategies for managing these impacts.

F3 - Skills & qualifications: This field focuses on the skills and qualifications that are required for careers in robotics, and the education and training pathways that can prepare individuals for these careers. It involves identifying the core competencies needed for robotics-related jobs, and developing training programs that can provide students with these skills.

F4 - Future skills: This field focuses on the future skills that will be required as robotics continues to evolve and advance. It involves predicting the skills and knowledge that will be needed for future robotics-related jobs and identifying ways to develop these skills through education and training programs.

Other fields that involve robotics include:

- **Industrial automation:** This field focuses on the use of robotics in manufacturing and industrial processes, including applications such as material handling, assembly, and quality control.
- **Service robotics:** This field focuses on the use of robotics in service industries, such as healthcare, hospitality, and retail, where robots are used to perform tasks such as cleaning, food service, and customer assistance.
- **Human-robot interaction:** This field focuses on the design and development of robots that can interact with humans in natural and intuitive ways, including applications such as social robots, educational robots, and assistive robots.
- **Robotics engineering:** This field focuses on the design, development, and testing of robotic systems, including aspects such as robotics mechanics, control systems, and sensors.
- **Robotics ethics:** This field focuses on the ethical and social implications of robotics, including issues such as privacy, safety, and the impact of robotics on human society.

3.7.2 Contextualisation

Contextualization for **robotics could be described by these examples:**

Example 1: Competences and skills associated with robot integration in digitalized industries. Transformed jobs and emerging skills.

Example 2: Integration of collaborative robotics in VET labs. Approaches for education of robotics in VET centres (EQF 3-6) use cases.

Example 3: Reference centres of robotic education the VET system in Spain.

Example 4: Job transformations due to the integration of robotic systems (robots, cobots…) in SMEs in the automotive sector in Spain. Qualitative and quantitative analysis.

Example 5: Technology trends in robotics.

The topic in all those examples is robotics but the contents will differ significantly.

3.7.3 Objectives / Research Question / Problem Statement

Objectives: The objectives of this work are to understand the robotics sector's, its trends, and the changes that can be expected in that sector evolution.

Research question: What are the big trends within robotics?

Problem statement: "The robotic revolution will create 97 million new jobs, but communities most at risk of disruption will need the support of businesses and governments, as they become more vulnerable to being replaced over the next five years"[205].

That is why so many lower tasks are left to automation: machines can do everything that can be done predictably and repeatedly today, and it makes less sense to use human labour on this type of tasks. Currently about 1.5 million tasks no longer depend on human labour, but that number is expected to rise as technology improves[206].

New jobs will replace old ones. The robotic revolution is here, and it is creating a new industrial revolution, but one, in which humans will still play the most important role. We look forward to a

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[205] Claude Calleja, «Robots Taking Jobs, But Creating Careers | Digital Skills and Jobs Platform», Digital skills & jobs platforem, 2 août 2021, https://digital-skills-jobs.europa.eu/en/community/online-discussions/robots-taking-jobs-creating-careers.

[206] tagesschau.de, «Baden-Württemberg: Würth-Gruppe: Gedämpfter Optimismus für 2023», tagesschau.de, s. d., https://www.tagesschau.de/inland/regional/badenwuerttemberg/swr-wuerth-gruppe-100.html.

future where robots will drive job growth and create exciting jobs that we cannot even imagine today. The Skills Malta Foundation[207] welcomes this change, predicting it will make lives easier and will create new jobs. [208] [209]

3.7.4 Findings

3.7.4.1 Industrial Robots

Industrial robots are universally usable moving machines with more than 3 axes, whose movements are freely programmable and sometimes sensor guided. Industrial robots can be equipped with grippers, tools or other means of production and can carry out handling and/or production tasks in an industrial environment. the market for industrial robots is largely saturated. The new installations of robots in Europe are about the number of decommissioned robots.[210]

Industrial robotics will gain a high degree of standardization. To reduce the number of spare parts and to simplify the supply chain, robot producers will try to find a modular system to realize different robots with the same components. Especially gears drives and the controller cabinet will become common for large number of robots. Another trend is to simplify the operation of robots and make it very easy for robots to be operated by less qualified personnel. The average workers should be able to operate an industrial robot. [211] [212] [213] [214]

[207]«E-Skills Malta Foundation | Digital Skills and Jobs Platform», s. d., https://digital-skills-jobs.europa.eu/en/organisations/e-skills-malta-foundation.

[208]«Robots Taking Jobs, But Creating Careers | Digital Skills and Jobs Platform», s. d., https://digital-skills-jobs.europa.eu/en/community/online-discussions/robots-taking-jobs-creating-careers.

[209]Amrita Pathak, «Robots, IoT, and Artificial Intelligence Are Leading Digital Transformation», Geekflare, 27 avril 2022, https://geekflare.com/digital-transformation-ai-robots-iot/.

[210]https://ifr.org/industrial-robots

[211]IFR International Federation of Robotics, «Top 5 Robot Trends 2023», IFR International Federation of Robotics, s. d., https://ifr.org/ifr-press-releases/news/top-5-robot-trends-2023.

[212] Contributing Authors, «Six Emerging Trends in the World of Industrial Robotics», s. d., https://blog.isa.org/trends-industrial-robotics-collaboration-machines-humans.

[213]«Robotics Trends - Fraunhofer IPA», Fraunhofer Institute for Manufacturing Engineering and Automation IPA, s. d., https://www.ipa.fraunhofer.de/en/about-us/guiding-themes/robot-technologies-and-services/robotics-trends.html.

[214]«Automation and Robotics Trends in 2023», Visual Components, 23 février 2023, https://www.visualcomponents.com/resources/blog/automation-and-robotics-trends-in-2023/.

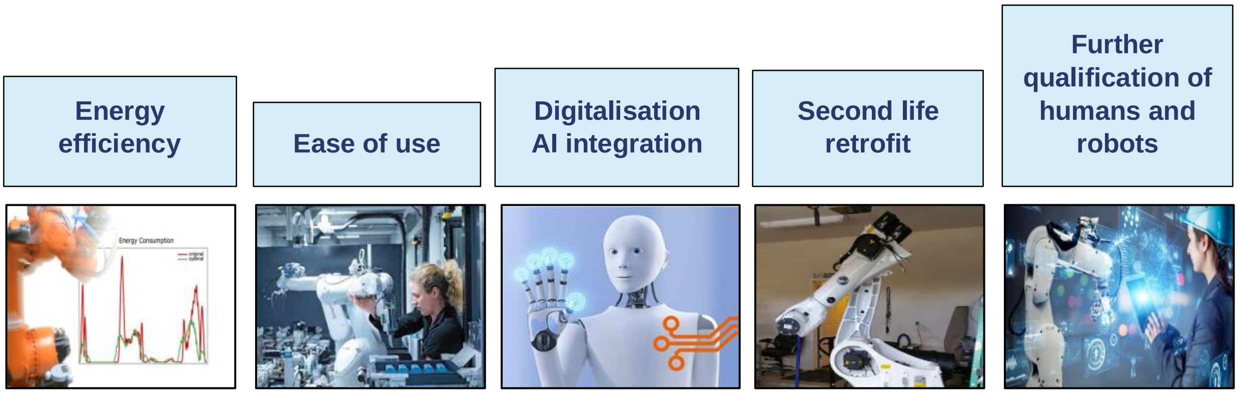

Figure 44: Mains trends in industrial Robotics

Very high level of security

The socially accepted risk is increasingly being reduced. The automation industry is particularly sensitive to this trend. According to Performance Level, we always try to be higher in the pure performance phase. For the safety risk of an industrial robot, this means that a single error must not lead to the loss of the safety function. And in the case of redundant execution, a single error must be detected.

High mechanical precision

Especially in the case of industrial robots, there is a trend towards higher precision. Due to the development in the gear sector and the improved design of the mechanical structure with optimized heat transfer, industrial robots are becoming more and more precise. The repeatability is more than sufficient for modern robot applications. Absolute accuracy is becoming increasingly important as more and more applications rely on an offline process chain. The integration into real processes with different environmental conditions also forces increased absolute accuracy.

Energy efficiency

A trend is to reduce their energy consumption and energy efficiency. This will be reached by raising the efficiency of the Drive systems including the gears. By optimizing the control cabinet and by reducing the non-value-adding energy consumption especially in the standby mode.

Resilience

The robot should have properties that allow it to realize emergency operations despite malfunctions and move with reduced speed or accuracy. Or at least to realize a movement in a service position so that other robots can take over its service.

Trend towards smaller robots

While a few years ago larger and larger robots were introduced, the trend is more towards smaller units. This is supported by other trends such as the trend towards greater flexibility and safety, as well as by the trend towards energy efficiency. The robots have also become more efficient in the use of materials. The weight of the robots used has been reduced by more than 70%.

3.7.4.2 Collaborative Robotics

Cobot describes robots designed for direct interaction/collaboration with humans. If humans and robots share a workspace without a separating protective device, this is also referred to as human-robot collaboration.

Low-cost system

The market for low-cost systems is very weak. If companies offer their robots in the low-cost area, they usually lack the financing for interesting further developments and integration into an environment. Especially the customer for low-cost robots is only conditionally willing to pay for technology packages and robot-related services.

High flexibility[215] [216]

Cobots will not replace standard industrial Robots. They will find new areas of production to spread across. Areas such as care, hospital, department stores or gastronomy will be future fields of application. In the industrial environment, fields such as setting up machine tools, quality control or maintenance and inspection are occupied by service robots.

Cobots are developed with higher loads. In the last years many robots with a maximum load below 10kg were established. New cobots will have a payload of 35kg and more. This could be reached though smarter sensor systems and load compensation. Protective cases with capacitive and tactile sensors enables also classical industrial robots.

Collaborative robots are placed on a mobile platform to be able to be used flexibly at different work locations. Technological integration and adaptation to weakly structured environments have so far been the main obstacles.

Intelligent automation[217] [218]

A new level in the cooperation between man and machine will be enabled through intelligent automation. Smart automation is changing the business processes in companies fundamentally though AI and analytics.

Goals of intelligent Automation are:

- reduced lead time,
- mass customized products,
- increased transparency and thus creating trust,
- increased efficiency.

[215]Calleja, «Robots Taking Jobs, But Creating Careers | Digital Skills and Jobs Platform».

[216]Schlütersche Fachmedien GmbH, «Cobots: Das sind die drei Trends auf dem Markt», Text (Schlütersche Fachmedien GmbH, 7 juin 2022), https://www.k-zeitung.de/cobots-das-sind-die-drei-trends-auf-dem-markt.

[217] Manfred Bremmer, «Bereit für den nächsten Level?», 2023, 14.

[218] «Intelligent Automation by Alchemmy», *Alchemmy* (blog), 2022, https://alchemmy.com/intelligent-automation/.

3.7.4.3 Service Robots

Service robotics[219] is an area of robotics that focuses on the use of robots in service industries. Service robots are specially designed robots for services to Humans.

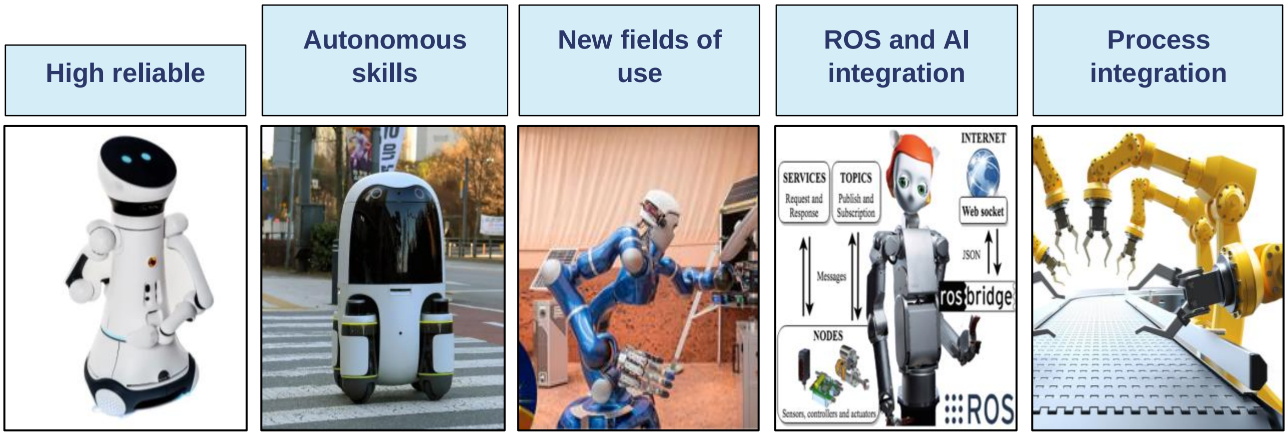

Figure 45: Main trends in Service Robotics

Service robots in new domains: These types of robots can perform tasks that are normally performed by humans, such as customer service, cleaning, transportation, monitoring, and assisting with physical labour. They can be used in warehouses, healthcare, gastronomy, indoor logistics etc. Such robots are built in Turkey's robot factory[220], which is building Humanoid Robots to be used in households.

To build up a mobile service robot, usually a common platform is used like the differential drive from the Turtle Robot[221]. On the LCAMP Platform the Open Innovation Community will provide information on a standardized mobile robot using the most important Technologies like ROS.

[219] «Service Robotics Market Size, Share & Growth Drivers [2029]», Fortune business insights, s. d., https://www.fortunebusinessinsights.com/industry-reports/service-robotics-market-101805.

[220] *Turkey's robot factory*, 2018, https://www.youtube.com/watch?v=vScv-tt05Ng.

[221] «TurtleBot», s. d., https://www.turtlebot.com/.

Standardized control systems using ROS [222] [223] [224]

Standardized control systems using ROS (Robot Operating System) are pre-designed and pre-built software components that provide a foundation for building different types of robots. ROS is an open-source software framework that provides a set of tools and libraries for building robot applications. ROS provides a standardized way of developing software components for robots, allowing for easier integration of different hardware and software components.

Healthcare robotics[225]

There is a growing trend towards using robots in healthcare to assist with tasks such as patient care, medication management, and telemedicine. This includes robots that can help with physical therapy, provide companionship to elderly patients, and even perform surgery.

Hospitality robotics: In the hospitality industry, robots are being used for tasks such as cleaning, room service, and concierge services. For example, hotels are starting to use robots to deliver towels, pillows, and other items to guests' rooms.

Retail robotics: In retail, robots are being used for tasks such as inventory management, customer service, and product delivery. For example, some stores are starting to use robots to help customers find products, while others are using robots to deliver online orders to customers' homes.

Personal service robotics: There is also a growing trend towards using robots for personal services, such as cleaning, cooking, and lawn care. This includes robots such as vacuum cleaners, robotic lawnmowers, and robotic chefs.

The trends in service robotics are focused on providing more personalized and collaborative services to individuals, using advanced technologies such as artificial intelligence and cloud computing to improve performance and efficiency. As service robotics continues to evolve, we can expect to see even more innovative and transformative applications in a wide range of industries

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[222]«Robot Operating System Market Size & Share Analysis - Industry Research Report - Growth Trends», s. d., https://www.mordorintelligence.com/industry-reports/robot-operating-system-market.

[223]Contrive Datum Insights Pvt Ltd, «Robot Operating System (ROS) Market Is Expected To Reach around USD 0.7 Billion by 2030, Grow at a CAGR Of 9.2% during Forecast Period 2023 To 2030 | Data By Contrive Datum Insights Pvt Ltd.», GlobeNewswire News Room, 3 septembre 2023, https://www.globenewswire.com/news-release/2023/03/09/2624510/0/en/Robot-Operating-System-ROS-Market-Is-Expected-To-Reach-around-USD-0-7-Billion-by-2030-Grow-at-a-CAGR-Of-9-2-during-Forecast-Period-2023-To-2030-Data-By-Contrive-Datum-Insights-Pvt-.html.

[224]«Robot Operating System Market – Global Industry Trends and Forecast to 2029 | Data Bridge Market Research», s. d., https://www.databridgemarketresearch.com/reports/global-robot-operating-system-market.

[225]Karim Youssef et al., «A Survey on Recent Advances in Social Robotics», *Robotics* 11, nº 4 (août 2022): 75, https://doi.org/10.3390/robotics11040075.

and settings. These trends are driving innovation and growth in the field of service robotics and are helping to create new opportunities for robots to assist and augment human workers in a wide range of service industries.

Social Robots are robots designed to operate and interact with humans, in contexts like human–human interaction contexts. These are based on communication and empathetic interactions. They are not focused on services.

A strict division of robots into individual categories is not possible. Individual robots can be used in several areas. The transition from entertainment robot to service robot is fuzzy. Depending on the application, whether commercial or not, the classification can look different. Typical toy robots are more and more placed as educational robots.

The time when a robot was perceived as an attraction at a trade fair is over. Rather, these robots with additional abilities move into restaurants or care homes.[226]

3.7.4.4 Entertainment Robots

Entertainment robots are more serious than they sound. Starting from simple toys to high sophisticated robot demonstration platforms, everything is included. In this context, toy robots used for education are of special interest[227].

Educational robots are used in various environments to teach science, technology, engineering, and math (STEM) subjects in schools or to bring gamification into the curriculum: gamification is being used to make educational robots more engaging and entertaining for students.

Interactive exhibit robots are robots that are used in museums, galleries, and other public spaces to provide interactive exhibits that engage and educate visitors.

Performance robots are robots that are designed to perform on stage or in other public spaces, often with human-like movements and expressions, providing entertainment for audiences.

Research robots that are not mature enough for real processes deserve special mention here. They are mainly humanoid or other walking robots with the research focus on control or Human Robot interaction. The classical wheel-based robots are the focus of research on autonomous navigation.

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[226] Jürgen Klauber et al., éd., *Krankenhaus-Report 2023: Schwerpunkt: Personal* (Berlin, Heidelberg: Springer, 2023), https://doi.org/10.1007/978-3-662-66881-8.

[227] IBERDROLA CORPORATIVA, «Como Os Robôs Educativos Ajudam No Desenvolvimento de Seus Filhos?», Iberdrola, s. d., https://www.iberdrola.com/innovation/educational-robots.

3.7.4.5 Qualification for Robot Engineers

There is not one way to be a robot engineer. The qualification is divided in several specialists within robotics.

Robot teachers

These are people working with the robot. Workers get closer to the robot, and they get involved in the robot programming.

The need skills in the robot programming languages like KAREL or KRC. Industrial robot teachers must be knowledgeable about safety protocols and regulations and be able to train students and trainees on safe practices when working with robots.

Service technicians

A robot service engineer is responsible for installing, maintaining, and repairing robots and robotic systems. People who work in Maintenance and Service are responsible for System Down time. A robot service engineer must have a good understanding of robotics technology and its applications. They should be able to read and interpret technical documentation and understand software and hardware components of robotic systems. A robot service engineer should have excellent problem-solving skills to identify issues with robots and robotic systems and develop solutions to fix them. Communication Skills: A robot service engineer should be able to communicate effectively with customers, team members, and other stakeholders. They should be able to explain technical concepts in simple terms and provide clear instructions.

Their tasks include Preventive and Predictive maintenance of Robots with their highly optimized components, as well as replacement of complete robots or robot controllers in a very short time.

Process owners

Process owners try to integrate the robot very early in their Process planning. A robot process owner should be able to identify and map out processes in an organization and design workflows. A robot process owner needs analytic skills and should be able to analyse data and make decisions based on that analysis. They should also be able to identify problems and develop solutions.

They should have the ability to use Process enhancements for Off-Line Programming environment like FastSuite[228].

Robot developers

They should have the ability to develop intelligent components like gripping in a weakly structured environment. They need programming skills for embedded real time systems. Robot developers need to have a solid background in electrical and mechanical engineering to understand how to design and build robots that are reliable and efficient. Robot developers often work as part of a team, so they need to have strong collaboration and communication skills to work effectively with others. They need to be able to manage agile projects.

3.7.4.6 New Ways to Operate

Standardized control systems using ROS

Standardized control systems using ROS (Robot Operating System) are pre-designed and pre-built software components that provide a foundation for building different types of robots. ROS is an open-source software framework that provides a set of tools and libraries for building robot applications. ROS provides a standardized way of developing software components for robots, allowing for easier integration of different hardware and software components.

Cloud based collaboration[229]

Cloud-based collaboration tools are increasingly being integrated with other collaboration tools, such as project management tools, video conferencing tools, and messaging tools. This integration makes it easier for teams to collaborate seamlessly across different tools and platforms. Cloud-based collaboration tools are increasingly offering features like real-time editing and co-authoring to support this trend. With cloud-based services the robots could use a common database. Already learned skills could be shared by all connected robots.

[228]«FASTSUITE Edition 2: Der digitale Fabrik Zwilling», s. d., https://www.fastsuite.com/de/software/software-portfolio/fastsuite-edition-2.

[229]*Service-Roboter Bella sorgt für Begeisterung in Gersthofen*, 2022, https://www.augsburg.tv/mediathek/video/service-roboter-bella-sorgt-fuer-begeisterung-in-gersthofen/.

3.7.5 Conclusions

Main Trends in Industrial Robotics are:

Trend 1: **Standardization and higher reliability of industrial robotics** to reduce the number of spare parts and to simplify the supply chain to produce robots with modular systems.

Trend 2: **Energy efficiency** to reduce their energy consumption and to increase energy efficiency: for example, efficiency of the Drive systems including the gears, and by optimizing the control cabinet and reducing non-value-adding energy consumption especially in the standby mode.

Trend 3: **Smaller robots** towards greater flexibility and safety, which are more efficient in the use of materials. The weight of the robots will continue to decrease.

Trend 4: **More autonomous and easier to use robots**, to simplify the operation of robots and to make it very easy for robots to be operated by less qualified personnel. The average worker should be able to operate industrial Robots.

Trend 5: **Integration of digitalisation and AI** in robots 'operations.

Trend 6: **Second life retrofit of robots**.

Trend 7: **Training humans to operate robots**, to integrate all evolutions seen in other trends, at all levels, including engineers, technicians, developers.

Trend 8: **Collaborative Robots = Cobots: easily to serve, high in flexibility**, through intelligent automation **and low-cost system**. With the aim that machine tools, quality control or maintenance and inspection can be delegated to service robots (to see complements on TOPIC Assisted Jobs TOPICS 2.1.3).

Trend 9: **ROS, AI and other process integrations**

For the time being, human-robot cohabitation remains in the realm of science fiction, but the robot revolution is just beginning. From Asimov's novels to all around us: Let's welcome the robot revolution[230].

[230]Cordis, «From Asimov to All around Us: Welcome to the Robot Revolution | Research*eu Magazine | Issue 80 | CORDIS | European Commission», Cordis, mars 2019, https://cordis.europa.eu/article/id/401287-from-asimov-to-all-around-us-welcome-to-the-robot-revolution.

In novels ("I, Robot" by Isaac Asimov) or science fiction films ("Bladerunner" by Ridley Scott), androids, sometimes impossible to identify except by superior strength, speed and agility, act like humans.

What would be the consequences for society if industrial and service automation were to continue and completely replace humans? Would we have to redefine what it means to be human if we were able to make beings like the replicants in "Bladerunner"? Fascinating as it is to ponder these philosophical conundrums, robotics research has not yet reached the point where we will have to tackle this subject any time soon.

But the projects that have been completed, or are currently being studied and developed, are pushing us in this direction. Robots already perform repetitive or menial tasks, they replace humans in dangerous tasks (difficult, toxic environments, etc.) or those requiring precision (surgical procedures performed by a robot under the supervision of a surgeon, sometimes remotely). Tomorrow, we expect to see the presence of Cobots in the field of services and personal assistance to increase.

While Japan and South Korea have been pioneers, the EU is taking an active part worldwide, providing 32% of the supply and use in industrial robotics and about 63% in service robotics thanks to its expertise in interdisciplinary research on "intelligent robots".

The European Horizon 2020 project has a strong focus on robotics research, and the European partnership, SPARC, dedicated to robotics, is furthering the EU's effort in all sectors of society, science, and economy. Between 2014 and 2020 SPARC was the largest civilian-funded robotics innovation programme in the world with €700 million in funding.

Every year SPARC organises its annual European Robotics Forum where innovations in research, development and adoption of robotics in Europe are presented in 4 major areas:

- **Industrial robotics:** focused on the development of robots to perform repetitive and hazardous tasks in manufacturing environments. Research areas include robot flexibility, safety, computer vision and machine learning.
- **Service robotics:** aiming to develop robots capable of providing useful services to people, such as assistance to the elderly or disabled, environmental monitoring and infrastructure maintenance. Research areas include human-robot interaction, mobility, autonomous navigation, and sensory perception.

- **Medical robotics:** develops robots capable of assisting health professionals in medical tasks, such as surgery, rehabilitation, and patient monitoring. Research areas include precision, safety, adaptability, and communication with healthcare professionals.
- **Agricultural robotics:** adapting robots for agriculture, such as crop harvesting, crop condition monitoring and crop processing. Research areas include autonomous navigation, sensory perception and collaboration between robots.

These four research areas are considered priorities for SPARC and are intended to help Europe become a world leader in robotics.

3.8 MOBILE ROBOTS BASED ON ROS TECHNOLOGY

3.8.1 Main Used Source(s)

Identification	Description	Geographical scope	Sectorial scope	Links
ROS-Industrial Consortium Europe	The ROS-Industrial Consortium Europe is a consortium of industry, research, and academic institutions that promotes the use of ROS in industrial applications. They provide training and support for companies interested in developing ROS-based mobile robots for industrial use.	Europe	Manufacturing and industrial applications	**LINK**
ROS Robotics Companies	ROS Robotics Companies provides a list of companies that use ROS in their products and services.	Global	Various	**LINK**
ROS-Industrial for Real-World Solutions	ROS-Industrial for Real-World Solutions is a program that aims to promote the use of ROS in real-world industrial applications. It provides support for companies interested in using ROS for industrial automation, including software development, training, and consulting.	Global	Industrial automation	**LINK**
ROS (Robot Operating System)	ROS is an open-source software framework for developing robotics applications. It provides a comprehensive set of tools and libraries for developing mobile robots, including navigation, mapping, and localization algorithms.	Global	Various	**LINK**
EU project: OFERA - micro-ROS	The EU project OFERA (Open Framework for Embedded Robotics Applications) is a project that aims to develop a new generation of embedded robotic systems that are modular, adaptable, and scalable. One of the project's goals is to develop a micro-ROS platform for embedded systems.	Europe	Robotics and automation	**LINK**
"ROS-Based Unmanned Mobile Robot Platform for Agriculture"	The paper presents a mobile robot platform based on ROS for agricultural applications. The platform is designed to perform tasks such as crop monitoring, harvesting, and spraying, and it has the	Global	Agriculture	**LINK**

	potential to improve crop yields and reduce the use of pesticides, fertilizers, and water.			
"Substantial capabilities of robotics in enhancing industry"	The paper reviews the capabilities of robotics in enhancing industry, including mobile robots based on ROS technology. The paper highlights the potential of mobile robots based on ROS technology to improve efficiency, productivity, and safety in various industries.	Global	Industrial automation	**LINK**
"Towards next generation digital twin in robotics: Trends"	The paper presents the latest trends in digital twin technologies for robotics, including mobile robots based on ROS technology. The paper highlights the potential of digital twins to improve the performance and reliability of mobile robots based on ROS technology.	Global	Robotics and automation	**LINK**
"A review of mobile robots: Concepts, methods, theoretical"	The paper provides a comprehensive review of mobile robots, including mobile robots based on ROS technology. The paper covers the concepts, methods, theoretical approaches, and future directions of mobile robots.	Global	Mobile robotics	**LINK**
Statista	A market research firm that provides data on the size and growth of the autonomous robot market in Europe.	Europe	Autonomous robots	**LINK**
Research and Markets	A market research firm that provides a report on the autonomous mobile robot market in Europe, including trends, drivers, and challenges.	Europe	Autonomous mobile robots	**LINK**
ROS Wiki	An online resource that provides documentation, tutorials, and courses on ROS.	Global	Robotics and automation education	**LINK**
The European Commission's Digital Skills and Jobs Platform	An online platform that offers a free introductory course on ROS for beginners.	Europe	Robotics and automation education	**LINK**
NobleProg	ROS Training Courses in Germany.	Germany	Robotics and automation education	**LINK**

3.8.1.1 Context and Limitations

The sources used in this report provide a reliable and up-to-date overview of the latest trends and developments in mobile robots based on ROS technology. However, the sources have varying degrees of focus on mobile robots based on ROS technology and may not provide the same level of detail. Moreover, there are also potential limitations and challenges that need to be considered, such as ethical and legal issues, safety and security concerns, and the potential impact on employment and social welfare. It is important for researchers, policymakers, and industry representatives to continue to explore these issues and work towards developing mobile robots based on ROS technology that is safe, reliable, and beneficial for society.

3.8.1.2 Why is it Relevant?

Mobile robots based on ROS technology have become increasingly important in many different industries due to their numerous advantages. For example, they can significantly improve efficiency, reduce costs, and enhance safety. Understanding the latest trends and developments in mobile robots based on ROS technology is crucial for researchers, policymakers, and industry representatives.

3.8.2 Main Data

The main data used in this report are as follows:

- Overview of ROS-based mobile robots' development
- Trends in ROS-based mobile robotics development
- Examples of applications of ROS-based mobile robots

Context and presentation

The main data presented in this report provide an overview of the latest trends and developments in mobile robots based on ROS technology, as well as their applications in different industries. The data is presented in a clear and concise manner, using tables and figures where appropriate to enhance the presentation.

3.8.2.1 Context and Presentation

The main data presented in this report provide an overview of the latest trends and developments in mobile robots based on ROS technology, as well as their applications in different industries. The data is presented in a clear and concise manner, using tables and figures where appropriate to enhance the presentation.

3.8.2.2 Summary and Synthesis

The data presented in this report highlight the importance of mobile robots based on ROS technology as a powerful and flexible platform for developing autonomous vehicles. Recent trends and developments in ROS-based mobile robotics have focused on improving their performance and reliability using techniques such as digital twins and deep learning. Mobile robots based on ROS technology have many different applications, ranging from inspection and surveillance to transportation and maintenance, and they have the potential to revolutionize these industries by improving efficiency, productivity, and safety. However, there are also potential limitations and challenges that need to be considered, such as ethical and legal issues, safety and security concerns, and the potential impact on employment and social welfare. It is important for researchers, policymakers, and industry representatives to continue to explore these issues and work towards developing mobile robots based on ROS technology that is safe, reliable, and beneficial for society.

3.8.3 Data Analysis

The data analysis presented in this report aims to provide a comprehensive overview of the latest trends and developments in mobile robots based on ROS technology.

3.8.3.1 Introduction

Mobile robots based on the Robot Operating System (ROS) technology have become increasingly popular and are now the preferred platform for developing autonomous vehicles. ROS provides a comprehensive set of tools and libraries for developing mobile robots, including navigation, mapping, and localization algorithms.

With the increasing demand for automation in various industries, mobile robots based on ROS technology have become increasingly important, as they can perform a wide range of tasks autonomously, such as inspection, surveillance, transportation, and maintenance. They have the potential to revolutionize these industries by improving efficiency, productivity, and safety.

The objective of this report is to provide a comprehensive overview of the latest trends and developments in mobile robots based on ROS technology as well as explore the trends, challenges, and opportunities of mobile robots based on ROS technology in advanced manufacturing. We will also identify the skills and competencies required for VETs and learners to integrate these robots into their operations.

3.8.3.2 Contextualisation

Mobile robots based on ROS technology are becoming increasingly important in many different industries, as they can perform a wide range of tasks autonomously, such as AM, inspection, surveillance, transportation, and maintenance. ROS provides a comprehensive set of tools and libraries for developing mobile robots, including navigation, mapping, and localization algorithms. In advanced manufacturing, these robots are used to perform tasks that are dangerous, repetitive, or require precision. The integration of mobile robots based on ROS technology in advanced manufacturing can lead to significant improvements in efficiency, productivity, and safety.

The development of mobile robots based on ROS technology in advanced manufacturing covers various fields, including F1: Trends, F2: Impact on Jobs, F3: Skills & Qualifications, and F4: Future Skills. The geographical scope of this report will focus mainly on European countries.

3.8.3.3 Objectives / Research Question / Problem Statement

Objectives: The objectives of this sub-report are:

- To understand the current and future trends of mobile robots based on ROS technology in advanced manufacturing. We will also identify the challenges and opportunities that these robots present to VETs, learners, and companies.
- To highlight the applications of mobile robots based on ROS technology.
- To analyse the potential benefits and limitations of mobile robots based on ROS technology.

Research question: What are the trends, challenges, and opportunities of mobile robots based on ROS technology in advanced manufacturing, and what are the skills and competencies required for their integration?

Problem statement: Mobile robots based on ROS technology have the potential to revolutionize the manufacturing industry, but there are challenges and opportunities associated with using this technology. This report aims to analyse the current state of ROS technology in the manufacturing industry, identify the challenges and opportunities, and explore the future directions of ROS technology in the manufacturing industry.

3.8.3.4 Findings

Mobile robots based on ROS (Robot Operating System) technology are transforming the field of advanced manufacturing. Integrating mobile robots based on ROS technology into advanced manufacturing operations requires specific skills and competencies, such as programming, data analysis, and maintenance[231]. Vocational Education and Training (VET) and learners need to develop these skills and competencies to integrate and maintain these robots.

Companies that employ mobile robots must provide their employees with training and resources to ensure they have the necessary knowledge and skills to work with ROS-based robots[232].

Mobile robots based on ROS technology offer several advantages in advanced manufacturing, including increased efficiency, accuracy, and safety[233]. They can perform hazardous or strenuous tasks that are challenging or dangerous for humans, such as working in hazardous environments or carrying heavy loads, and can operate 24/7 without fatigue or errors, which improves productivity.[234] [235]

Advantages of Mobile robots based on ROS

Mobile robots based on ROS technology have been recognized for their positive impact on manufacturing. According to a report from the International Journal of Advanced Robotic Systems, ROS-based mobile robots have been shown to improve productivity, reduce errors, and increase safety in manufacturing operations (Saha, Chowdhury, and Mamun, 2019). They can perform tasks more quickly and accurately than humans, leading to increased efficiency in the

[231] Markus D. Kobelrausch et al., «Skill Acquisition for Resource-Constrained Mobile Robots through Continuous Exploration», in *Cognitive Robotics and Adaptive Behaviors* (IntechOpen, 2022), https://doi.org/10.5772/intechopen.104996.

[232] Alex Owen-Hill, «10 Essential Skills That All Good Roboticists Should Have», 2020, https://blog.robotiq.com/10-essential-skills-that-all-good-roboticists-have.

[233] Jeff Kerns, «3 Trends in Mobile Industrial Robotics», Machine Design, octobre 2019, https://www.machinedesign.com/automation-iiot/article/21838201/3-trends-in-mobile-industrial-robotics.

[234] «ROS-Industrial», ROS-Industrial, 10 mai 2023, https://rosindustrial.org.

[235] «Robots.Ros.Org», robots.ros.org, s. d., https://robots.ros.org/.

manufacturing process. These robots can be programmed to perform tasks with a high level of precision, reducing errors ad improving product quality. They can also work around the clock without fatigue or errors, increasing efficiency and productivity.

Mobile robots based on ROS technology offer several advantages in advanced manufacturing, including improved efficiency, accuracy, and safety (ros.org, 2021). They can be used to perform tasks that are dangerous or difficult for humans, such as working in hazardous environments or carrying heavy loads, reducing the risk of accidents or injuries. Furthermore, according to a study by the Robotics Industries Association, the use of mobile robots in manufacturing can lead to significant improvements in efficiency and cost savings (Robotics Industries Association, 2019).

In short, the use of mobile robots based on ROS technology in manufacturing has been shown to have a positive impact on productivity, safety, and cost savings. These robots can perform tasks more quickly and accurately than humans, reducing errors and improving product quality. They can also work around the clock without fatigue or errors, increasing efficiency and productivity.

Mobile robots based on ROS technology offer several advantages in advanced manufacturing, including improved efficiency, accuracy, and safety. These robots can perform tasks more quickly and accurately than humans, leading to increased efficiency in the manufacturing process.

They can be programmed to perform tasks with a high level of precision, reducing errors and improving product quality. Mobile robots based on ROS technology can be used to perform tasks that are dangerous or difficult for humans, such as working in hazardous environments or carrying heavy loads, reducing the risk of accidents or injuries.

Furthermore, these robots can work around the clock without fatigue or errors, increasing efficiency and productivity. [236] [237]

Challenges of Mobile robots based on ROS

The integration of mobile robots based on ROS technology into advanced manufacturing presents some challenges.

Companies must provide training and resources to ensure that their employees have the necessary knowledge and skills to work with mobile robots based on ROS technology[238]. The cost of implementing mobile robots based on ROS technology can be high, depending on the complexity of the manufacturing process and the number of robots required.

[236]«ROS-Industrial».

[237]«Robots.Ros.Org».

[238]Owen-Hill, «10 Essential Skills That All Good Roboticists Should Have».

Moreover, the integration of mobile robots based on ROS technology into advanced manufacturing could lead to job displacement, as some tasks previously performed by humans could be automated.

In addition, the lack of standardization in mobile robot development and deployment can lead to interoperability issues and hinder their adoption[239] [240] [241].

Opportunities of Mobile robots based on ROS

Mobile robots based on ROS technology offer several advantages in advanced manufacturing, including increased efficiency, accuracy, and safety[242].

ROS-Industrial is an open-source project that extends the advanced capabilities of ROS software to industrial-relevant hardware and applications[243]. The ROS-Industrial Consortium provides technical support and training to facilitate the continued adoption of ROS-Industrial by industry.

The integration of mobile robots based on ROS technology into advanced manufacturing operations requires specific skills and competencies, such as programming, data analysis, and maintenance[244]. Companies that employ mobile robots must provide their employees with training and resources to ensure they have the necessary knowledge and skills to work with ROS-based robots[245].

The development of mobile robots based on ROS technology is an active area of research, with new applications and capabilities being developed[246]. The open-source nature of ROS technology allows for collaboration and innovation among developers and researchers, leading to the development of new applications and capabilities for mobile robots[247] [248] [249].

[239]Murat Koseoglu, Orkan Murat Celik, et Omer Pektas, «Design of an autonomous mobile robot based on ROS», *2017 International Artificial Intelligence and Data Processing Symposium (IDAP)*, septembre 2017, 1-5, https://doi.org/10.1109/IDAP.2017.8090199.

[240]«ROS-Industrial».

[241]«Robots.Ros.Org».

[242]Kerns, «3 Trends in Mobile Industrial Robotics».

[243]«ROS-Industrial».

[244]Kobelrausch et al., «Skill Acquisition for Resource-Constrained Mobile Robots through Continuous Exploration».

[245] Owen-Hill, «10 Essential Skills That All Good Roboticists Should Have».

[246]Luo et al., «Modular ROS Based Autonomous Mobile Industrial Robot System for Automated Intelligent Manufacturing Applications».

[247]«ROS-Industrial».

[248]«Robots.Ros.Org».

[249]Luo et al., «Modular ROS Based Autonomous Mobile Industrial Robot System for Automated Intelligent Manufacturing Applications».

Skills and competencies required

The integration of mobile robots based on ROS technology into advanced manufacturing requires a combination of skills and competencies.

ROS-Industrial is an open-source project that extends the advanced capabilities of ROS to manufacturing automation, providing a solid foundation for the integration of mobile robots in advanced manufacturing. Knowledge of ROS and related tools is important as it provides a wide range of tools for common tasks such as motion planning or visualization[250]. Learners can be guided to set up and plan paths and tasks for mobile robots, design Human Machine Interface (HMI), write robot motion programs, and have skills in automated task planning.

Programming is another critical skill required for mobile robot integration, as mobile robots based on ROS technology use a programming language such as C++ or Python to operate. VETs and learners must have a good understanding of these programming languages to integrate and maintain these robots. Data analysis is also essential for mobile robot integration, as these robots generate a large amount of data that needs to be analysed to optimize their performance. VETs and learners must have a good understanding of data analysis techniques to interpret and use this data. Maintenance is a crucial competency required for mobile robot integration, as these robots require regular maintenance to ensure their optimal operation. VETs and learners must have a good understanding of maintenance techniques to keep these robots in good condition.

In addition to technical skills, good communication, problem-solving, and teamwork skills are important for mobile robot integration. Companies must provide training and resources for VETs and learners to develop these skills. To become a good roboticist, a variety of skills are necessary such as programming, mechanical design, electrical engineering, and data analysis. These skills can be developed through formal education, online courses, or on-the-job training. Robotics engineers also need soft skills such as communication, problem-solving, and teamwork skills to collaborate with other team members effectively.

[250]«ROS-Industrial».

Skills	Description
ROS knowledge	A good understanding of ROS technology and related tools is important to integrate mobile robots in advanced manufacturing
Programming	Mobile robots based on ROS technology use a programming language, such as C++ or Python, to operate. VETs and learners must have a good understanding of these programming languages to integrate and maintain these robots.
Data analysis	Data generated by mobile robots needs to be analysed to optimize their performance. VETs and learners must have a good understanding of data analysis techniques to interpret and use this data.
Maintenance	Mobile robots require regular maintenance to ensure their optimal operation. VETs and learners must have a good understanding of maintenance techniques to keep these robots in good condition.
Communication	Good communication skills are important for effective mobile robot integration.
Problem-solving	Problem-solving skills are important to overcome any issues encountered during mobile robot integration.
Teamwork	Good teamwork skills are important for effective mobile robot integration.
Path and task planning	Learners can be guided to set up and plan paths and tasks for mobile robots in advanced manufacturing.
HMI design	Learners can be guided to design Human Machine Interfaces (HMIs) for mobile robots in advanced manufacturing.
Robot motion programs	Learners can be guided to write robot motion programs for mobile robots in advanced manufacturing.
Automated task planning	Learners can have skills in automated task planning for mobile robots in advanced manufacturing.

Table 2: Skills and Competencies Required for the Integration of Mobile Robots Based on ROS Technology in Advanced Manufacturing[251] [252] [253] [254] [255]

[251] Kobelrausch et al., «Skill Acquisition for Resource-Constrained Mobile Robots through Continuous Exploration».

[252] Owen-Hill, «10 Essential Skills That All Good Roboticists Should Have».

[253] Kerns, «3 Trends in Mobile Industrial Robotics».

[254] «ROS-Industrial».

[255] Luo et al., «Modular ROS Based Autonomous Mobile Industrial Robot System for Automated Intelligent Manufacturing Applications».

Current and future trends

According to a report by MarketsAndMarkets, the adoption of mobile robots based on ROS technology in advanced manufacturing is expected to increase significantly in the coming years.

The ROS-based robot market is projected to grow from USD 1.0 billion in 2020 to USD 3.4 billion by 2026, at a CAGR of 20.6% from 2020 to 2026.

The current trends in mobile robots based on ROS technology in advanced manufacturing are the development of more intelligent and autonomous robots and the development of mobile robots for agriculture.

Researchers are developing modular ROS-based autonomous mobile industrial robot systems for automated intelligent manufacturing applications. They are proposing finite state machine-based methods to integrate and manage various modular functions on mobile robots.

Autonomous Mobile Industrial Robots (AMIR) have been developed with a carefully designed mechanism and a fully modular ROS environment in robotics labs. Robots are designed to collect materials and deliver products from one location to another.

ROS-based unmanned mobile robot platforms are also being developed for agriculture. These robots are designed to perform tasks such as crop monitoring, spraying, and harvesting.

The robots are equipped with sensors and systems that enable them to navigate through the fields and perform their tasks autonomously.

The ROS-based mobile robot system is used to control the robots, and the robots are calibrated using cam-lidar calibration. The robots are also equipped with a virtual private network that enables them to communicate with each other and with the central control system. [256] [257] [258] [259]

The future trends in mobile robots based on ROS technology in advanced manufacturing are expected to include the increasing use of mobile robots, the integration of mobile robots with other technologies, the development of new applications and use cases for mobile robots, and the development of swarm robotics.

The adoption of mobile robots based on ROS technology in advanced manufacturing is expected to increase significantly in the coming years.

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[256] Luo et al., «Modular ROS Based Autonomous Mobile Industrial Robot System for Automated Intelligent Manufacturing Applications».

[257] Eu-Tteum Baek et Dae-Yeong Im, «ROS-Based Unmanned Mobile Robot Platform for Agriculture», *Applied Sciences* 12, nº 9 (janvier 2022): 4335, https://doi.org/10.3390/app12094335.

[258] «Modular ROS Based Autonomous Mobile Industrial Robot System for Automated Intelligent Manufacturing Applications | 2020 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)», s. d., https://dl.acm.org/doi/abs/10.1109/AIM43001.2020.9158800.

[259] Luo et al., «Modular ROS Based Autonomous Mobile Industrial Robot System for Automated Intelligent Manufacturing Applications».

The integration of mobile robots based on ROS technology with other technologies, such as blockchain and edge computing, could lead to more efficient and flexible manufacturing processes. [260] [261] [262] [263]

The adoption of mobile robots based on ROS technology could lead to the development of new applications and use cases in advanced manufacturing, such as logistics, warehouse management, and quality control.

The integration of mobile robots based on ROS technology with swarm robotics could lead to the development of new applications in advanced manufacturing, such as decentralized manufacturing and collaborative assembly.

The ROS-Industrial project is an open-source initiative that extends the advanced capabilities of ROS software to industrial-relevant hardware and applications.

The project aims to accelerate the development of ROS-Industrial by managing a roadmap to identify and prioritize ROS-Industrial capabilities for industrial robotics and automation, instituting and enforcing code quality standards appropriate for an industrial software product, and providing a wide range of user services, including technical support and training, to facilitate the continued adoption of ROS-Industrial by industry. [264] [265] [266] [267]

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[260]«Top 15 Robotics Engineer Skills», 1 octobre 2020, https://www.zippia.com/robotics-engineer-jobs/skills/.

[261]«ROS-Industrial for Real-World Solutions», Automate, s. d., https://www.automate.org/industry-insights/ros-industrial-for-real-world-solutions.

[262]Lisa Heuss, Clemens Gonnermann, et Gunther Reinhart, «An Extendable Framework for Intelligent and Easily Configurable Skills-Based Industrial Robot Applications», *The International Journal of Advanced Manufacturing Technology* 120, nº 9 (1 juin 2022): 6269-85, https://doi.org/10.1007/s00170-022-09071-w.

[263]«Autonomous Robotics in Advanced Manufacturing | Temasek Polytechnic», s. d., https://www.tp.edu.sg/schools-and-courses/adult-learners/all-courses/skillsfuture-series/autonomous-robotics-in-advanced-manufacturing.html.

[264]Ricardo Tellez, «Top 10 ROS-Based Robotics Companies to Know in 2019», The Robot Report, 22 juillet 2019, https://www.therobotreport.com/top-10-ros-based-robotics-companies-2019/.

[265]«ROS-Industrial».

[266]«Robots.Ros.Org».

[267]Peng Guo et al., «An ROS Architecture for Autonomous Mobile Robots with UCAR Platforms in Smart Restaurants», *Machines* 10, nº 10 (octobre 2022): 844, https://doi.org/10.3390/machines10100844.

Year	Market size (USD billion)	CAGR
2023	0.44	9.2%
2024	0.48	9.2%
2025	0.53	9.2%
2026	0.58	9.2%
2027	0.63	9.2%
2028	0.69	9.2%
2029	0.75	9.2%
2030	0.81	9.2%

Table 3: ROS-based Robot Market Size and Growth Forecast (2023 - 2030) Source: Robot operating system (ROS) market is expected to reach around USD 0.7 billion by 2030, grow at a CAGR of 9.2% during forecast period 2023 to 2030 - Data by contrive datum insights Pvt. Ltd.

Year	Market Size (USD million)
2019	455.9
2020	498.2
2021	549.6
2022	603.2
2023	657.8

Table 4: Autonomous Robots Market Size in Europe (2019 - 2023) Source: Statista - Autonomous robots market size in Europe from 2019 to 2023 (in million U.S. dollars)

3.8.3.5 Conclusions

In conclusion, mobile robots based on ROS technology are a rapidly growing field with a wide range of applications. The open-source nature of ROS has enabled researchers and developers to collaborate and build upon each other's work, resulting in the development of many innovative robotics applications. The use of ROS-based mobile robots has the potential to improve safety, efficiency, and productivity in many industries, including manufacturing, healthcare, agriculture, and service industries. As the technology continues to advance, we can expect to see even more exciting developments in the field of mobile robotics based on ROS. However, there are also potential limitations and challenges that need to be considered, such as ethical and legal issues, safety and security concerns, and the potential impact on employment and social welfare. It is important for researchers, policymakers, and industry representatives to continue to explore these issues and work towards developing mobile robots based on ROS technology that are safe, reliable, and beneficial for society.

To realize the full potential of mobile robots based on ROS technology, VETs, learners, and companies need to develop the necessary skills and competencies to integrate and maintain these robots. The creation of new jobs that require skills and competencies related to mobile robot integration, programming, and maintenance is also an opportunity for VETs and learners. CoVEs can play a crucial role in the development of these skills and competencies. By providing focused training and resources, CoVEs can help VETs and learners integrate mobile robots based on ROS technology into their operations. Additionally, CoVEs can work with companies to develop customized training programs that address the specific needs of their operations.

Standardization efforts in mobile robot development and deployment can help overcome interoperability issues and accelerate the adoption of mobile robots based on ROS technology in advanced manufacturing. While there are some challenges associated with using ROS, its many advantages make it an essential tool for researchers and developers working in the field of robotics. The adoption of mobile robots based on ROS technology has the potential to create new job opportunities, but it also requires workers to acquire new skills and qualifications to remain competitive in the job market.

In conclusion, mobile robots based on ROS technology have become an increasingly important area of research and development in many different industries. Understanding the latest trends and developments in mobile robots based on ROS technology is crucial for researchers, policymakers, and industry representatives alike. Researchers, policymakers, and industry representatives must continue to explore issues such as ethical and legal concerns, safety and security concerns, and the potential impact on employment and social welfare. By addressing these issues and developing mobile robots based on ROS technology that is safe, reliable, and beneficial for society, we can harness the full potential of mobile robots based on ROS technology to improve safety, efficiency, and productivity in many industries.

Statements

1. The demand for mobile robots based on ROS technology is increasing across various industries, due to their numerous advantages, such as increased efficiency, accuracy, and safety.
2. The development of mobile robots based on ROS technology is an active area of research, with new applications and capabilities being developed, driven by the need for advanced automation in manufacturing, healthcare, and logistics.
3. The lack of standardization in mobile robot development and deployment can lead to interoperability issues and hinder their adoption, which highlights the need for collaboration and cooperation among researchers, policymakers, and industry representatives.
4. The integration of mobile robots based on ROS technology into advanced manufacturing presents both challenges and opportunities, such as job displacement, cost of implementation, and the need for specific skills and competencies, which need to be addressed by VETs and learners, policymakers, and industry representatives.
5. CoVEs can play a crucial role in developing the necessary skills and competencies to integrate and maintain mobile robots based on ROS technology. By providing focused training and resources, CoVEs can help VETs and learners integrate mobile robots based on ROS technology into their operations and work with companies to develop customized training programs.

3.9 MOBILE ROBOTICS IN ADVANCED MANUFACTURING FACTORIES

3.9.1 Introduction

In recent years, great technological advances have been made in areas such as the Internet of Things, Big Data and artificial intelligence. These advances have a direct impact on robotics and make the level of autonomy that a robot can have increased considerably. This autonomy includes the possibility of learning or mapping spaces and having the ability to move through them, without the need for human intervention; that is, go from one point to another point, being able to avoid the different obstacles that may be on the way[268].

In the manufacturing industry, where good intralogistics is necessary, mobile robots can play a very important role. Although today the use of mobile robots in the industrial sector in the Basque Country is low, it is probable that mobile robotics will gain more and more prominence as new technologies are incorporated to improve production processes.

For this reason, it is essential that knowledge about autonomous and mobile robotics be worked on in vocational training in the Basque Country.

The following sections will be discussed below:

- The current state and problems of intralogistics in the industry.
- Solutions and advantages offered by mobile robotics for intralogistics.
- The current state of the Euskadi Vocational Training regarding autonomous and mobile robotics.

3.9.2 Problem Statement

Intralogistics in the industry has been and continues to be in most cases, a task carried out by people; people who carry the weight of work tools or material directly on their body or using carts, tugs and forklifts. This way of operating has several disadvantages:

- Highly qualified workers spend time on intralogistics tasks that do not have added value.

[268] Robotnik, «Robots móviles y Industria 4.0: automatización y flexibilidad», *Robotnik* (blog), 12 janvier 2021, https://robotnik.eu/es/robots-moviles-en-la-industria-4-0-automatizacion-y-flexibilidad/.

- Many human errors are made, depositing materials in the wrong places and using methods that can put the safety of personnel at risk.
- It is very difficult to track the material: know its location, quantities, how long it has been on that site, etc.
- Transportation is not flexible, since it is very difficult to handle a variety of products.

These inefficiencies directly affect the production process of the company, causing possible losses, both economic and human.

3.9.3 Mobile Robotics Solutions for Advanced Manufacturing

The use of mobile robotics in industrial intralogistics solves many of the problems discussed in the previous section. Here are some of the benefits it offers:

- Skilled workers will dedicate themselves to those tasks that add value.
- Human errors are eliminated, optimizing space and protecting the physical integrity of workers, preventing them from moving heavy weights or harmful materials.
- The traceability of the material will be inherent to intralogistics.
- Has the ability to easily adapt to changing production needs.

Clearly, AMR fleet-based intralogistics solutions are a trend and are already sufficiently consolidated from a technological point of view. Therefore, there are already many manufacturers and providers of this type of solution on the market.

Mobile robots designed for industrial intralogistics are called AMR[269] (Autonomous Mobile Robot). These robots are equipped with multiple sensors: cameras, lidar, ultrasound, etc. Through these sensors, they learn the map of the place and in this way, they are able to move through space autonomously, choosing the optimal route for each trip. The routes are flexible, so that if an obstacle gets in the way, the robot is able to detect the obstacle, avoid it and recalculate an alternative route to reach its destination.

[269]RdR, « ¿En qué destaca el nuevo controlador de robots AMR de Omron?», *REVISTA DE ROBOTS* (blog), 2 mars 2022, https://revistaderobots.com/robots-y-robotica/en-que-destaca-el-nuevo-controlador-de-robots-amr-de-omron/.

Figure 46: Autonomous mobile robot

The key for a company's intralogistics to be as efficient as possible is to have a fleet of AMR robots and that the individual behaviour of each robot contributes so that the joint behaviour of the fleet is optimal. That is to say, that the robots work collaboratively, not only with the rest of the robots, but also sharing space and interacting with the company's personnel. For this, mobile robot systems have fleet management software, which can be accessed from any location and using any type of device. From the fleet manager it is possible to carry out the following actions:

- Monitor the status of all robots and collect relevant metrics or data and display them on a dashboard. Identifying bottlenecks or critical points on which action must be taken to optimize intralogistics.
- Plan missions and routes, to minimize transport times and improve route efficiency. Said orchestration may be graph-based.
- Optimize the use of time, maximizing the autonomy times of the robots, avoiding downtime or production stops.

Although in its infancy, there are also a small number of vendors developing and offering mobile robots that incorporate a collaborative robotic arm. In this way, the robot is made more versatile and can carry out more complex tasks: picking up and depositing material at different heights, loading and unloading the AMR, pressing buttons to open doorways or elevators that get in the way of planned route, etc.

Figure 47: Collaborative robotic arm

3.9.4 Euskadi Vocational Training Regarding Autonomous and Mobile Robotics

Although industrial robotics is a deeply rooted subject and is dealt with in various cycles and specialization courses in the Euskadi FP, work is carried out exclusively with collaborative robotic arms, since in the environment industry it is the most abundant. Therefore, students do not acquire skills related to autonomous and mobile robotics for industrial environments.

However, the Council of Ministers, at the proposal of the Ministry of Education and Vocational Training, on 10/25/2022, approved the Royal Decree establishing the Higher-Level Vocational Training Specialization Course in Collaborative Robotics[270] [271]. One of the professional modules that make up this course is dedicated to mobile and autonomous robots. Among the different learning outcomes of this professional module, mention is made of the acquisition of skills related to environment mapping, autonomous navigation, creation and establishment of missions, the implementation of the fleet manager, etc.

Along with this specialization course, a new framework of possibilities opens to be able to work on skills related to mobile autonomous robotics for industrial environments and achieve students aligned with industrial digital transformation and advanced manufacturing.

[270] «El Gobierno crea un nuevo curso de especialización en robótica colaborativa», 25 octobre 2022, https://www.educacionyfp.gob.es/prensa/actualidad/2022/10/20221025-cursorobotica.html.

[271] «BOLETÍN OFICIAL DEL ESTADO N 273» (BOLETÍN OFICIAL DEL ESTADO, 14 novembre 2022), https://ivac-eei.eus//upload/sp/documentos/291/ele_ce3_rob_col_rd.pdf.

3.9.5 Statements

After carrying out this analysis on the current problems of intralogistics, the technological trend in mobile robotics for industrial environments and the current state of skills related to mobile robotics in Euskadi FP, it is possible to conclude some of the following conclusions:

- Intralogistics is one of the key points of a company. The more efficient intralogistics is, the better the company's production process will be and economic losses and exposure of operators to accidents will be avoided.
- Mobile robotics is a technology that can perform intralogistics tasks efficiently; the transfer of material is achieved safely, with traceability, without waiting times, etc.
- Knowledge and skills on industrial mobile robotics are a field to be addressed in Euskadi FP. And the new specialization course offers the opportune opportunity for this.

3.10 ADDITIVE MANUFACTURING: GENERATIVE DESIGN AND TOPOLOGY OPTIMIZATION

3.10.1 Main Used Source(s)

Title	Description	Scope	Sector	Link
PUBLIC SOURCES				
Additive manufacturing	Advocacy for additive manufacturing in industry	Global	Manufacturing	LINK
ACADEMIC SOURCES				
Engineering.com	Journal that shares in-depth original paired with a customizable platform called ProjectBoard	Global	Multisector	LINK
Nature	International journal for peer-reviewed research	Global	Multisector	LINK
INDUSTRY SOURCES				
Autodesk	Design technology firm	Global	Multisector	LINK
Bugatti	Car manufacturer	Global	Automotive	LINK
Fractory	Engineering service for increased manufacturing sustainability	UK+EU	Manufacturing	LINK
Inceptra	Project lifecycle management company	North America	Multisector	LINK
McKinsey & Company	Market investment company	Global	Finance	LINK

Context and limitations

Sources are largely drawn from industrial publications and websites. As discussed below, academic sources for these topics are commonly either limited or outdated, and industry sources provide the most up-to-date information available.

Relevance

CoVEs and VETs are dedicated to remaining current in the advanced manufacturing landscape, and key to this goal is maintaining an understanding of topics and technologies. This section focuses on generative design and topology optimization which are helping firms re-imagine the ideation process from concept through manufacturing.

3.10.2 Main Data

Identification	Topic Name	Link
PUBLIC SOURCES		
Additive manufacturing	3D Printed Tool for Machining Electric Vehicle Motors: The Cool Parts Show #39	LINK
ACADEMIC SOURCES		
Engineering.com	Can You Use Generative Design for Internal Fluid Flow?	LINK
Nature	Eco-engineering: Living in a materials world	LINK
INDUSTRY SOURCES		
Autodesk	Topology optimization	LINK
Bugatti	World Premiere: Brake Caliper from 3-D Printer	LINK
Fractory	Generative Design – the Future of Engineering?	LINK
Fractory	Topology optimisation	LINK
Inceptra	Need to Lightweight your Products Quickly and Efficiently?	LINK
McKinsey & Company	How generative design could reshape the future of product development	LINK

3.10.2.1 Context and Presentation

Sources largely draw from a mixture of top-level information for interested industry partners and specific examples of processes used in actual projects.

3.10.2.2 Summary and Synthesis

Generative Design (GD) and Topology Optimization (TO) are both computer-aided design techniques, using algorithms to optimize design for specific goals through opposing design features. These design techniques operate in conjunction with one another, with Generative Design serving at the start of a design project and Topology Optimization taking place at the end. The objective of this report is to provide a summary of the considerations, potential, and opportunities created by Generative Design and Topology Optimization. This report will study manufacturing criteria, the current industrial and educational states of GD and TO, and the current trends in their uptake, with conclusions regarding our desired path forward. Elements address include the uses of generative design, applicable software, industrial applications, manufacturing considerations, manufacturing trends, and education trends. Both generative design and topology optimization are in growing usage in the manufacturing industry, but academic institutes are lagging behind. The situation is complicated by the use of proprietary technology in GD and TO. Many of the industries currently making use of GD and TO, especially in the aerospace and automotive industries, are doing so using proprietary software and with the goal of developing proprietary parts for specific corporations. Nevertheless, generative design and topology optimization are vital tools in need of uptake.

3.10.3 Data Analysis

3.10.3.1 Introduction

Design for Manufacturing (DfM) is the process of designing a product or component with consideration for its manufacturing requirements. It involves designing products that are easy and cost-effective to manufacture, while also meeting performance requirements. This includes factors such as material selection, part size, geometry, complexity, and ease of assembly. By incorporating DfM principles, designers can improve product quality, reduce costs, and shorten production times. Generative Design and Topology Optimization are two key techniques utilized in DfM procedures.

3.10.3.2 Contextualisation

Generative Design (GD) and Topology Optimization (TO) are both computer-aided design techniques, using algorithms to optimize design for specific goals through opposing design features. These design techniques operate in conjunction with one another, with Generative Design serving at the start of a design project and Topology Optimization taking place at the end.

Generative design

Generative Design[272] is a design exploration process, used to generate multiple design options meeting a shared set of design constraints. These options are made up of the conceptual elements that are necessary for a successful design (including required points of attachment, manufacturing material and methodology, weight, etc.) and performance objectives, made up of the requirements for a design to function effectively (including aerodynamics, heat dispersion, deflection limits, etc.) Generative Design software generates multiple potential design alternatives to meet different constraints and objectives, allowing the designer to rapidly iterate potential geometries and designs via iterative design software. It is thus most valuable at the beginning of a design process.

Topology optimization

Topology Optimization[273] begins with an **existing design** and narrows its focus to optimize its material distribution to maximize specific **performance criteria**, such as stiffness, weight resistance, etc. Using simulation technology, it predicts design performance without the need for expensive physical generation, and then automatically adjusts improves designs. Topology Optimization typically occurs toward the end of the design process, when weight issues and material costs become a concern for manufacturers.

Design criteria – Constraints and performance criteria

The constraints of a generative design study translate approximately into the setup conditions of the study. A project's starting geometry determines where the software can and cannot make modifications or place geometry, defined by any geometric limits known to exist for a part or object before design begins. An object may also have a maximum or minimum mass or weight required to function, and many parts have required safety factors depending on the industry and purpose that they will be put to.

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[272] «What Is Generative Design», Tools Software, Autodesk, s. d., https://www.autodesk.com/solutions/generative-design.

[273] «Topology Optimization», Software And Resources, Autodesk, s. d., https://www.autodesk.com/solutions/topology-optimization.

Performance criteria include any requirement performance outputs of a part or object. These can overlap with design criteria: for example, mass or weight limits may be required due to other design restraints or might be required as a criterion of successful performance. Parts may also require the ability to hold up under certain forces and moments without failing or may require a certain amount of flexibility to not break under pressure.

3.10.3.3 Objective

The objective of this report is to provide a summary of the considerations, potential, and opportunities created by Generative Design and Topology Optimization. This report will study manufacturing criteria, the current industrial and educational states of GD and TO, and the current trends in their uptake, with conclusions regarding our desired path forward.

3.10.3.4 Findings

Uses of generative design

Generative design holds the potential to reshape the nature of product development. Using traditional design processes, each iteration of a project takes significant time and expense, with the result that teams are rarely able to explore alternatives to their base assumptions. The result is designs that are functional, but not optimal for their intended usage.

Generative algorithms change these calculations. Because each iteration of generative design allows for the creation of hundreds of design alternatives, designers can quickly consider a wide array of strengths and weaknesses of different potential manufacturing options, allowing them to create extremely precise final refinements to develop exactly the part or object that they are seeking.

Generative Design should be considered computer-aided design, not software that designs on behalf of engineers. GD software can rapidly process iterative design according to engineer specifications but does so according to engineer inputs, and manual refinements are required for final designs to achieve the best results.

Structural optimization[274]

Structural optimization is the standard usage of GD in most industrial settings. Through this process, engineers improve the strength and fatigue resistance of parts in the design process, especially where weight is a primary consideration, such as in the automotive or aerospace industries. By reducing the weight of parts to be developed, industries can improve performance, increase sustainability, reduce production costs by up to 20 percent, and reduce development times by up to 50 percent.

Internal flow optimization

Fluid flow is currently a difficult field to measure and simulate. Physical testing for either external or internal fluid flow is difficult and expensive, requiring elaborate testing facilities and costly operations. The result is that outside of aeronautics and advanced automotive design, fluid optimization is rarely undertaken.

Generative design holds the potential to simulate fluid dynamics for product engineers, allowing for the iterative design of internal product structure, adjusting fluid flows in ways that dramatically improve pressure requirements and reduce the weight and cost of parts.

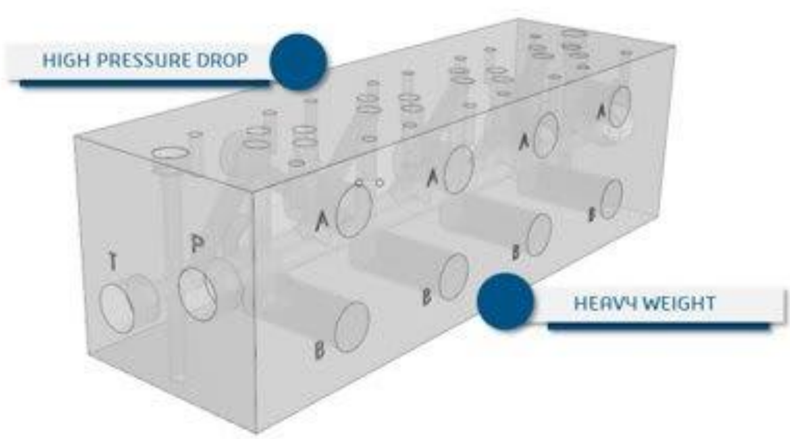

Figure 48: Legacy design[275]

[274]Mickael Brossard et al., «How generative design could reshape the future of product development | McKinsey», McKinsey, 2020, https://www.mckinsey.com/capabilities/operations/our-insights/how-generative-design-could-reshape-the-future-of-product-development.

[275]«Can You Use Generative Design for Internal Fluid Flow?», Engineering.com, 2021, https://www.engineering.com/story/can-you-use-generative-design-for-internal-fluid-flow.

An example of this can be found in hydraulic manifolds. Traditionally, a hydraulic manifold is a solid block of material with ports drilled into it that act as passageways for highly pressurized hydraulic fluid. Fluid flow dynamics can't be considered within the block due to restrictions in the manufacturing methods available. For example, to create a 90-degree direction change in the block for fluid flow, a machinist would drill one hole into the top or bottom of the block & drill a second hole that meets the first hole into the side of the block. This produces hard edges and unnecessary pockets due to the drill points in the cavity, and as a result, creates turbulence in the flow of fluid which in turn reduces the efficiency of the manifold. Through structural generative design and 3D printing, the manifold could remove sharp corners and reduce turbulence and pressure on the manifold.

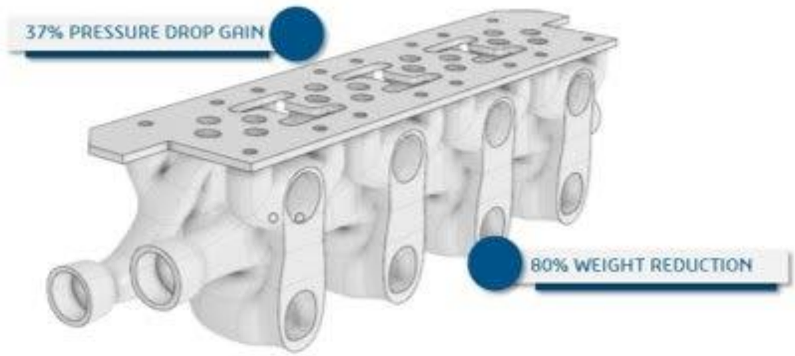

Figure 49: Structural Generative Design[276]

Uses of topology optimization

Weight reduction and shape optimization

The primary current usage of Topology Optimization lies in the weight reduction of manufactured parts. Designers begin by developing a CAD model of the part to be optimized, defining the material to manufacture the part from and the magnitude and direction of forces that will act on the part in the operation. TO software analyses the stresses that will apply to the part, removes any materials that do not affect its functionality and then provides a final simulation for manufacture. These components cannot be manufactured using traditional processes, requiring an additive manufacturing process. Part areas can be optimized based on several varying requirements, such as load, boundary conditions, deformation, and stiffness constraints, producing parts with enhanced performance in the best possible structure.

[276] Ibid

Shape optimization technology helps inform certain geometry decisions to specific constraints such as manufacturing methods. Shape Optimization is available through customized CAD programs and models and is typically used as a component of other functions, especially weight optimization.

Applicable software

Currently, there are five major applicable software models for generative design. The most common is Autodesk's **Fusion 360 Generative Design Module**, which is available to students, educators, and industry professionals. Users start with a set of initial conditions and design constraints, and the solver will generate multiple outcome models that will perform the functions set. This means that the setup is extremely important, and a user who is not familiar with correctly setting up Finite Element Analysis (FEA) studies will struggle with correctly completing a generative design study.

SolidThinking inspire is a software package that takes design constraints and an initial starting shape and performs topological shape optimization to find an ideal solution. The system is highly proficient at structural analysis and dynamic motion simulation but is designed only for industry professionals.

Siemens NX generative design and siemens NX topology optimization are a pair of engineering software solutions that integrate GD and TO for industrial designers. This system has the advantage of integrating both processes, embedding topology optimization within generative design systems to enable unified 3D modelling capabilities.

Hexagon's generative design suite MSC apex GD[277] is advertised to take designers from screen to machine faster with less human intervention than any other software on the market. It does this using a proprietary "Generative Design Engine" based on Finite Element Analysis (FEA), diverging from traditional density field computation to use very fine meshes with well-defined/stable elements. The software is focused primarily on additive manufacturing optimization with the target of sending the result to a printer with no corrections/edits required. See this link for case studies & detailed program information.

Dassault systemes includes Topology Optimization in the Simulation-Level license of SolidWorks, and the study options contain 3 objectives: Best Stiffness to Weight Ratio, Minimize Maximum Displacement (under a given loading), and Minimize Mass. SolidWorks requires a

[277] «MSC Apex Generative Design», Hexagon, s. d., https://hexagon.com/products/msc-apex-generative-design?accordId=47C305DC8B9D47C0858D99096802A4E4.

starting point (solid model), this means true Generative Design which is the AI creation of a part from nothing but constraints isn't offered by Dassault Systemes at this time. The Topology Optimization is embedded in their FEA software and uses the same process for stress determination/meshing creation combined with an iterative solver provided by SIMULIA's Tosca range for shape production. Results can be obtained for both additive and subtractive manufacturing methods.

ANSYS Generative design, despite the name, is a topology optimization tool exclusively. It takes in shaped parts or objects and undergoes real-time topology optimization, allowing the designer to observe the system in motion and make any adjustments as necessary.

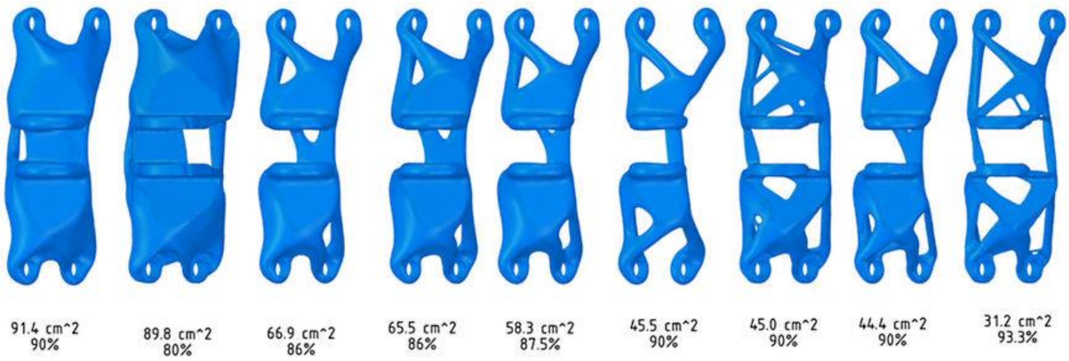

Figure 50: ANSYS Topology Optimization of an established bracket

Industrial applications

Aerospace and Automotive manufacturing[278] [279] [280] [281]

Generative design has begun to take hold in the aerospace and automotive manufacturing fields. Airbus, in collaboration with Autodesk, has been applying generative design to aircraft manufacturing for nearly a decade. Their "Bionic Partition 2.0" separates seating components from one another and from the gallery of a plane, creating a final design that is 45% lighter than comparable aircraft; once applied to the current Airbus fleet, this design will save over 500,000 metric tons of CO2 emissions per year.

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[278]«Building with a New Generation», Aerospace Manufacturing, 20 janvier 2020, https://aero-mag.com/airbus-autodesk-generative-design-aircraft-components-200120.

[279]«General Motors | Generative Design in Car Manufacturing», Autodesk, s. d., https://www.autodesk.com/customer-stories/general-motors-generative-design.

[280]Alex Leanse, «The Czinger 21C Is So Much More Than an American-Made Hypercar», MotorTrend, 26 août 2021, https://www.motortrend.com/features/czinger-21c-3-d-hypercar-details-photos/.

[281]Josh Welton, «How Kevin Czinger Is Changing the Automotive Assembly Game with 3D Printing», The fabricator, 2 novembre 2022, https://www.thefabricator.com/thefabricator/blog/metalsmaterials/how-kevin-czinger-is-changing-the-automotive-assembly-game-with-3d-printing.

In the automotive field, Autodesk is working with General Motors to employ GD & TO across their entire range of vehicles, with the goal of reducing the weight of Electric Vehicle (EV) batteries, which will not only improve their range but reduce wear and tear on brakes and tires.

Czinger, an automotive supercar maker based in Los Angeles, California, develops extremely high-performance cars through generative design & metal 3D printing. By employing an advanced proprietary AI-powered generative design known as Divergent Adaptive Production Systems (DAPS) alongside metal 3D printing, Czinger can produce entire car chassis without the traditional multi-million-dollar infrastructure and tooling of a mass-market OEM. Their methodology and process have caught the eyes of major OEM automakers, with several contracting Czinger to generate optimized versions of their traditionally designed components & manufacture them on a contract basis.

Aerospace and automotive sources:

Medical applications[282]

Currently, the medical industry makes use of metal fixation plates to repair and fixate bone fractures. The high-stiffness metal plates and rods used to shield the surrounding periosteum from stress. It is this bone tissue that possesses osteogenic potential and shielding the tissue from stress results in decreased bone modelling and bone loss. By making use of topology optimization which mimics the ways in which the human body responds to stresses placed through the skeletal structure, doctors can develop a porous model optimized for each patient, which utilized less material, was lighter, less rigid, and structurally more reliable than a conventional plate.

Fusion builds[283]

Nnaisense, a Swiss-based engineering company, is in the process of developing an AI which uses optical topology to study laser-powered bed fusion builds, combining additive manufacturing and topology optimization. Using only a heat map and a few minor data points, this AI system can match layers of a fusion build to one another and create a simulated digital twin. By doing this, the model can recognize potential defects early in the creation process, raising concerns which can then be studied and addressed by engineers without requiring expensive testing processes.

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[282] Irfan Kaymaz et al., «A New Design for the Humerus Fixation Plate Using a Novel Reliability-Based Topology Optimization Approach to Mitigate the Stress Shielding Effect», *Clinical Biomechanics* 99 (1 octobre 2022): 105768, https://doi.org/10.1016/j.clinbiomech.2022.105768.

[283]Peter Zelinski, «Artificial Intelligence and Additive Manufacturing Are Connected: AM Radio #36», 4 avril 2023, https://www.additivemanufacturing.media/articles/artificial-intelligence-and-additive-manufacturing-are-connected-am-radio-36.

Manufacturing considerations

The primary consideration for the use of generative design or topology optimization software is the method to be used to manufacture the resulting component. Manufacturing method considerations are just as important in generative design as they are in what can be considered "standard" computer-aided design. Common manufacturing methods using GD and TO include casting, additive manufacturing, injection moulding, and CNC machining, each of which requires differing methodologies and may not be useable with all designs.

To account for this, it is possible to define the manufacturing method that is intended for use when setting up a generative design study. This means that GD and TO can be used to create optimized parts regardless of manufacturing limitations such as lack of access to a metal 3D printer or 5-axis milling machine.

Manufacturing trends[284]

Airbus is currently collaborating with Autodesk to employ generative design in multiple areas of the business. The design & manufacturing side of the business has employed generative design for nearly a decade, and the Bionic Partition 2.0 is a great example of generative design & topology optimization, it separates the seating compartments from each other & the galley of the plane. Airbus estimates that the design will be 45% lighter than their previous standard design while saving almost 500,000 metric tons of C02 emissions per year if applied to all Airbus A320 planes on Earth. Airbus has also employed generative design to architecture and factory workflow planning culminating in multiple concepts for a new engine assembly factory in Hamburg, Germany. Using the generative design, Airbus was able to generate layouts for the new factory that maximized the space available & allows for efficient and flexible workflows for assembling the various engines.

Czinger[285] is an automotive supercar maker based in Los Angeles, California that has made its name in the automotive market by creating extremely high-performance cars through generative design and metal 3D printing. By employing AI-powered generative design and metal 3D printing, Czinger can produce an entire car chassis without the traditional multi-million-dollar infrastructure and tooling of a mass-market OEM. Their methodology and process have caught the eyes of major OEM automakers with several contracting Czinger to generate optimized versions of their traditionally designed components and manufacture them on a contract basis. Czinger does not mention the specific companies, presumably as they have NDAs in place with Czinger. One

[284]«Building with a New Generation».

[285]Leanse, «The Czinger 21C Is So Much More Than an American-Made Hypercar».

company came to Czinger with a mass-produced component and requested a topology optimization with the goal of a 5% reduction in mass. Czinger's software & production method produced a result with a 20% reduction in mass with the same performance and the company awarded the contract to produce that component to Czinger going forward.

Czinger[286] employs Divergent 3D's DAPS (Divergent Adaptive Production System), an advanced proprietary Design-Manufacturing-Assembly process to create the components for its cars. Kevin Czinger founded divergent 3D, with the intent of disrupting the traditional design and manufacturing market by applying generative design and industrial metal 3D printing at a scale not seen before. Aston Martin contracted divergent 3D to generate and produce assemblies for their car production.

General Motors[287] is also working with Autodesk to employ generative design and topology optimization across their range of vehicles.

Weight is one of the biggest issues with Electric Vehicles due to the mass of batteries they must house. The heavyweight reduces the range of the EV and hampers performance while also wearing out tires and brakes faster. This means that anything that helps to lighten the rest of the vehicle is crucial whilst lightweight battery technology is further developed. By adopting generative design and topology optimization, automakers like GM and Audi (to name just two) are finding ways to reduce the mass of many components in their EV's and reduce manufacturing costs through employing additive manufacturing.

Education trends

Most of what has been found is either an introduction to generative design as a concept or showing how it applies to architecture; generative design as a concept is not widely taught and an advanced course on the topic with specialized aims is yet to be found online. Examples of current offerings follow:

- University of Toronto[288] (CAN) offers a generative design course focusing on its application to architecture.
- Columbia University[289] (US) offers several courses in generative design under the banner "Visual Studies Building Science & Technology Elective".

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[286] Welton, «How Kevin Czinger Is Changing the Automotive Assembly Game with 3D Printing».

[287] «General Motors | Generative Design in Car Manufacturing».

[288] «Selected Topics in Architecture: Generative Design Thinking & Workflows | Daniels», University of Toronto, s. d., https://www.daniels.utoronto.ca/selected-topics-architecture-generative-design-thinking-workflows-0.

[289] «Generative Design I», Columbia GSAPP, s. d., https://www.arch.columbia.edu/courses/79029-1825-generative-design-i.

- Cornell University[290] (US) offers a course aiming to familiarize students with the generative approach to the design process and allow them to explore opportunities to create novel cyber-human systems for the design/fabrication of a physical space.
- Plymouth University[291] (UK) offers a short new course (2 weeks full-time or 8 weeks blended) introducing the concepts of generative design and how to use them in a multitude of fields.
- Illinois Tech Institute of Design[292] (US) offers an introductory course in generative design concepts and methodologies.
- Griffith University[293] (AUS) offers an online course in experimental and generative design.
- Australia National University[294] (AUS) offers a course in Dynamic Design and Generative Systems through their school of art and design.
- Autodesk[295] offers webinar sessions that introduce generative design concepts utilizing their software.
- Dassault Systemes[296] offers a webinar dedicated to the use of generative design in architecture.

[290] Cornell University Registrar Office of the University, «Spring 2022 - DEA 3306», 2022, https://classes.cornell.edu/browse/roster/SP22/class/DEA/3306.

[291] «Generative Design», University of Plymouth, s. d., https://www.plymouth.ac.uk/study/cpd/generative-design.

[292] «Generative Design», Institute of Design, s. d., https://id.iit.edu/course/generative-design/.

[293] Squiz] Matt Dobie, «Experimental and Generative Design - 3642QC», Griffith University, s. d., https://www.griffith.edu.au/study/courses/experimental-and-generative-design-3642QCA.

[294] «Dynamic Design and Generative Systems - ANU», Australian National University, s. d., https://programsandcourses.anu.edu.au/2022/course/desn6004.

[295] «Introduction to Generative Design | Autodesk», Autodesk, s. d., https://www.autodesk.com/campaigns/pdm-collection/webinar-series/intro-generative-design/on-demand.

[296] «Design Unique and Complex Façades up to 50% Faster», Dassault Systèmes, 2 septembre 2022, https://discover.3ds.com/webinar-embrace-generative-design.

3.10.4 Conclusion

Statement 1: Both generative design and topology optimization are in growing usage in the manufacturing industry, but academic institutions are lagging. Educational institutions in North America and the United Kingdom currently primarily teach both GD and TO only as introductory courses, with the goal of familiarizing students with the concepts of generative design rather than offering in-depth instruction and hands-on experience. The primary exception is in the field of architecture, with a handful of courses focusing on how generative design can be used for architectural design and construction.

Statement 2: The situation is complicated through proprietary technology in GD and TO. Many of the industries currently making use of GD and TO, especially in the aerospace and automotive industries, are doing so using proprietary software and with the goal of developing proprietary parts for specific corporations. These programs and designs are not available to educational facilities or to the public, leading to a significant duplication of effort and training across competitors. This lack of communication is slowing adoption of these methods of design outside of highly specialized or lucrative fields.

Statement 3: Generative design and topology optimization are vital tools in need of uptake. Over the past ten years, it has grown dramatically as a field and is producing impressive results across several industrial sectors. Educational facilities that can develop and provide advanced courses on the topic, especially those with specialized aims for specific fields, will be able to greatly improve the ability of students to enter into a revolutionary field and forward the next wave of design modernization.

3.11 DIGITAL FACTORY: CYBER SECURITY

3.11.1 Main Used Source(s)

Identification	Description	Geographical scope	Sectorial scope	Links
PUBLIC SOURCES				
EFFRA	The European Factories of the Future Research Association (EFFRA) is a non-for-profit, industry-driven association promoting the development of new and innovative production technologies. EFFRA has been representing the private side of the manufacturing partnership with the EU Commission. Named under Horizon 2020, Factories of the Future to become Made in Europe nowadays under Horizon Europe	Europe	Multisector	LINK
Groupe AFNOR	French national agency for standardization	International	Multisector	LINK
OECD	2520 documents	World	Multisector	LINK
EUROPA		Europe	Multisector	
ENISA	European agency for cybersecurity	Europe	Multisector	
CORDIS	7587 documents	Europe		LINK
TRAINING SOURCES				
MINALOGIC	European competitiveness cluster on mechanics	EU & Regional France	Aerospace	LINK
CETIM	French national agency for all mechanics subjects & Ind 4.0	France	Multisector	LINK 1 LINK 2
FRANCE COMPETENCES	French National Center for technical learning	France	Industry and I 4.0	LINK

EFVET	EfVET is the European Forum of Technical and Vocational Education and Training	Europe		**LINK**
INDUSTRIAL SOURCES				
BPi	French National Public Bank for development	France	Industry and I 4.0	**LINK**
Usine Nouvelle	French national Newspaper for Industry	France	Multisector	**LINK**
Journal du Net	8940 docs in trends cyber	France	IT	**LINK**
Techniques de l'ingénieur	258 documents	National / international	Multisector	**LINK**
Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB	The Cybersecurity Training Lab of Fraunhofer Academy is a cooperation between Fraunhofer and selected universities of applied sciences. Specialists and managers from industry and public administration receive a compact qualification in high-quality laboratories with up-to-date IT infrastructure. There, they simulate real threat scenarios, learn to recognise their significance and consequences and study suitable solution concepts in a practical manner in their use and efficiency.	Germany	Cybersecurity	**LINK**
C4iiOT	C4IIOT will design, build and demonstrate a novel and unified Cybersecurity 4.0 framework	Europe	Cybersecurity	**LINK**
DELOITTE	Deloitte Consulting LLP's Supply Chain and Manufacturing Operations practice helps companies understand and address opportunities to apply Industry 4.0 technologies in pursuit of their business objectives. Our insights into additive manufacturing, IoT, and analytics enable us to help organizations reassess their people, processes, and technologies considering advanced manufacturing practices that are evolving every day.	World	Multisector	**LINK**

- All FIELDS are concerned and covered. **F1: Trends; F2: Impact on jobs; F3: Skills & Qualifications; F4: Future Skills**
- Language: English and French
- Already used in industry and in global transformation.

3.11.1.1 Context and Limitations

The review was done using sources found in Europe and France and provided in the English and French languages. Further analysis, taking into account sources from all partner countries needs to be tackled in the coming year.

3.11.1.2 Relevancy

We considered those sources to be relevant for this analysis, which have provided information on this specific sub-topic.

3.11.2 Main Data

Identification	Topic name	Links
PUBLIC SOURCES		
EFFRA	Connected-Factories Cybersecurity for Digital Manufacturing Pathway webinar	**LINK**
EFFRA	ConnectedFactories	**LINK**
EFFRA	Cybersecurity workshop: Presentations and Recordings	**LINK**
EFFRA	Connected-Factories Cybersecurity for Digital Manufacturing Pathway	**LINK**
EFFRA	Standards for Digital Manufacturing webinar	**LINK**
EFFRA	SECOIIA	**LINK**
EFFRA	COLLABS	**LINK**
EFFRA	INFRASTRESS	**LINK**

Groupe AFNOR	Cybersécurité: ISO 27001, une norme devenue incontournable	**LINK**
CORDIS	Strengthening European efforts in Cyber Capacity Building	**LINK**
CORDIS	Making global supply chains cyberthreat-proof	**LINK**
TRAINING SOURCES		
Bpi	La Cybersécurité de ma PME: par où commencer?	**LINK**
Bpi	Cursus Cybersécurité	**LINK**
MINALOGIC	Minalogic lance son label "Sécurité économique"	**LINK**
CETIM	Introduction à la cybersécurité	**LINK**
FRANCE COMPETENCES	Opérateur en cybersécurité	**LINK**
EFVET	REWIRE Cybersecurity Blueprint: The Future of Cybersecurity Education in Europe	**LINK**
EFVET	How to train more Cybersecurity experts in Europe	**LINK**
EFVET	DTAM: A new EU project to facilitate the digital transformation in advanced manufacturing	**LINK**
INDUSTRIAL SOURCES		
CORDIS	Protect your company with a new cybersecurity self-assessment	**LINK**
BPi	Formation: Autodiag Cybersécurité	**LINK**
Journal du Net	Cybersécurité: 41.000 documents	**LINK**
Journal du Net	Cybersécurité: les tendances qui auront un impact sur vos applications en 2022	**LINK**
Techniques de l'ingénieur	L'industrie et les défis de la cybersécurité, Publié en décembre 2022	**LINK**
CORDIS	Effective protection of Critical Infrastructures against cyber threats	**LINK**

CORDIS	Cybersecurity risk management: How to strengthen resilience and adapt in 2021	LINK
CORDIS	Dynamic cybersecurity management for organisations and local/regional networks based on awareness and collaboration	LINK
OECD	Analysing a New Generation of National Cybersecurity Strategies	LINK
OECD	Recommendation of the Council on Digital Security Risk Management	LINK
EUROPA	Digitising Industry (Industry 4.0) and Cybersecurity	LINK
ENISA	Cybersecurity is a key enabler for Industry 4.0 adoption	LINK
Fraunhofer Institute of Optronics, System Technologies and Image Exploit	Cybersecurity Training Lab	LINK
C4iiOT	European project	LINK
DELOITTE	Industry 4.0 and cybersecurity	LINK
PWC	Manufacturers ramp up cyber defences as supply-chain bottlenecks – and vulnerabilities	LINK
E&Y	Cybersecurity generalities	LINK
NDIA	Cybersecurity for Advanced Manufacturing (CFAM)	LINK
FORTINET	2022 State of Operational Technology and Cybersecurity Report	LINK
ATMS	Cybersecurity for Advanced and Intelligent Manufacturing Environments	LINK
EJBMR	The State of Cybersecurity in Smart Manufacturing Systems: A Systematic Review	LINK
Lane Thames Dirk Schaefer	Cybersecurity for Industry 4.0 - Springer Series in Advanced Manufacturing - Analysis for Design and Manufacturing	LINK

i-scoop	Industrial Internet of Things (IIoT) – cybersecurity risks, solutions and evolutions	LINK
FORBES	cybersecurity In The Industry 4.0 Era	LINK
NATO	Cybersecurity and reliability challenges from adoption of Industry 4.0 in IACS environments	LINK

3.11.3 Data Analysis

3.11.3.1 Introduction and Contextualisation

General situation

Industry 4.0 brings a change in manufacturing systems, which is driven by the further development of communication and information technologies, the adding of intelligence components in manufacturing factories, the novelties of connectivity and interaction, the supply chain (intelligent manufacturing systems and cyber-physical systems), while still with people at the centre of all activities. However, the sustainability of the revolution of Industry 4.0 depends on an extremely sensitive and critical question of data and systems security.[297]

Industry 4.0 and optimization of production in Advanced Manufacturing to obtain greater productivity and generate more profits has led towards smart manufacturing, with the Internet of Things, a global network of interrelated physical devices, such as sensors, actuators, intelligent applications, computers, mechanical machines, and objects, and even people, through the Internet.

These devices are data sources that provide abundant information on manufacturing processes in an industrial environment. These challenges raise concerns about security, more specifically cybersecurity, which makes it possible to avoid damage to production lines and to information and data. [298]

Particularly in combination with the Internet and other disruptive technologies such as cloud computing, so many opportunities and new business models are emerging.

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[297]Armando Araújo de Souza Junior et al., «The State of Cybersecurity in Smart Manufacturing Systems: A Systematic Review», *European Journal of Business and Management Research* 6, nº 6 (16 décembre 2021): 188-94, https://doi.org/10.24018/ejbmr.2021.6.6.1173.

[298]Roman Rudenko et al., «A Brief Review on Internet of Things, Industry 4.0 and Cybersecurity», *Electronics* 11, nº 11 (janvier 2022): 1742, https://doi.org/10.3390/electronics11111742.

However, there are also many risks associated with this transformation, particularly regarding cyber security. Against the backdrop of increasing dependence on networked information technology, the attack on companies is increasing. To this end, it is necessary to assess the negative impact on businesses caused by cyber security attacks in Industry 4.0. [299]

New situation: Homework

More people than ever have joined the digital economy, and an Owl Labs survey found that 80% of people expect to work at least three days a week from home. A report by Upwork predicts that "by 2025, 36.2 million Americans will be working remotely, an 87% percent increase from pre-pandemic levels."[300]

Rise in attacks

Manufacturers worldwide are being targeted by cybercriminals at an astonishing − and increasing − rate.

Last year, the number of cyberattacks on manufacturers spiked by more than +300%, accounting for 22% of all attacks across all sectors, up from +7% the previous year.

Most US industrial sector executives (Deloitte, 2021) expect cyber threats to increase, with 66% saying they believe there will be an increased number of threats from cyber criminals and hacktivists (62%) as well as nation-states (60%).

- Increasing complexity is creating critical vulnerabilities. Most of the executives agree that complexity across their organization poses cyber- and privacy risks at "concerning levels." Complex cloud environments pose risks for 81% of respondents, as do complex governance of data (79%).
- Cyber lies at the core of business, attested to by 82% of respondents agreeing that they've seen an increased alignment of cyber strategy with business strategy over the last two years. Another 82% say recent key mergers and acquisitions have involved cybersecurity considerations.

[299] Antonio João Gonçalves de Azambuja, Alexander Kern, et Reiner Anderl, «Analysis of Cyber Security Features in Industry 4.0 Maturity Models», in *Computer Security. ESORICS 2021 International Workshops: CyberICPS, SECPRE, ADIoT, SPOSE, CPS4CIP, and CDT&SECOMANE, Darmstadt, Germany, October 4–8, 2021, Revised Selected Papers* (Berlin, Heidelberg: Springer-Verlag, 2021), 91-106, https://doi.org/10.1007/978-3-030-95484-0_6.

[300] Yevgeny Dibrov, «Council Post: How Can Your Company Stay Safe Amid Skyrocketing Cyber Attacks?», Forbes, s. d., https://www.forbes.com/sites/forbestechcouncil/2021/10/11/how-can-your-company-stay-safe-amid-skyrocketing-cyber-attacks/.

- Supply chain risks are the next big thing. 63% of sector leaders expect that third-party threats will increase, with 58% anticipating an increase in reportable incidents occurring at the supply chain software level. [301] [302] [303]

Based on a survey of 500 companies, one thing that has improved very little in the past year is organizations' security outcomes. A staggering 93% of organizations experienced an intrusion in the past 12 months, and 78% experienced more than three. Impacts included downtime, financial or data loss, brand degradation, and even reduced physical safety. Clearly, most organizations have work to do. Fortunately, a small percentage of respondents managed to avoid intrusions for the past year, and this report identifies several of the best practices they are more likely to employ in the future. [304]

- Ransomware was the top attack type, accounting for 23% of attacks on manufacturing organizations and underscoring the heavy focus ransomware actors placed on manufacturing.
- Server access attacks came in second place at 12%, representing probably some failed attacker operations.
- BEC and data theft tied for third place, at 10% each. BEC attackers are probably seeking to capitalize on the many supplier and wholesale shipping relationships manufacturing organizations develop and attempt to redirect payments between partners to accounts under the BEC attackers' control.

In terms of Geography, manufacturing faced most attacks in Asia (32%), North America (27%), and Europe (26%).

Manufacturing threat intelligence

Based on their survey, Fortinet found that organizations report modest moves forward in the overall maturity of their OT security posture. But looking at specific best practices brings nuance to the issue. Only 13% of respondents have achieved centralized visibility of all OT activities, and only 52% are able to track all OT activities from the security operations centre (SOC). Only around half of respondents claim to track and report various basic security metrics, and fewer than half of respondents are using any of a dozen specific security technologies and practices. The latter

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[301]«Industry 4.0 and Cybersecurity | Deloitte Australia | Cyber Risk», Deloitte Australia, 2022, https://www2.deloitte.com/au/en/pages/risk/articles/industry-4-cyber-security.html.

[302]«Global Threat Intelligence Report 2022», NTT, 2022, https://www.security.ntt/global-threat-intelligence-report-2022.

[303]PricewaterhouseCoopers, «Manufacturer Cybersecurity and Supply Chain», PwC, 24 février 2022, https://www.pwc.com/us/en/industries/industrial-products/library/cyber-supply-chain.html.

[304]«Fortinet | Arcview Research Analysis», Fortinet, 2022, https://global.fortinet.com/lp-en-ap-arcview

indicates diversity in how organizations address OT security and reflects a market that is still evolving. [305]

What is coming next: Third-party- and supply-chain risks

Looking ahead, manufacturers will continue to up their cybersecurity systems. Top goals for the next three years include achieving more successful outcomes for their organization's transformation, preventing attacks, and gaining more confidence in leaders in their ability to manage current and future attacks. But the next big subject for industrials will be third-party- and supply-chain risks. [306]

Public strategies

An OECD report analyses the latest generation of "national cybersecurity strategies" in ten countries and identifies commonalities and differences.

This comparative analysis reveals that cybersecurity policymaking is at a turning point. In many countries, it has become a national policy priority supported by stronger leadership. A single definition of cybersecurity cannot be derived from these strategies. Nevertheless, all new strategies are becoming integrated and comprehensive. They approach cybersecurity in a holistic manner, encompassing economic, social, educational, legal, law enforcement, technical, diplomatic, military and intelligence-related aspects. "Sovereignty considerations" have become increasingly important.

The new generation of national cybersecurity strategies aims to drive economic and social prosperity and protect cyberspace-reliant societies against cyber-threats. A key challenge of cybersecurity policy making today is to pursue these two objectives while preserving the openness of the Internet as a platform for innovation and new sources of growth. [307]

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[305] «Fortinet | Arcview Research Analysis».

[306] PricewaterhouseCoopers, «Manufacturer Cybersecurity and Supply Chain».

[307] «Comparative analysis of national cybersecurity strategies», OECD, s. d., https://www.oecd.org/digital/ieconomy/comparativeanalysisofnationalcybersecuritystrategies.htm.

3.11.3.2 Objectives / Research question / Problem statement

The objective of the report is to detect major challenges and trends for cybersecurity in Advanced Manufacturing:

- What are major challenges of cybersecurity in Advanced Manufacturing?
- What are the challenges of IoT cybersecurity?
- What types of cybersecurity are used in IoT?
- With Industrial Cybersecurity, how can we secure these new use cases and support business projects?

3.11.3.3 Findings

Facing increasing data flow, and numerous and subtler threats, we have noticed four major trends in Cybersecurity for Advanced Manufacturing and I4.0 in the recent years:

- **Efforts on national / public level to support Cybersecurity**
- **Developments in standardisation**
- **New training courses in cybersecurity and self-control analysis**
- **New ways to work**

Efforts on national / public level to support Cybersecurity: The implementation of a programme for digitising European industry (Industry 4.0) is an ambitious endeavour, linked to several new challenges that go beyond the large-scale cybersecurity framework tackled until now by the European strategies and legislation.

- Key European strategies and legislation on cybersecurity, including R&D investments, are currently focused on:
    - Protection of personal data
    - Security of operation of large scale and publicly accessible information networks
    - Protection of operation of key infrastructures (of public importance)
- The importance of cybersecurity in industrial settings is only marginally recognised in relevant EU policies.
- Development of appropriate legislative and support activities particularly adapted to computerized manufacturing must become a more vigorous feature of the Digital Single Market.
- Cybersecurity in the context of digitised industry requires a more holistic approach[308].

[308] Miklos Gyorffi, «Digitising Industry (Industry 4.0) and Cybersecurity», *PE 607.361*, s. d., 12.

Strengthening European efforts in cyber capacity-building

Enhancing cybersecurity capacity-building is quickly becoming a priority for governments, international organisations, and the private sector. While the demand for skilled cybersecurity professionals continues to accelerate, organizations are struggling to find the right talent to fill jobs.

Efforts in standardisation

Cybersecurity: ISO 27001 is a standard that has become unavoidable. It deals with the security of information systems and concerns both digital and paper data. This is a trajectory in line with global developments, since the number of certificates worldwide has jumped from 36,000 to 58,000 between 2019 and 2021. Nearly 100,000 sites hold certificates worldwide, including nearly 1,600 in France. In terms of countries, the top three are China, Japan, and the United Kingdom, all of which have more than 5,000. The main reason for this growth is the central role played by data protection issues.[309]

Development of training courses and self-control analysis

A report from Cybersecurity experts in Europe found that in the last years, there has been a significant increase in the number of programmes offered by the higher education systems in Europe, most of them on master's degree level. Overall, these programmes do train to attain the skills required in the field, but there is still room for improvement. Some skills such as Law, Compliance or Privacy are underrepresented, suggesting more diversity in modules offered in the programmes is required. The number of enrolled students is increasing, and with that the number of graduate students in cybersecurity, both of which is estimated to double in the next two to three years. However, there is a gender balance issue in enrolment. From all new students enrolled, the number of female students (20%) is still much smaller than that of their male counterparts (80%). [310] [311]

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[309] CHRISTELLE MAMBUENI, «Cybersécurité : ISO 27001, une norme devenue incontournable», *Groupe AFNOR* (blog), 23 novembre 2022, https://www.afnor.org/actualites/cybersecurite-iso-27001-norme-incontournable/.

[310] «EC Webinar: 'How to Train More Cybersecurity Experts in Europe' - European Forum for Vocational Education & Training», 21 mars 2022, https://efvet.org/ec-webinar-how-to-train-more-cybersecurity-experts-in-europe/.

[311] «DTAM: A New EU Project to Facilitate the Digital Transformation in Advanced Manufacturing - European Forum for Vocational Education & Training», 18 janvier 2021, https://efvet.org/dtam-a-new-eu-project-to-facilitate-the-digital-transformation-in-advanced-manufacturing/.

Economic Security labels

Projects such as MINALOGIC[312] in France, aim to provide a simple and effective response to help cluster members (and in this case, companies in the Auvergne-Rhône-Alpes French region) to assess their risk exposure and provide them with support in setting up a phased remediation plan.

Based on proven cooperation models between Fraunhofer and universities of applied sciences, a model is being implemented for the further training of IT security specialists which involves the universities of applied sciences as partners in cooperative research, in the development of further training concepts and teaching modules, and finally in the teaching of the course content.

By setting up the Cyber Security Training Laboratory[313] as well as the networking opportunities, the continuing education offers of various partner consortia, users and decision-makers are addressed. The modules are tailored to the needs of industry and public administration in terms of sectors, topics, and functions.

Because companies in all sectors are well into their digital transition, they concentrate a lot of their know-how, their strategic information, and their operational capacities on their digital uses. This opens the door to cyber theft, interruptions or malfunctions that can severely impact their prosperity.

Therefore, it becomes necessary to control the business risk linked to the use of new digital technologies. This objective is made difficult by the technical and varied nature of cybersecurity issues. But it is achievable if we do it right.

The "Cybersecurity Best Practices For SMEs Assessment" is a simple and quick online self-assessment questionnaire launched by four Cybersecurity research projects funded by the European Commission. In less than 15 minutes SMEs can easily understand where they stand in terms of cybersecurity practices implementation and learn basic security guidelines to be applied in their day-to-day routine.[314]

The result is a personalized diagnosis that establishes a company's maturity in terms of cybersecurity and recommendations for services and training based on the answers in each of the areas covered. The results obtained are exportable and resources are suggested according to the

[312] «Minalogic lance son label pour augmenter la cyber-résilience de ses adhérents», Minalogic, 21 février 2023, https://www.minalogic.com/cybersecurite-comment-proteger-votre-entreprise/.

[313] «Cybersecurity Training Lab - Fraunhofer IOSB», Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB, s. d., https://www.iosb.fraunhofer.de/en/projects-and-products/cybersecurity-learning-lab.html.

[314] «Making Global Supply Chains Cyberthreat-Proof | News | CORDIS | European Commission».

results, some of which are available online. The main objective of the self-diagnosis is to measure the level of cybersecurity of a company and its ability to protect themself. [315] [316]

Major challenges of cybersecurity in Advanced Manufacturing

One of the challenges highlighted in the recent NATO Energy Security Center of Excellence (NATO ENSEC COE) guide is the adoption of Industry 4.0 or Industrial Internet of Things (IIoT) that has led to the integration of manufacturing with business functions, with sensors added to collect data on all the machine-to-machine activity for data analysis, and risks about cybersecurity.[317]

Taking the time to evaluate software security within an organization is paramount and could be among the best solutions. Many technologies have emerged in recent years with cybersecurity challenges. Here are a few that will likely be a part of our daily lives in the years to come.

Ubiquitous connectivity: We are moving towards a world where everything is connected: devices, software, objects... As data flows between enterprise applications, cloud- and SaaS-connected software, and IoT devices, the risk of cyberattack increases exponentially for businesses. A shared responsibility model between cloud providers and companies will address this, alongside a zero-trust approach.

Abstraction and componentization: Software and technology continue to be at the core of business development. As a result, companies are constantly looking for ways to innovate and create software faster. To get faster, many development teams are turning not only to the cloud but also to microservices. Microservices break down entire applications into the smallest reusable blocks possible, so they can be assembled into processes or workflows.

Hyper-automation of software delivery: The hyper-competitiveness of the market leads to a need to go faster and faster and to eliminate all process inefficiencies through hyper automation. This also concerns software development, and all processes that interact with software delivery. This will put code at the centre: security as code, compliance as code, and infrastructure as code. In addition, IT security teams will be more involved in defining security policies.

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[315]«Formation en ligne Cursus Cybersécurité - Bpifrance Université», *BPI France Universite* (blog), s. d, https://www.bpifrance-universite.fr/formation/e-parcours-cybersecurite/.

[316]«Formation en ligne Autodiag Cybersécurité - Bpifrance Université», *BPI France Universite* (blog), s. d., https://www.bpifrance-universite.fr/formation/autodiag-cybersecurite/.

[317]Anna Ribeiro et al., «Cybersecurity and Reliability Challenges from Adoption of Industry 4.0 in IACS Environments», *Industrial Cyber* (blog), 30 janvier 2022, https://industrialcyber.co/industry-4-0/cybersecurity-and-reliability-challenges-from-adoption-of-industry-4-0-in-iacs-environments/.

Evolution of open-source libraries: Open-source libraries provide teams with common features that can be easily incorporated into code and thus make them more efficient. Unfortunately, most developers admit that they never update third-party libraries after incorporating them into the code base. As open-source libraries continue to evolve, not updating their vulnerabilities is a major cause for concern. In fact, nearly one-third of applications now have more security flaws in their third-party code than in their source code. [318]

3.11.3.4 Conclusions

New generation of national cybersecurity strategies[319] [320]

OECD recommends that Members and non-Members adhere to their recommendation to adopt a digital security risk management approach to build trust and take advantage of the open digital environment for economic and social prosperity, applicable at all levels of government and in public organisations; based on their proposed principles, which are complementary, should be taken as a whole, and are meant to be consistent with risk management processes, best practices, methodologies, and technical standards; and calls on private organisations to promote and implement those principles.

Cybersecurity in industry for advanced and intelligent manufacturing environments[321]

Companies can adopt several different tactics to create an effective cybersecurity strategy - enterprises should conduct audits on a regular basis, use two-factor authentication, identify the major threats, and enforce a strong sign-off policy. Investments into platforms that have a track record of robustness and security strength must be a priority in this information era. Similarly, Garrett Austin, Business Development Lead at Rockwell Automation, describes a three-pronged approach to help manufacturers stay safe, which involves determining OT Maturity by increasing visibility and monitoring; establishing an IT/OT Strategy and creating governance around it; and building bridges between engineering, operations, and IT.

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[318]«Cybersécurité : les tendances qui auront un impact sur vos applications en 2022», JDN, 7 janvier 2022, https://www.journaldunet.com/solutions/dsi/1507951-cybersecurite-les-principales-tendances-qui-auront-un-impact-sur-vos-applications-en-2022/.

[319]«OECD Legal Instruments», OECD Legal Instruments, s. d., https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0479.

[320]«Science and Technology - OECD», OECD, s. d., https://www.oecd.org/science/.

[321]Carla Larkin, «Cybersecurity for Advanced and Intelligent Manufacturing Environments», *ATMS*, s. d., 1.

Best practices of top-tier organizations

1. Appropriate security measures for I4.0 might be those with proven track-records in other (industry-related) environments:
    - Strengthening detection resources, especially the flows from and to industrial IS, to prevent threats from spreading. If a company has not already done so, docking with the Group SOC is recommended.
    - Ensuring the integrity and traceability of transmitted/received data, encryption, and authentication should be implemented. If a company already has a Group PKI, they should consider extending it to industrial perimeters.
    - Strengthening OCM / SCM process, installing antivirus protection, regularly updating it, and installing security patches on the most used OS.
    - Finally, considering which solutions are critical for the business. A cyber-resilience component must be anticipated so that the solution can be quickly rebuilt and restarted in the event of an attack.

    There are plenty of solutions, but they require adapted support from the cybersecurity teams and going beyond theoretical models.[322]

2. Top-tier organizations are 177% more likely to have security vulnerability response time as one of their top three success metrics.

    As the adage goes, "What gets measured gets improved," and responding quickly to OT security vulnerabilities is key to protecting these systems. The organizations with the best outcomes are nearly three times as likely to have this measurement as a prominent part of their performance review.

3. Top-tier organizations are 37% more likely to have network access control technology in place.

    Ensuring that only authorized parties can access specific systems is critical for securing any technology asset. When it comes to OT, people who need access to such systems have a relatively narrow range of job titles. Organizations that avoided intrusions last year are much more likely to have such controls in place.

4. Top-tier organizations are 48% more likely to report security compromises to senior/executive leadership. Items that are included in regular reports to executive leadership tend to remain at front of mind throughout the year. Organizations that keep top leaders apprised of security compromises tend to have fewer of them. Top-tier organizations tend to be more transparent with executive management.

[322] Julien Verrier, «La cybersécurité industrielle à l'ère de l'Industrie 4.0», RiskInsight, 2021, https://www.riskinsight-wavestone.com/en/author/julien-verrier/.

5. Top-tier organizations are 32% more likely to have their SOC monitor and track OT security.

   Security operations centres (SOCs) have existed for decades and have developed granular best practices for managing IT security. OT leaders who have avoided intrusions are more likely to have entrusted OT security to the same group.

6. Top-tier organizations are 44% more likely to track and report intrusions detected and remediated.

   Understanding past attacks sharpens an organization's skills at thwarting future ones, and this starts with keeping records. Organizations that avoided intrusions are more likely to routinely report them when they do occur.

7. Top-tier organizations are infinitely more likely to use just one vendor for their IP-enabled OT devices. Avoiding complexity in networking and systems is a good way to reduce the attack surface and improve the security posture. None of the organizations that experienced 10 or more intrusions were using just one vendor for their IP-enabled OT devices, while nearly one-third of top-tier organizations had achieved this. [323]

The challenges of IoT cybersecurity

The biggest challenge is the rapid detection of attacks and their identification to act more effectively, thus reducing severe consequences, as we are talking about an IoT environment that consists of several connected sensors. Usually, low processing capacity makes it difficult to protect them. Researchers seek to create innovative tools that can overcome these obstacles while keeping IoT sensors protected to solve this problem. A significant challenge is linked to the evolution of increasingly innovative and sophisticated attacks, leading industries to seek innovative solutions to combat current and future attacks. As security evolves, cyberattacks evolve too.

Types of cybersecurity used in IoT

Several forms of protection against cyberattacks lay in different industries. The cybersecurity of intelligent manufacturing must be developed in a personalized way. There is no common method of use, although the concept presents variations with similarities. However, the most promising are based on machine learning and blockchain. [324]

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[323] « Fortinet | Arcview Research Analysis ».

[324] Rudenko et al., « A Brief Review on Internet of Things, Industry 4.0 and Cybersecurity ».

We have noticed four major trends in the past years in cybersecurity for Advanced Manufacturing & I4.0:

- **Cybersecurity is becoming a national and public concern.**

  Europe, national governments, and national bodies are concerned with cyber threats in industry, which have increased significantly in the past years. that have increased a lot in the last few years. The rules and good practices to apply across industry to counter threats are across Europe. Educational courses within Advanced Manufacturing should consider cybersecurity.

- **Standardisation is becoming a general trend in Industry, Industry 4.0 and Advanced manufacturing.**

  National and European organisations are working on standardisation within cybersecurity. Educational courses for future industry professionals should take this into account.

- **New training courses must involve cybersecurity in each step, and self-control analysis by professional users must become more common.**

  Educational courses need to include cybersecurity at each step. Professionals within the industry need to apply self-control analysis at each step of their work.

- **Cybersecurity must be introduced in Industry 4.0 and Advanced manufacturing, for within- and between company communication.**

  Industry 4.0 should threat cybersecurity within and between companies seriously, considering the increase of cyber threats in the past years. Educational courses for future industry professionals should take this into account.

3.12 ADDITIVE MANUFACTURING: 3D METAL PRINTING

3.12.1 Introduction

First patented in 1995 by the Fraunhofer Institute in Germany as a laser fusion technique[325], 3D metal printing has continued to evolve to become an essential tool to manufacturing in many sectors such as the aerospace, automotive, and industry sectors.

Like 3D plastic printing, 3D metal printing offers various advantages. It allows to quicken the process between the idea and the manufacturing of the part. It also allows to make parts with less material than with machining. It can be used to repair parts by remaking subparts, which allows parts to last longer as a whole and reduces waste. Finally, printing parts means producing parts locally instead of importing them. These various advantages mean a lesser cost in transportation, materials, and parts. However, a drawback is the lack of reproducibility of parts.

According to a Wohlers report from 2018 on the 3D printing material market, metal represented 16,2% in 2017. [326] This report also estimated that the metal 3D market was worth $720 million and that the sales of 3D printers using metal increased by 80%. [327]

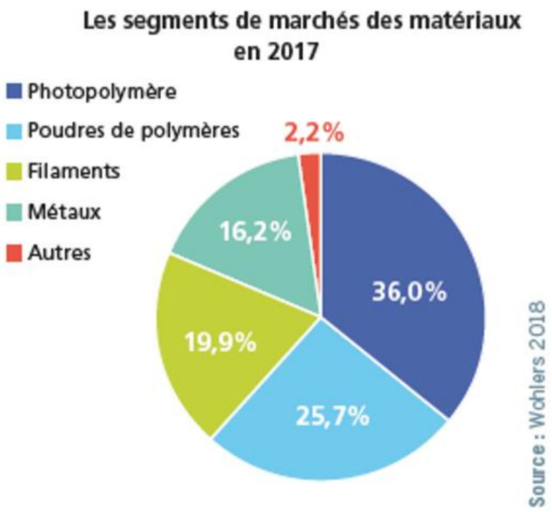

Figure 51: Materials market in 2017

[325]'Impression 3D métal : Le guide de l'impression métal', Hubs, accessed 14 April 2023, https://www.hubs.com/fr/guides/impression-3d-metal/.

[326]«Wohlers Report 2018 Shows Dramatic Rise in Metal Additive Manufacturing and Overall Industry Growth of 21%», *Wohlers Associates* (blog), 27 mars 2018, https://wohlersassociates.com/press-releases/wohlers-report-2018-shows-dramatic-rise/.

[327]«Impression 3D métal».

3.12.2 3D technologies in the Industrial Sector

Title	Description	Geographical scope	Sectorial scope	Link
3Dnatives	Industry publication specialized in 3D printing	French and International	3D printing	LINK LINK
Aniwaa	Website that advises professionals on additive manufacturing equipment	French	Additive manufacturing	LINK
L'Usine Nouvelle	Industry publication providing manufacturing news	French, International	Multisector	LINK
The Manufacturer	Industry publication providing manufacturing news	European, International	Multisector	LINK
Manufacturing	Industry publication providing manufacturing news	European, International	Multisector	LINK
IDTex	Independent market research provider	European, International	Multisector	LINK

Table 5: Sources 3D technologies

Since then, many different printing technologies have been developed. As more and more companies developed 3D metal printing techniques, the future of the sector appeared bright. During the 2010s market research expected the sector to boom however 10 years later the sector has not grown nor changed as much as expected. Despite a great number of innovations over the years, the DMLS technique is still the most common used technology in companies.

It appears that this sector is slowed down in its growth by the price-range of 3D metal printers and their implementation in a company unsure of its efficiency.

The 3D metal printing sector is constantly putting forward new printing techniques that allow companies to print parts more easily.

Different printing processes

Companies also use varying 3D printing techniques to take advantage of different aspects of 3D printing. [328]

The two most common types of techniques are Powder Bed Fusion and Directed Energy Deposition[329]. These two are types of techniques that include many different techniques and labels with each their own advantages, drawbacks, price range and uses.

Powder bed fusion

The first technique[330] developed in the 1990s is still the most common one. It works by sintering or melting a powder bed using a heat source such as a laser or electron beam. EOS' Direct Metal Laser Sintering is one of the most renowned technologies using that technique. Though this technique can either sinter or melt metals, melting is considered more convenient because sintering implies that metal particles are agglomerated together leaving holes. Because of these holes, the mechanical resistance of the final part is weaker than if it had been melted.

If the heat source used is an electron beam, the technique is called Electron Beam Melting. The process is faster and there are fewer strains. However, it is not as precise as laser melting and the maximum size of parts is about two times smaller for EBM depending on the printer used.

There is currently research being led on ways to make 3D metal printing more sustainable. That is for instance the case of F3nice which worked on working with more sustainable metal powder. [331]

Directed energy deposition

The second one[332] melts the metal (provided in the form of powder or wire) using concentrated energy such as a laser, an electron beam, or a plasma arc. This technique requires machining post-treatment. It can be used with every weldable metal, which isn't the case with the Powder Bed Fusion technique.

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[328] 'Tout savoir sur l'impression 3D métal', 3Dnatives, accessed 23 March 2023, https://www.3dnatives.com/impression-3d-metal/.

[329] Tom Comminge, 'Fusion laser sur lit de poudre VS DED : quel procédé d'impression 3D métal choisir ?', 3Dnatives, 13 March 2023, https://www.3dnatives.com/metal-pbf-ded-14032023/.

[330] Mélanie W, 'Fusion laser sur lit de poudre, on vous explique tout !', 3Dnatives, 2 September 2019, https://www.3dnatives.com/frittage-laser-poudres-metalliques-on-vous-explique-tout/.

[331] Tom Comminge, '#Startup3D : F3nice développe des poudres d'impression 3D métal plus durables', 3Dnatives, 9 November 2022, https://www.3dnatives.com/f3nice-poudres-metalliques-091120223/.

[332] Mélanie W, 'L'impression 3D par dépôt de matière sous énergie concentrée, on vous explique tout !', 3Dnatives, 9 September 2019, https://www.3dnatives.com/depot-de-matiere-sous-energie-concentree-10092019/.

Other techniques

A somewhat-similar technique worth mentioning is the binder jetting[333] technique. Instead of melting the powder, the particles are bound together by a jetted binder. This technique is more cost effective than PBF processes but as the particles aren't melted together the product is slightly weaker[334].

There is also the Fused Deposition Modelling process, also called Fused Filament Fabrication335. Instead of using a powder, a composite filament of melted metal or polymer is used. It is more accessible as its price starts at 200€ and it is easier to use. However, the parts aren't as detailed as parts made with other processes.[336]

Companies such as the Italian F3nice[337] or the American VEL03D[338] have also developed printers that require no or much less support to print parts. This allows the manufacturing of parts using less material.

Size of 3D printed parts

A major obstacle to 3D printing is the size of the final product. As the part can't be bigger than the printer, the parts' size is limited. But companies are working on making bigger printers to print bigger parts. As such in 2020 Titomic unveiled a new printed that they claimed to have developed the world's largest 3D metal printer[339], capable of even printing aeroplane wings.

As such bigger parts have been printed through 3D printing. For instance, Czinger has made an entire gearbox through 3D metal printing[340].

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[333]Philippe G, 'Avec l'acquisition de Digital Metal, Markforged se lance dans le liage de poudre', 3Dnatives, 20 July 2022, https://www.3dnatives.com/digital-metal-markforged-21072022/.

[334]Tom Comminge, 'TOP 5 des vidéos de la semaine : Tout savoir sur le binder jetting', 3Dnatives, 25 February 2023, https://www.3dnatives.com/top-5-des-videos-de-la-semaine-tout-savoir-sur-le-binder-jetting/.
'Understanding Binder Jetting'.

[335]Mélanie W, 'Un procédé d'impression 3D FFF plus rapide et précis', 3Dnatives, 9 August 2022, https://www.3dnatives.com/procede-mf3-impression-3d-10082022/.

[336]Mélanie W, 'FDM ou SLA : quelle technologie d'impression 3D choisir?', 3Dnatives, 14 January 2018, https://www.3dnatives.com/fdm-ou-sla-technologie-15012018/.

[337]Mélanie W, 'EOS développe une solution d'impression 3D métal sans support', Newspaper, 3Dnatives, 19 February 2023, https://www.3dnatives.com/eos-impression-3d-metal-sans-support-20022023/.

[338]Mélanie W, 'Knust-Godwin mise sur la technologie de VELO3D pour imprimer en 3D des pièces métal sans supports', 3Dnatives, 22 June 2020, https://www.3dnatives.com/velo3d-et-knust-godwin-impression-3d-23062020/.

[339]Chapman, 'World's Largest 3D Metal Printer Unveiled in Melbourne'.

[340]Mélanie W, 'Czinger présente une première boîte de vitesses imprimée en 3D en aluminium', Newspaper, 3Dnatives, 21 March 2023, https://www.3dnatives.com/czinger-boite-de-vitesses-3d-22032023/.

Components

3D metal printing can be done using different metals. Each has different advantages and inconvenient which make them more suitable for some sectors compared to others.

Steel is versatile, to have good corrosion resistance, an overall strong resistance, and a strong hardness, but a loss of resistance when submitted to high temperatures. Because of these characteristics and particularly its resistance, steel is more used in the aerospace, automotive, manufacturing, and medical sectors.

Aluminium is another common resource for 3D metal printing. It has excellent mechanical properties and it can produce complex parts. However, it has a high cost. As such it is mostly used in the aeronautics, space, automotive, and medical sectors.

Cobalt-chrome is an alloy used in 3D metal printing for its high resistance to wear, biocompatibility, and heat resistance. But, like aluminium, this alloy is also expensive. It is mostly used in surgical implants, engine parts, wind turbines, and the aeronautics sector.

Finally, nickel is used for its high-temperature corrosion resistance, its mechanical properties equivalent to forgings, its good ductility at low temperatures, and the fact that it is a refractory material. However, it is particularly costly. It is mostly used in jet engines, for rockets for instance.

Companies have also been working on new metal alloys to exploit their advantages. The most common metal used is aluminium as it's sturdy and light. Other metals are used in different industries such as steel in the manufacturing sector for its mechanical properties and good surface finish, a cobalt-chrome alloy for medical applications, titan for corrosion resistance, and precious metals in the jewellery sector. However, using precious metals makes it difficult to manage the finishing stages of a product. But companies working on high-end products in automotive for instance are working on ways to use these metals more easily, like Bentley Motors[341]. Recently a new alloy made of steel and bronze was used in 3D printing, thus combining the advantages of both components[342].

Impacts on sectors

New metal alloys and 3D printing techniques are key factors in improving 3D printed metal products, for instance in terms of weight. 3D metal products are used in sectors where lightness is a priority and thus always an axis for improvements, such as in the aerospace, automotive, and

[341]'Bentley Motors Uses Ground-Breaking 3D Printed Gold in Mulliner Batur', The Manufacturer, 19 December 2022, https://www.themanufacturer.com/articles/bentley-motors-uses-ground-breaking-3d-printed-gold-in-mulliner-batur/.

[342]Mélanie W, 'Un nouvel alliage de bronze et d'acier développé grâce à l'impression 3D DED', 3Dnatives, 16 January 2023, https://www.3dnatives.com/alliage-bronze-acier-impression-3d-160120233/.

sports sectors. For instance, companies such as Mythos[343] and the Italian Pinarello344 have both made bicycles using 3D-printed parts.

In the defence sector, the use of 3D printing has also evolved. In the US[345] and the Dutch[346] marines, ships are being equipped with printers to avoid the obsolescence of parts while out at sea. As 3D printers allow the creation of parts in small quantities it is a very useful tool in these circumstances. In France, the company Dassault Aviation has tasked Addup with setting up a 3D metal printing workshop for 2025.[347]

Retail price

Companies are also working on making 3D metal printers more accessible, as most are at least 100 000$ Because of the price-range for printers, companies are deterred to switch their manufacturing process from machining to 3D printing.

This explains the large difference in growth between 3D plastic and 3D metal printing.

As such, the German Fraunhofer Institute[348] and the American company IRO3D[349], for instance, have both designed cheaper 3D printers. The first one cost 30 000€ and the second one starts at 5 000$. However, despite the announcements they are not available on the market as of today.

To add to the steep price of 3D metal printers, materials are also expensive, especially those particularly resistant and lasting, such as titan and the alloy Inconel®.

Companies also need CAO software to design parts before using the 3D metal printer. That can represent an additional spending.

These prices make 3D metal printing inaccessible to individuals and most companies apart from a niche that made the leap.

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[343]Tom Comminge, 'Mythos et IXO, sa nouvelle potence imprimée en 3D métal', 3Dnatives, 9 December 2022, https://www.3dnatives.com/mythos-potence-velo-091220223/.

[344]Mélanie W, 'Tour d'horizon des vélos qui ont misé sur l'impression 3D', 3Dnatives, 30 March 2023, https://www.3dnatives.com/velo-imprime-en-3d-22092020/.

[345]Tom Comminge, 'La Marine américaine intègre l'impression 3D métal dans ses navires de guerre', 3Dnatives, 8 November 2022, https://www.3dnatives.com/marine-americaine-impression-3d-metal-081120228/.

[346]Tom Comminge, 'La Royal Netherlands Navy fait appel aux solutions d'impression 3D de Nanoe', 3Dnatives, 16 September 2022, https://www.3dnatives.com/marine-neerlandaise-impression-3d-nanoe-160920223/.

[347]Gautier Virol, '[L'instant tech] Chez Dassault Aviation, AddUp automatise l'impression 3D métallique', L'Usine Nouvelle (www.usinenouvelle.com, 6 December 2022), https://www.usinenouvelle.com/editorial/l-instant-tech-chez-dassault-aviation-addup-automatise-l-impression-3d-metallique.N2074551.

[348]'L'Institut Fraunhoffer dévoile une imprimante 3D métal low-cost', 3Dnatives, 2 November 2016, https://www.3dnatives.com/imprimante-3d-metal-low-cost-02112016/.

[349]Michelle J, 'Iro3d Lowers the Cost of 3D Metal Printing with a $ 5,000 Machine', 3Dnatives, 27 November 2018, https://www.3dnatives.com/en/iro3d-lowers-cost-3d-metal-printing-machine-271120185/.

Training

These prices also make it difficult to train anyone in 3D metal printing processes. Buying only one printer already requires a big budget and it may not be enough to teach multiple students.

Furthermore, as shown previously, there is a wide variety of technologies used in 3D metal printing, even in just the Powder Bed Fusion category. That means that ideally, students should be able to train on different types of printers to acquire knowledge and experience on a range of processes. But buying multiple kinds of printers is difficult for training centres. That makes training more difficult as students are not able to get experience in many kinds of processes.

Moreover, while powder bed fusion printers are the most common, and thus the main kind of printer students should practice on, using metal in the form of powder poses health and safety risks.[350]

Finally, because of the health threats posed by the metal powders used in Powder Bed Fusion. There are many safety instructions to be taken to use these types of printers. These make training sessions more complicated to organise. As such, it's easier for training centres to buy cheaper and less dangerous printers. But that implies that students are being taught about 3D metal printing on printers such as FDM printers that are not common in companies using 3D.

Furthermore, to use 3D metal printers, students need to train not only on how to use to the printer but how to design the part using CAO and how to do the necessary post-treatments of the part for it to last.

As such these trainings are not meant to make students specialists in 3D metal printing. They are just introductions to the subject. That means that companies will have to train workers themselves if they need someone specialized in working on a 3D metal printer.

Training in 3D metal printing is limited by the prices of the printers and their adoption by companies. The investment required to switch to 3D metal printers is too important to risk it. It is a vicious cycle that slows the growth of a sector that shows a lot of promise.

[350] 'Health and Safety – Metal Powder AM', The National Centre for Additive Manufacturing, accessed 13 April 2023, https://ncam.the-mtc.org/resources/core-research-programme/health-and-safety-metal-powder-am/.

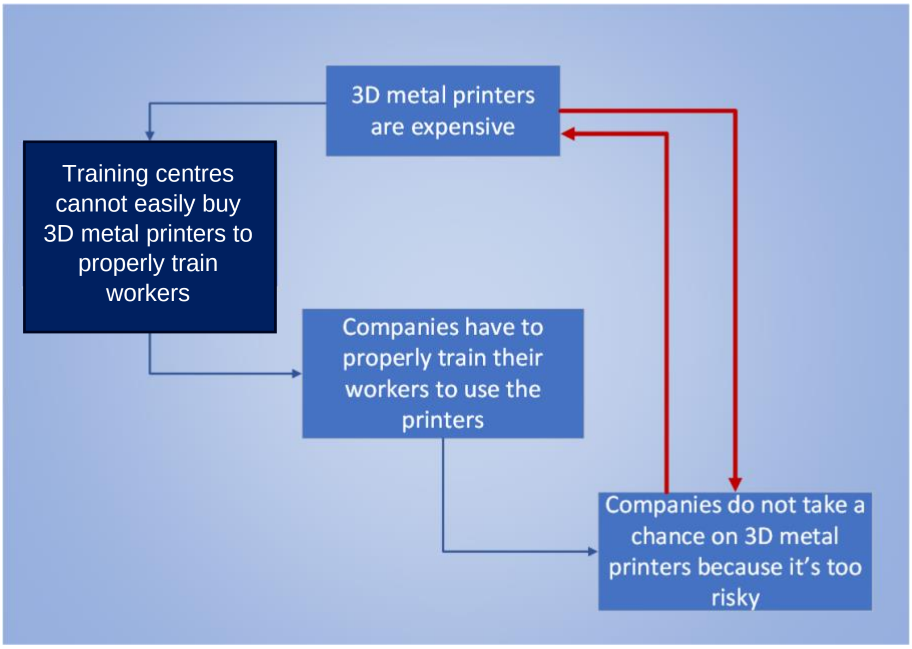

Figure 52: vicious cycle that slows the growth of a sector

3.12.3 3D Technologies in the Educational Sector

With the new year just beginning, many education leaders are wondering what the future holds for classrooms. The short answer is more attention to Education 4.0. The use of technology in education prior to the pandemic was sparse, but during the close of 2020 the Fourth Education Revolution or Education 4.0 began to blossom and is transforming and bringing a new era of learning for Generation Z students.

3D printing and scanning technology has grown so rapidly that it is making waves in all sectors. Its application has become so versatile and in demand that there is a growing need for people who can understand, manage and deliver innovation through 3D printers and 3D modelling concepts. This is why educational technologists and academics are working together in the search for better ways to engage, attract and retain students. Adopting different technologies in education is the way forward. So much so that the global 3D printing market is expected to grow and reach 15.3 million 3D printer units.

The growing demand is in response to prototyping, functional component and tooling applications in various sectors such as healthcare, automotive, industrial equipment, aerospace and defence, which are expected to drive global market growth. To meet these future demands, 3D printing and scanning need to become a key element in all levels of academic and professional research; this will prepare students for work that demands sharp critical thinking and collaborative skills.

Although 3D printing and scanning technology has not yet become a standard in higher education, its adoption by some colleges, universities and training centres is causing a worldwide sensation.

Thanks to 3D printing and scanning, educators can design enriching learning experiences to deepen theoretical constructs, bringing learning from computer screens into the hands of students. 3D printing and design allow medical students to print organs, chemistry students to study 3D printed molecules in detail, graphic design students to create 3D versions of their artwork, history students to print ancestral artefacts, architecture students to 3D print models of their projects, engineering design students 3D printing prototypes, and dental students confidently advancing their endodontic training by 3D printing teeth to practice procedures such as pulp chamber access, root canal enlargement, irrigation, and root canal filling, among other examples.

The main driving force behind the explosion of job growth and demand in the sector is that even traditional organizations are realizing the potential of 3D printers and scanners, and interest is expanding with tremendous momentum. It is already a reality today, that an increasing number of job openings are requesting professionals who can implement 3D printing, additive manufacturing and 3D scanning into company processes.

Institutions are already embracing this massive educational transformation by bringing into classrooms the tools that will help both students and faculty adopt the new model as soon as possible. So much so that the Ministry of Education and Vocational Training has developed with the MEFP, new specialization courses that allow complete training of those who already have a VET degree and want to incorporate the latest innovations in productive areas of high employability such as additive manufacturing.

3.12.4 Most Relevant Fields

Engineering

3D printers and scanners are a rapidly advancing technology that requires engineers who can understand, maintain and operate the equipment. Mechanical, industrial or software engineers will have a better understanding of what is involved in producing accurate working models and components for manufacturing and architectural designs.

Aeronautics sector

MAM has proven to be a key technology for manufacturing highly complex parts and customized geometries with advanced materials in the aeronautics sector. Its advantages in terms of weight reduction, cost and improved efficiency and safety are important for the aerospace industry.

Animation and design

One field that uses many of the same tools is 3D animation, which is used in many places, from web graphics to feature films. 3D design software is used to translate visual concepts into tangible objects. A background in 3D animation ensures an understanding of the software and modelling concepts.

Software developers

The current state of 3D printing software is much less user-friendly than conventional applications, but as the technology progresses there will be opportunities for programmers who can develop cross-platform software, better interfaces, and more features and functions that make using 3D printers and scanners easier and more productive.

Biomedical technology

The constant demand for better healthcare treatments has also become part of the expanding market for 3D printers. Medical researchers can create functional organ models and even functional arterial implants from 3D materials. Biomedical experts can lead the development of new medical solutions through this new 3D technology.

3.12.5 Transversal Skills

Creativity and innovativeness: Creative skills are fundamental to the development of a successful student. Designing models and figuring out how to optimize the 3D printing process takes students' creativity to new levels, as well as triggering innovation.

Real-world understanding: It is important for educators to create opportunities for students to better understand how the skills they gained can be applied to real-life professional work after graduation. 3D printing provides an invaluable platform to create real-world models that allow for visualization and touch, such as performing root canals on 3D printed tooth model specimens.

Reinforcing digital engagement: 3D printing involves learning skills other than CAD design and post-processing. Students can learn the workflow of 3D scanning, which involves obtaining accurate measurements from a set of overlapping photos and converting them into a 3D model using a series of computer algorithms.

Problem-solving skills: Students learn to solve real-world problems. It was 3D printing that solved the problem of the global shortage of personal protective equipment (PPE) during the Covid-19 pandemic. Students learn how to go from an abstract idea to a 3D printed object.

Leveraging design thinking: Collaboration is a critical component of design thinking. By using 3D printing, students can collaborate with their peers on assigned projects. In group projects, students learn from each other's perspectives and different working styles. 3D printing and scanning also encourages students to improve designs based on previous results and feedback.

3.12.6 Conclusions and Challenges to be Addressed

VET students and graduates do not have the skills demanded by the industry, therefore, it is necessary the approach between study centres and the industry, through an educational environment that promotes this type of personal development of students.

The new challenges faced by our industry require professionals with multidisciplinary and transversal skills that must be matured in a second stage of continuous training, between companies and training centres.

Metal printing requires advanced knowledge that cannot be addressed from the basic start of training. It is therefore necessary a previous stage of training of concepts and knowledge linked to the technology to subsequently deepen the specialization.

Despite various advantages to 3D metal printings and various printing techniques, the 3D metal printing sector's growth is limited by the high price-range of the printers. Due to the high cost of metal printing installations, the distribution of these means to educational centres is complicated. It is necessary to pool resources and provide travel facilities for students who opt for this specialization.

Metal printing technology should not be understood as the action of printing an object within the reach of any domestic user. In this sense, it is necessary to work on the culture of adding instead of "printing" in order to avoid trivializing the professionals in the sector.

3.12.7 Statements

The 3D metal printing sector's main obstacle is printers' high retail price. 3D metal printing would be much more implemented in companies if printers were more affordable.

There are a wide variety of 3D metal printers which makes it harder to train people in using them.

Future 3D metal printing innovations are expected to make using 3D metal printing more useful in the automotive and aerospace sectors

Metal printing requires advanced knowledge that cannot be addressed from the basic start of training. It is therefore necessary for a previous stage of training of concepts and knowledge linked to the technology to subsequently deepen the specialization.

Due to the high cost of metal printing installations, the distribution of these means to educational centres is complicated. It is necessary to pool resources and provide travel facilities for students who opt for this specialization.

3.13 ADDITIVE MANUFACTURING: 3D SCANNING

3.13.1 Introduction

3D scanning is the process of capturing the shape, texture, and colour of physical objects using specialized equipment and software. This technology creates a digital model of the object that can be used for a wide range of applications, from design and manufacturing to quality control and inspection.

3.13.2 Use of 3D Technologies in Education

3D scanning has become an increasingly popular tool in education, as it provides students with a hands-on and interactive way to learn about various subjects. Here are some ways 3D scanning is used in education:

Engineering and technology: 3D scanning can be used in engineering and technology courses to create digital models of parts and components. This allows students to explore and experiment with different designs and configurations, and helps them understand how different parts fit together to create a working product.

Science: 3D scanning can be used to create digital models of specimens such as bones, rocks, and plants. This allows students to examine and study these objects in detail without the need for a physical specimen, which may be difficult to obtain or handle.

Art and design: 3D scanning can be used to capture and create digital models of physical objects, which can be used in art and design projects. This allows students to explore different design concepts and experiment with various materials and shapes.

History and culture: 3D scanning can be used to create digital models of artefacts, historical sites, and cultural landmarks. This provides students with a more immersive and interactive way to learn about history and culture, allowing them to explore these subjects in greater depth.

Overall, 3D scanning provides a powerful tool for educators to enhance student learning and engagement in a variety of subjects.

3.13.3 Most Relevant Fields

In the industry, 3D scanning is used in a variety of ways, such as:

Product design and development: 3D scanning is used to capture the shape and geometry of physical objects, which can then be used to create digital models for product design and development. This allows designers to work with real-world objects and make accurate modifications to the design before producing the final product.

Quality control and inspection: 3D scanning is also used for quality control and inspection purposes. By scanning parts and components, manufacturers can compare the digital model to the original design and identify any discrepancies or defects that may impact performance or safety.

Reverse engineering: 3D scanning is often used for reverse engineering, which involves creating a digital model of an existing physical object in order to reproduce it or modify it. This can be useful for creating replacement parts or improving the design of existing products.

Cultural heritage preservation: 3D scanning is also used for cultural heritage preservation, allowing museums and other institutions to create digital models of artifacts and historic sites. This allows them to share the objects with a wider audience and preserve them for future generations.

In industries such as **architecture, engineering,** and **construction,** 3D scanning is used for building documentation, inspection, and quality control. It helps in the creation of accurate and precise models of structures, providing a more in-depth understanding of the physical space.

In the **manufacturing** industry, 3D scanning is used for quality control, reverse engineering, and prototyping. It helps in the detection of defects or irregularities in products and the creation of digital models that can be used to develop new products or improve existing ones.

3D scanning is also used in the **entertainment** industry for creating special effects, video games, and animation. It helps in the creation of realistic characters and environments by capturing real-world objects and scenes.

In the **medical** industry, 3D scanning is used for patient diagnosis, treatment planning, and prosthesis.

Overall, 3D scanning has become an essential tool in different industries, allowing manufacturers to create more accurate and efficient processes while improving product quality and safety.

3.13.4 Transversal Skills

The use of 3D scanning in education can help develop several transversal skills in students, including:

Problem-solving: 3D scanning requires critical thinking and problem-solving skills, as students need to identify the best approach to capture the object, clean up the resulting data, and create a usable digital model.

Spatial reasoning: 3D scanning involves the use of spatial reasoning skills, as students need to understand how physical objects translate into digital models and how to manipulate these models in a virtual environment.

Creativity: 3D scanning can help develop students' creativity, as it allows them to experiment with different designs and shapes and explore new possibilities for creating and modifying objects.

Digital literacy: 3D scanning involves the use of specialized software and equipment, which can help students develop digital literacy skills, including the ability to use digital tools to create, edit, and manipulate data.

Communication: 3D scanning can help develop communication skills, as students need to be able to explain their approach and thought process to others, and collaborate effectively with their peers.

Overall, the use of 3D scanning in education can provide students with a range of transversal skills that are essential for success in the 21st century workplace.

3.13.5 Conclusions and Challenges to be Addressed

The use of 3D scanning technology presents several challenges for the vocational education and training system. Here are a few of the challenges that need to be addressed:

Access to equipment and software: 3D scanning requires specific equipment and software, we have more different solutions, they are in general more polyvalent and we can find more affordable options right now. That's why this type of technology is becoming more present in VET centres. Vocational education and training institutions need to ensure that students have access to these resources in order to gain practical experience with the technology.

Training and skills development: 3D scanning requires a range of technical skills, including the ability to use scanning equipment and software, to process and manipulate data, and create digital models. Vocational education and training institutions are incorporating these training programmes into their provision, but they are not yet part of the curriculum.

Keeping up with technological advancements: it is expected that in 3D scanning hardware and software will evolve substantially. This will require more collaboration between educators and the industry in order to maintain training processes and equipment updated.

Overall, the use of 3D scanning technology presents several challenges for the vocational education and training system, but with effective planning and implementation, it can provide students with the practical skills and knowledge needed for success in the next future workforce.

3.14 LASER SINTERING

3.14.1 Introduction

What is digital selective laser sintering?

Laser sintering is a sub-segment or a type of additive manufacturing.

3.14.1.1 Additive Manufacturing

Additive manufacturing is a process of creating a three-dimensional object by successive layers of material, most commonly plastic or metal.[351] [352]

Additive manufacturing, also known as 3D printing, is a process of producing a three-dimensional object from a digital model. The process involves successive layers of material being built up to form a physical object, usually from metals or plastics. This process can be used to create products from a wide variety of materials, from plastic to metal, and is often used for rapid prototyping and parts production.[353] [354]

3.14.1.2 Types of Additive Manufacturing

1. Fused Deposition Modelling (FDM)
2. Selective Laser Sintering (SLS)
3. Direct Metal Laser Sintering (DMLS)
4. Stereolithography (SLA)
5. Binder Jetting (BJ)
6. Electron Beam Melting (EBM)
7. Laminated Object Manufacturing (LOM)
8. Digital Light Processing (DLP)
9. Material Jetting (MJ)
10. High-Speed Sintering (HSS)

[351]«Additive Manufacturing Solutions | Prima Additive», s. d., https://www.primaadditive.com/en/additive-manufacturing-solutions?gclid=Cj0KCQjwlumhBhClARIsABO6p-ym0nMqRetErSvck2MzfLuMVzuyMZ7qaVMuBdYf_k-v1taW8tb1aEcaAilgEALw_wcB.

[352]«What Is Additive Manufacturing? (Definition & Types)», s. d., https://www.twi-global.com/technical-knowledge/faqs/what-is-additive-manufacturing.aspx.

[353]Ibid

[354]«Selective Laser Sintering (SLS)», MakerVerse, s. d., https://www.makerverse.ai/technologies-sls.

3.14.1.3 Selective Laser Sintering

Selective Laser Sintering (SLS) is a 3D printing technique that uses a laser to heat and fuse powdered material (such as plastic, metal, ceramic, or glass) layer by layer to create a three-dimensional object.[355] [356] [357]

Selective Laser Sintering (SLS) is an additive manufacturing process that uses a laser to selectively join powdered material by sintering to create a three-dimensional object. The laser selectively fuses the powdered material together one layer at a time, creating the desired 3D shape without the need for support structures. SLS is suitable for a range of materials, including metals, plastics, and ceramics, and is often used to create complex geometries and hollow parts.[358] [359] [360]

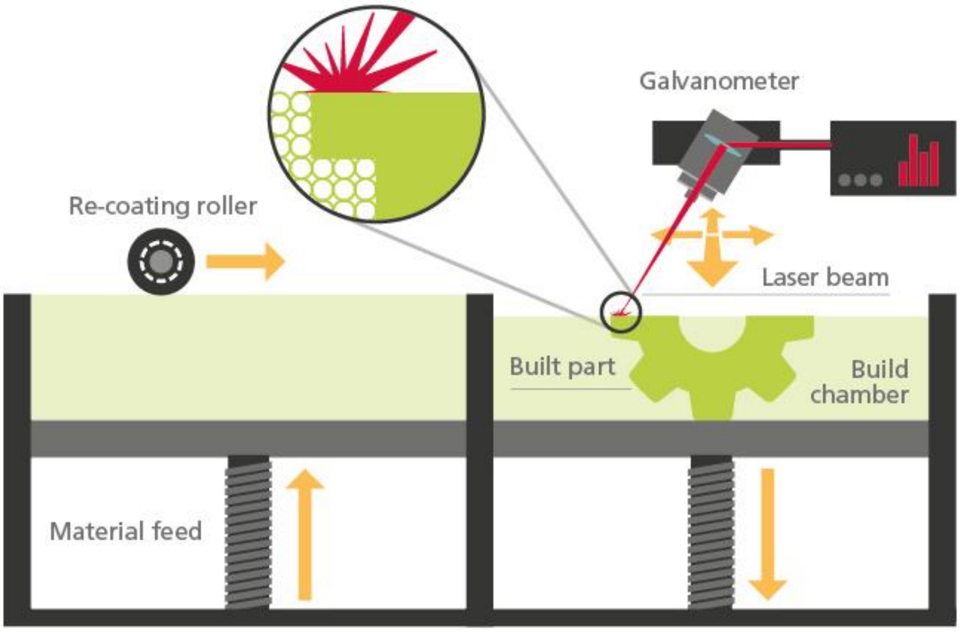

Figure 53: SLS - how it works - rapid prototyping

[355]«What Is Selective Laser Sintering (SLS)?», s. d., https://www.protolabs.com/resources/design-tips/designing-for-selective-laser-sintering/.

[356]Mahbub Hassan et al., «3D Printing of Biopolymer Nanocomposites for Tissue Engineering: Nanomaterials, Processing and Structure-Function Relation», *European Polymer Journal* 121 (décembre 2019): 109340, https://doi.org/10.1016/j.eurpolymj.2019.109340.

[357]«Selective Laser Sintering (SLS)».

[358]«What Is Selective Laser Sintering (SLS)?»

[359]Hassan et al., «3D Printing of Biopolymer Nanocomposites for Tissue Engineering».

[360]«Selective Laser Sintering (SLS)».

3.14.2 Contextualisation

Selective Laser Sintering (SLS) is likely to be the most widely utilized additive manufacturing technology in the future, due to its versatility and affordability. SLS is capable of producing highly detailed parts and components with strong physical properties, and its cost-effectiveness makes it ideal for large-scale production. Additionally, SLS technology is being increasingly used in a variety of industries, from medical to automotive to aerospace.[361]

The trend of SLS is currently expanding due to its increasing affordability, flexibility and accuracy. This technology has the potential to revolutionize production processes and enable mass customization of products.

Selective laser sintering (SLS) 3D printing is trusted by engineers and manufacturers across different industries for its ability to produce strong, functional parts.[362] [363] [364] [365]

3.14.2.1 Positive Impacts of SLS on Industry

- Increased speed of production: SLS is a rapid prototyping technology which allows for quicker production and testing of products, saving time and money.
- Increased flexibility: SLS has the capability to fabricate complex geometries with intricate details and customize the final product to meet specific needs.
- Increased accuracy: SLS is able to produce highly accurate parts with a high degree of precision, eliminating the need for costly post-processing.
- Reduced costs: SLS eliminates the need for tooling and can reduce the cost of production, as well as lead times.[366] [367]

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[361]«Selective Laser Sintering (SLS)».

[362]«Guide to Selective Laser Sintering (SLS) 3D Printing», Formlabs, consulté le 22 mai 2023, https://formlabs.com/eu/blog/what-is-selective-laser-sintering/.

[363]«Selective Laser Sintering (SLS)».

[364]Adrian Korycki, «Study of the selective laser sintering process : materials properties and effect of process parameters», 2020, https://oatao.univ-toulouse.fr/27651/1/Korycki_Adrian.pdf.

[365]E.O. Olakanmi, R.F. Cochrane, et K.W. Dalgarno, «A Review on Selective Laser Sintering/Melting (SLS/SLM) of Aluminium Alloy Powders: Processing, Microstructure, and Properties», *Progress in Materials Science* 74 (octobre 2015): 401-77, https://doi.org/10.1016/j.pmatsci.2015.03.002.

[366]Korycki, «Study of the selective laser sintering process : materials properties and effect of process parameters».

[367]Olakanmi, Cochrane, et Dalgarno, «A Review on Selective Laser Sintering/Melting (SLS/SLM) of Aluminium Alloy Powders».

3.14.2.2 Negative Impacts of SLS on Industry

- Limited materials: Currently, SLS only works with a limited number of materials, such as nylon and polycarbonate.
- Prone to defects: SLS is prone to defects caused by material shrinkage during the sintering process.
- Environmental concerns: SLS produces hazardous fumes and dust, which can be harmful to the environment.
- High cost: SLS can be expensive due to the cost of materials, equipment, and post-processing.[368] [369]

3.14.2.3 Market Insights

According to a report by MarketsAndMarkets, the SLS market is expected to reach USD 2,890.4 million by 2023.

According to a report by Global Market Insights, the selective laser sintering (SLS) market is expected to reach a market size of USD 3,269.2 million by 2025, and USD 4,977.9 million by 2030. [370] [371] [372]

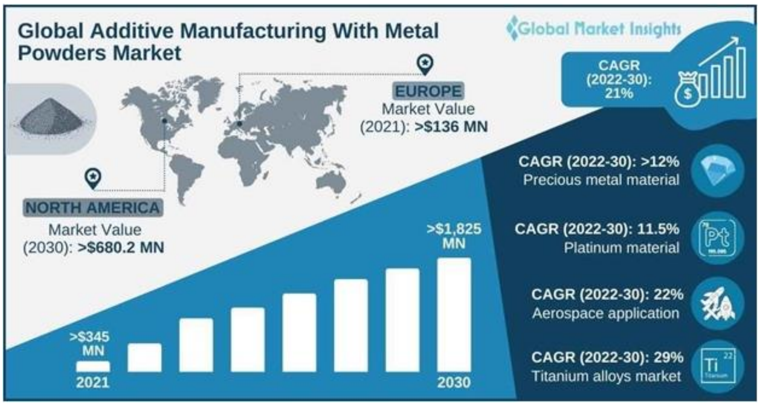

Figure 54: Additive manufacturing global market [373]

[368]Karel Kellens et al., «Environmental impact modeling of selective laser sintering processes», *Rapid Prototyping Journal* 20 (20 octobre 2014): 459-70, https://doi.org/10.1108/RPJ-02-2013-0018.

[369]Dayton Horvath, «The Hidden Promise and Challenges of Selective Laser Sintering for Plastic 3D Printing», 3D Printing Industry, 29 août 2017, https://3dprintingindustry.com/news/hidden-promise-challenges-selective-laser-sintering-plastic-3d-printing-120596/.

[370]Korycki, «Study of the selective laser sintering process : materials properties and effect of process parameters».

[371]Horvath, «The Hidden Promise and Challenges of Selective Laser Sintering for Plastic 3D Printing».

[372]«Additive Manufacturing with Metal Powders Market Statistics – 2030», Global Market Insights Inc., s. d., https://www.gminsights.com/industry-analysis/additive-manufacturing-with-metal-powders-market.

[373]Ibid.

3.14.2.4 Impacts of SLS on the Job Market

Selective laser sintering (SLS) is a 3D printing technology that is becoming increasingly popular in the manufacturing industry. It is a process that uses a laser to fuse small particles of plastic, metal, ceramic, or glass powder into a 3D-shaped object. As a result, it is being used in a variety of industries and occupations, from automotive to medical, to create complex and custom parts.

The industrial use of SLS is growing rapidly, which is resulting in a rise in job opportunities and training programs. SLS engineers and technicians are in high demand, and companies are beginning to offer advanced training in order to keep up with the technology.

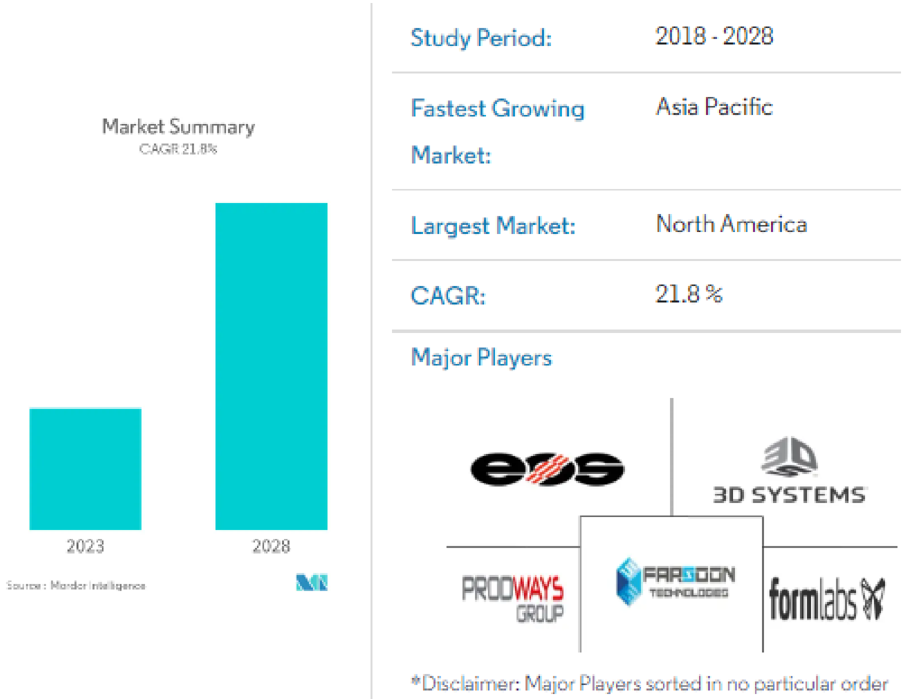

Figure 55: SLS market size[374]

Vocational schools and universities are also offering SLS-specific classes and programs. These courses teach students the fundamentals of the technology, such as the equipment, software, and processes. They can also go more in depth and learn how to design, build, and optimize SLS parts.

The demand for SLS technicians and engineers is also driving the development of online courses and tutorials. These resources provide a convenient way to learn the basics of SLS and help those who are interested in the technology get up to speed quickly.

[374] «Selective Laser Sintering Market Size & Share Analysis - Industry Research Report - Growth Trends», s. d., https://www.mordorintelligence.com/industry-reports/selective-laser-sintering-market.

In addition, the growing use of SLS is making it easier for professionals to get certified. Companies and organizations such as the American Society of Mechanical Engineers (ASME) and the National Institute for Metalworking Skills (NIMS) offer certifications in SLS, which can help professionals demonstrate their knowledge of the technology and gain an edge in the job market.[375] [376] [377]

Overall, the trend of selective laser sintering is one of growth and development. As the technology becomes more widely used, it is creating new job opportunities and providing more educational resources for those interested in learning more about it.

However, it also has the potential to cause job losses in the short-term, particularly in the areas of manual labour and traditional machining. Furthermore, this technology requires specific skills and knowledge to operate, which could require retraining of existing staff in order to remain employable.[378] [379]

The shift to automated manufacturing processes such as SLS can also have an impact on vocational training. This technology requires specific skills and knowledge, which may not be fully addressed in existing curricula. Furthermore, the presence of automated manufacturing processes could lead to a reduced demand for traditional vocational training and skills.[380] [381]

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[375] Digital Growth, «The Ultimate Guide to Selective Laser Sintering (SLS) 3D Printing», Quickparts, 12 avril 2023, https://quickparts.com/the-ultimate-guide-to-selective-laser-sintering-sls-3d-printing/.

[376] «Laser Sintering Jobs, Employment | Indeed.com», s. d., https://www.indeed.com/jobs?q=Laser+Sintering&from=mobRdr&_source=%2Fm%2F

[377] «Offres d'emploi "9 Laser Sintering" - États-Unis», 2 avril 2023, https://www.linkedin.com/jobs/laser-sintering-jobs.

[378] Alexandrea P, «The Complete Guide to Selective Laser Sintering (SLS) in 3D Printing», 3Dnatives, 18 juin 2022, https://www.3dnatives.com/en/selective-laser-sintering100420174/.

[379] Growth, «The Ultimate Guide to Selective Laser Sintering (SLS) 3D Printing».

[380] «2023 Global Selective Laser Sintering (SLS) Technology for 3D Printing Market: An In-Depth Analysis and Forecast of Industry till 2028», MarketWatch, 2023, https://www.marketwatch.com/press-release/2023-global-selective-laser-sintering-sls-technology-for-3d-printing-market-an-in-depth-analysis-and-forecast-of-industry-till-2028-2023-04-12.

[381] P, «The Complete Guide to Selective Laser Sintering (SLS) in 3D Printing».

3.14.3 Objectives / Research Question / Problem Statement

Objectives: Within this document, we try to offer some insight into shifts in the jobs market and how VETs and SMEs can adapt to the effects selective laser sintering will have on the manufacturing segment.

While equally as important, SLS and other additive manufacturing technologies will have environmental impacts as well, it is not the focus of the LCAMP project.

Research question:

- How will selective laser sintering impact the existing jobs market?
- Which competencies and skills will be needed for selective laser sintering related jobs?
- How can SMEs and VETs adapt to cater to the needs of people that wish to learn selective laser sintering?

Problem statement: Additive manufacturing and selective laser sintering have the potential to revolutionize the manufacturing industry. However, this technology could also have a significant impact on existing jobs in the manufacturing segment. This potential disruption raises the question of which jobs in the manufacturing segment will be replaced by additive manufacturing and selective laser sintering, and what new jobs will be created in their place.

One of the biggest challenges of additive manufacturing and in particular selective laser sintering is the potential disruption of existing jobs in the manufacturing industry. This technology is capable of producing components with a much higher degree of complexity than traditional manufacturing methods, requiring fewer manual labour and production costs. This could lead to a decrease in the demand for skilled labour, as well as a shift in the skillset required for manufacturing jobs.

Vocational training institutions may also experience changes due to the introduction of additive manufacturing. As this technology requires new skillsets, there may be a need to shift vocational training courses to fit the new requirements. Additionally, institutions may need to provide training on the use of the new technology, as well as how to design products that can be created using it.

Small and medium-sized companies may also be affected by the use of additive manufacturing. Due to the high cost of the equipment, and the need for specialized skillsets to operate it, SMEs may find it difficult to take advantage of this technology. This could lead to SMEs being unable to compete with larger companies, who have access to the necessary resources.

Overall, additive manufacturing and in particular selective laser sintering have the potential to cause significant changes in the existing jobs and the manufacturing industry. This technology has the potential to reduce the demand for skilled labour and to shift the skillset required for manufacturing jobs. Vocational training institutions may need to shift their courses to meet the new requirements, and SMEs may find it difficult to take advantage of the technology due to the high cost of the equipment and the need for specialized skillsets.[382 383 384 385]

3.14.4 Findings

3.14.4.1 Jobs That will Likely be Gradually Replaced by Additive Manufacturing and Selective Laser Sintering

11. **Traditional machinists:** Additive manufacturing, particularly selective laser sintering, will replace traditional machinists with more specialized roles such as 3D printing technicians and 3D printing engineers.
12. **CNC machinists:** Additive manufacturing will replace CNC machinists with 3D printing technicians and 3D printing engineers.
13. **Designers:** Additive manufacturing will replace designers with 3D designers, 3D printing engineers, and 3D printing technicians.
14. **Welders:** Additive manufacturing will replace welders with 3D printing technicians, 3D printing engineers, and 3D designers.
15. **Toolmakers:** Additive manufacturing will replace toolmakers with 3D printing technicians, 3D printing engineers, and 3D designers.
16. **Mold makers:** Additive manufacturing will replace mold makers with 3D printing technicians, 3D printing engineers, and 3D designers.
17. **Assembly line workers:** Additive manufacturing will replace assembly line workers with automated lines, robots, 3D printing technicians, 3D printing engineers, and 3D designers.
18. **Manufacturers:** Additive manufacturing will replace manufacturers with 3D printing technicians, 3D printing engineers, additive manufacturing experts.
19. **Data entry clerks:** Additive manufacturing will replace data entry clerks with various ML and AI programs and interfaces.
20. **Quality control inspectors:** Additive manufacturing will replace quality control inspectors with additive materials experts, 3D printing engineers

[382]«Additive Manufacturing Solutions | Prima Additive».

[383]«What Is Additive Manufacturing?»

[384]Horvath, «The Hidden Promise and Challenges of Selective Laser Sintering for Plastic 3D Printing».

[385]P, «The Complete Guide to Selective Laser Sintering (SLS) in 3D Printing».

21. **Material handlers:** Additive manufacturing will replace material handlers with 3D printing technicians, 3D printing engineers, and 3D designers.
22. **Logistics experts:** Additive manufacturing will replace logistics experts with 3D printing technicians, 3D printing engineers, and 3D designers.
23. **Prototype makers:** Additive manufacturing will replace prototype makers with 3D printing technicians, 3D printing engineers, and 3D designers.
24. **Machine operators:** Additive manufacturing will replace machine operators with 3D printing technicians, 3D printing engineers, and 3D designers.
25. **Fabricators:** Additive manufacturing will replace fabricators with 3D printing technicians, 3D printing engineers, and 3D designers.
26. **Patternmakers:** Additive manufacturing will replace patternmakers with 3D designers.
27. **Model makers:** Additive manufacturing will replace model makers with 3D printing engineers, and 3D designers.
28. **Quality engineers:** Additive manufacturing will replace quality engineers with advanced materials engineers, additive manufacturing engineers, 3D printing technicians, 3D printing engineers, and 3D designers.
29. **Production planners:** Additive manufacturing will replace production planners with automation experts, additive manufacturing experts, 3D printing technicians, 3D printing engineers, and 3D designers.
30. **Casting technicians:** Additive manufacturing will replace casting technicians with 3D printing technicians, 3D printing engineers, and 3D designers.

3.14.4.2 Manufacturing Jobs Replaced by Additive Manufacturing and Selective Laser Sintering

1. Metal fabricator
2. Metal caster
3. Tool and die maker
4. Machine operators
5. Mold maker
6. Machinist
7. Welder
8. Laser technician
9. Cnc machine operator
10. Sheet metal worker

11. Die maker
12. Punch press operator
13. Electronics assembly worker
14. Pattern maker
15. Prototype maker
16. Assembly worker
17. Press operator
18. Plastic injection mold maker
19. Metal worker
20. Metal spinner
21. Metal fabricator
22. Tool grinder
23. Sheet metal worker
24. Production technician
25. Foundry worker
26. Assembly line worker
27. Painter
28. Machine maintenance technician
29. Sheet metal worker
30. Injection molding technician
31. Industrial machinery mechanic
32. Quality control technician
33. Cnc programmer
34. Metal finisher
35. 3d printer operator
36. Laser cutting technician
37. Laser engraver
38. Metal stamping technician
39. Metal shaper
40. Metal forming technician

3.14.4.3 Jobs Created by Additive Manufacturing and Selective Laser Sintering

1. 3D printing technician
2. Additive manufacturing technician
3. Cad engineer
4. SLS operator
5. Rapid prototyping technician
6. 3D printing engineer
7. Selective laser sintering technician
8. Design engineer
9. Product development engineer
10. Manufacturing engineer
11. Quality assurance technician
12. 3D modeler
13. Cad operator
14. Materials engineer
15. Cad technician
16. Process engineer
17. Robotics technician
18. Automation engineer
19. Laser technician
20. Software engineer
21. 3D design engineer
22. Industrial engineer
23. Process technician
24. Quality control engineer
25. Maintenance technician
26. Industrial designer
27. Computer numerical control programmer
28. Automation technician
29. Mechanical engineer
30. Manufacturing technician
31. Production engineer
32. Quality engineer
33. Tool and die maker

34. Research engineer
35. Mechanical design engineer
36. Mechanical technician
37. 3d printing consultant
38. Robotics engineer
39. Computer aided design engineer
40. Additive manufacturing

3.14.5 Conclusions

As with most new Advanced Manufacturing jobs, significant upskilling will be needed – people will need to add new skills to their arsenal in order to be able to fulfil the Advanced Manufacturing needs of the market, additive manufacturing and selective laser sintering might just be a sub-segment of Advanced Manufacturing, but the same rules apply. In order for the right skills to be chosen, the appropriate VET programs and courses to be selected, learning Analytics and Learning Pathways will have to be utilized to get the best possible options, customized to each person's education portfolio, abilities, circumstances and needs.

The broad additive manufacturing, but in particular selective laser sintering, which will likely represent the highest portion of additive manufacturing, will require a shift to a different set of skills. Below are some of the skills and competencies that VETs and SMEs should focus on in the future, to be able to fulfil the needs of the manufacturing segment.

1. 3D Design skills: People transitioning from traditional manufacturing jobs to selective laser sintering should learn 3D design skills such as CAD, CAM and 3D modelling.
2. Laser sintering knowledge: People transitioning from traditional manufacturing jobs to selective laser sintering should learn about the laser sintering process, including materials, design and post-processing considerations.
3. Problem-solving skills: People transitioning from traditional manufacturing jobs to selective laser sintering should develop problem-solving skills to be able to address any issues that arise during the process.

Other skills and competences that VETs and SMEs should focus on to meet the additive manufacturing / selective laser sintering needs.

3.14.5.1 Skills to Learn to Transition to Additive Manufacturing and Selective Laser Sintering

1. Cad design[386]
2. 3D printing[387]
3. Computer aided manufacturing (cam)[388]
4. Machine programming[389] [390]
5. Machining[391]
6. Material selection[392]
7. Quality assurance[393]
8. Process documentation[394]
9. Troubleshooting[395]
10. Robotics and automation[396]

386 «Fusion 360 | 3D CAD, CAM, CAE, & PCB Cloud-Based Software | Autodesk», s. d., https://www.autodesk.com/products/fusion-360/overview.

387 «The Free Beginner's Guide», 3D Printing Industry, 14 mars 2023, https://3dprintingindustry.com/3d-printing-basics-free-beginners-guide/.

388 Bob Warfield, «The Secrets of CAM for Beginners», CNCCookbook: Be A Better CNC'er, 29 septembre 2014, https://www.cnccookbook.com/every-beginner-know-cam/.

389 «Machine Language For Beginners - Introduction», s. d., https://www.atariarchives.org/mlb/introduction.php.

390 «What is Machine Language - javatpoint», s. d., https://www.javatpoint.com/what-is-machine-language.

391 JOHN, «Machining Basics for Beginners: 101 - MellowPine», 10 novembre 2022, https://mellowpine.com/blog/machining-basics/.

392 Mohammed Alghamdy, Dr Rafiq Ahmad, et Basel Alsayyed, «Material Selection Methodology for Additive Manufacturing Applications», *Procedia CIRP* 84 (1 janvier 2019): 486-90, https://doi.org/10.1016/j.procir.2019.04.265.

393 Saeed Al-awai, Samir Omar, et Hussain A. Binthabet, «ADMA-OPCO Operational Approach for Competency Assurance» (Abu Dhabi International Petroleum Exhibition and Conference, OnePetro, 2002), https://doi.org/10.2118/78525-MS.

394 Carlo Borja, «The Ultimate Process Documentation Software Guide», *SweetProcess* (blog), 14 octobre 2021, https://www.sweetprocess.com/process-documentation-software/.

395 AMTech3D, «Troubleshooting», *Additive Manufacturing Technologies - AMTech3D* (blog), s. d., https://amtech3d.com/troubleshooting/.

396 BTerrell Group LLP, «The Basics of Robotic Process Automation (RPA)», s. d., https://www.bterrell.com/robotic-process-automation-rpa/basics-rpa.

3.15 DIGITAL FACTORY: ENERGY EFFICIENCY / CARBON FOOTPRINT

3.15.1 Main Used Sources

Source				Scope	
Identification	**Type of source**	**Link**	**Description**	**Geographical**	**Sectorial**
PUBLIC SOURCES					
EFFRA	Website	**LINK**	The European Factories of the Future Research Association (EFFRA) is a non-for-profit, industry-driven association promoting the development of new and innovative production technologies. EFFRA has been representing the private side of the manufacturing partnership with the EU Commission. Named under Horizon 2020, Factories of the Future to become Made in Europe nowadays under Horizon Europe	Europe	Multisector
Groupe AFNOR	Website	**LINK**	French national agency for standardization	International	Multisector
CORDIS	Website	**LINK**	European Website about European Projects	Europe	
TRAINING SOURCES					
MINALOGIC	Website	**LINKLINK**	European competitiveness cluster on mechanics	EU & Regional France	Aerospace

CETIM	Website	**LINK 1** **LINK 2**	French national agency for all mechanics subjects & Ind 4.0	France	Multisector
FRANCE COMPETENCES	Website	**LINK**	French National Center for technical learning	France	Industry and I 4.0
EFVET	Website	**LINKLINK**	EfVET is the European Forum of Technical and Vocational Education and Training	Europe	
INDUSTRIAL SOURCES					
BPi	Website & Newsletter	**LINKLINK**	European competitiveness cluster on mechanics	EU & Regional France	Aerospace
Usine Nouvelle	Website & Newspaper	**LINKLINK**	French national agency for all mechanics subjects & Ind 4.0	France	Multisector

3.15.2 Main Data

Source	Topic analysis	
Identification	**Topic name**	**Internet links**
PUBLIC SOURCES		
EFFRA	Pathways to Energy Efficient Manufacturing workshop at Sustainable Places 2021	**LINK**
Groupe AFNOR	Efficacité énergétique dans l'industrie : AFNOR Energies forme	**LINK**
	Audit énergétique : faites-le avec la NF EN 16247 version 2022	**LINK**
CORDIS	Assessing the intangibles : the socioeconomic benefits of improving energy efficiency	**LINK**
CORDIS	New trending in energy demand modelling	**LINK**
CORDIS	Creating Innovative Sustainability Pathways	**LINK**
TRAINING SOURCES		

FRANCE COMPETENCES	Speed up your ecological and energy transition	**LINK**
PUBLIC SOURCES		
BPi	Formation : Réalisez des économies vertueuses grâce à l'efficacité énergétique	**LINK**
	Efficacité énergétique : comment consommer moins d'énergie et de ressources naturelles et réduire son empreinte environnementale ?	**LINK**
Usine Nouvelle	Décarboner la production : les leviers de l'accélération	**LINK**

3.15.2.1 Context and Presentation

In this sub-article we have analysed different approaches to understand and compare Industrial 4.0 impacts on the supply chain.

We started with an overview of policy initiatives and instruments, which define the basic framework and requirements for the development of a potential approach for understanding the Industry 4.0's impact on the supply chain, the approaches related to the lifecycle of a product, and the main Industry 4.0 technologies.

This includes energy management systems, energy audits, environmental management systems, voluntary agreements, LCA (life cycle assessment), LCC (life cycle cost), Industry 4.0's impact on the supply chain, links between Industry 4.0 technologies and the supply chain, and other sustainability management systems.

Based on the analysis of the existing approaches of Industry 4.0's impact on the supply chain, we present clear criteria to determine what constitute Industry 4.0 impact on the supply chain.

3.15.2.2 Summary and Synthesis

Various policy initiatives and instruments define the basic framework and the requirements for developing a potential approach for understanding Industry 4.0's impact on the supply chain.

Next, there are main issues with current approaches related to the subject; none of these approaches are enabling a comparison of performances between companies as proposed by Europe for manufactured products:

- Energy management certificates confirm that a company is working to improve its energy efficiency according to a given management standard (ISO 50001). However, this gives no information on the actual energy efficiency achieved in its operations.
- Industry 4.0 benchmarks only provide reasonable information if the industrial operations of different companies are sufficiently similar to allow for comparison.
- Life cycle analysis is also performed on a product, not for a company, and hence would need to be done at least for every class of product of a company to generate results at the company level. Comparison between companies would still be possible only for the same class of products produced in the different companies.
- There are very few research studies available that explain Industry 4.0 technologies' impact on manufacturing companies' supply chain and Industry 4.0 technologies' role in achieving supply chain sustainability as explained by Naseem and Yang (August 2021) [2]. Currently there are only 57 such documents published.

Most of the supply chain models include only the traditional procurement-production-distribution sub-processes used for converting raw materials to final products and deliver them to the wholesalers, retailers or directly to end users. We observe a complex green supply chain model in which sophisticated operation research heuristics must be used to find the optimal solution in order to minimize the costs on all the supply chain.

The introduction of this approach generates new technological and non-technological needs. The change in ownership and material management concepts, both at a consumer and at business level, generates a need for upscaling and acceleration of business concepts such as: products as a service, sharing platforms, peer-to-peer interactions, and industrial symbiosis. The industrial symbiosis approach focuses on the hidden value of waste resources within an industrial network which can be exploited through the cooperation.[397]

As suggested by Wuppertal Institute[398], the diversity of policy instruments can be distinguished according to the strength of strategic measures and determining factors as shown in the matrix below. Regarding the scope of the present analysis, this differentiation provides already a first intuitive view on the relevance of a potential scheme for energy characterisation of companies in relation to such policy instruments.

[397]Muhammad Hamza Naseem et Jiaqi Yang, «Role of Industry 4.0 in Supply Chains Sustainability: A Systematic Literature Review», *Sustainability* 13, nº 17 (janvier 2021): 9544, https://doi.org/10.3390/su13179544.

[398]Wuppertal Institut, «The Institute - Wuppertal Institute for Climate, Environment and Energy», s. d., https://wupperinst.org/en/the-institute.

Figure 56: Resource efficiency policy matrix

In this review, the above policy instruments have been grouped under the following main themes:

- Regulatory instruments (norms and standards, liability, and control)
- Economic instruments (taxes, fees and charges, certificate trading, and environmental financing, procurement, and subsidies)
- Research & educational instruments
- Cooperation instruments (technology transfer, voluntary agreements)
- Informational instruments (eco labels, reporting, information centres)

Any meaningful characterisation of companies must provide relevant information about such policy instruments. In particular, the requirement is to develop an approach that would be coherent with the EU Eco-design directive.

3.15.3 Data Analysis

3.15.3.1 Introduction

None of these approaches about energy efficiency is enabling a comparison of performances of companies as proposed by Europe for manufactured products[399]:

- Energy management certificates confirm that a company is working to improve its energy efficiency according to a given management standard (ISO 50001). However, this gives no information on the actual energy efficiency achieved in its operations.
- Industry 4.0 benchmarks only provide reasonable information if the industrial operations of different companies are sufficiently similar to allow comparisons.
- Life cycle analysis also is performed on a product, not for a company, and hence would need to be done at least for every class of products of a company to generate results at the company level. Comparison between companies would still be possible only for the same class of products produced in the different companies.
- There are very few research studies available that explain Industry 4.0 technologies' impact on manufacturing companies' supply chain, life cycle and Industry 4.0 technologies' role in achieving supply chain sustainability.

3.15.3.2 Contextualisation

It is important to review the existing reviews to determine the best practices among them and be able to inform the best practices for training and new learning courses.

3.15.3.3 Objectives / Research Question / Problem Statement

Objectives: Determining the best practices regarding efficient supply chains and from that inform future training and learning courses.

Problem statement: Studying present norms and standards and analysing the current methods for energy efficiency.

[399] Anbesh Jamwal et al., «Industry 4.0 Technologies for Manufacturing Sustainability : A Systematic Review and Future Research Directions», *Applied Sciences* 11, nº 12 (January 2021): 5725, https://doi.org/10.3390/app11125725.

3.15.3.4 Norms and Standards

Norms and standards include laws, directives, and technical guidance documents as far as these are legally binding[400] [401] [402] [403], such as:

- Emission standards for maximum level of permitted emissions.
- Ambience standards for minimum level of air, water, or soil quality.
- Technology standards that describe what kind of technology must be used.
- Management and process standards.
- Product standards for certain product characteristics.

Energy efficiency directive

In Europe, since 2015, companies that don't qualify as SMEs (have more than 250 people, and more than 50 million turnover) are obliged to improve their energy efficiency and to have an energy audit performed. Article 8 of the European Energy Efficiency Directive describes the obligation for companies to perform an accredited energy audit at least every four years, with minimum demands prescribed (Annex VI of the Directive). Excluded are companies that hold a certificate of a management system, which includes an energy management system.

The most important systems are:

- ISO 50001 with a specific focus on Energy Management Systems,
- EN 16247 on Energy Audits,
- ISO 14001 if it includes an energy audit.

ISO 50 001 energy management system

Using energy efficiently helps organizations save money as well as helping to conserve resources and tackle climate change. ISO 50001 supports organizations in all sectors to use energy more efficiently, through the development of an energy management system (Enums).

[400]Bundesumweltministeriums, «Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection», Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, s. d., https://www.bmuv.de/WS1-1.

[401]«Waste from Electrical and Electronic Equipment (WEEE)», s. d., https://environment.ec.europa.eu/topics/waste-and-recycling/waste-electrical-and-electronic-equipment-weee_en.

[402]«Restriction of the Use of Certain Hazardous Substances (RoHS)», s. d., https://single-market-economy.ec.europa.eu/single-market/european-standards/harmonised-standards/restriction-use-certain-hazardous-substances-rohs_en.

[403]«Energy Efficiency Directive», s. d., https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en.

ISO 50001 is based on the management system model of continual improvement also used for other well-known standards such as ISO 9001 or ISO 14001. This makes it easier for organizations to integrate energy management into their overall efforts to improve quality and environmental management.

ISO 50001 describes the requirements for an energy management system. The standard is intended to help organisations with the development of systems and processes for improvement of energy-efficiency. ISO 50001 provides guidelines for both small and large organizations:

- to improve energy management systematically,
- set up an energy management system, implement, improve and / or maintain it,
- ensure that the energy system is up to date,
- assess and evaluate their energy management on the basis of the standard,
- demonstrate this to customers and stakeholders.

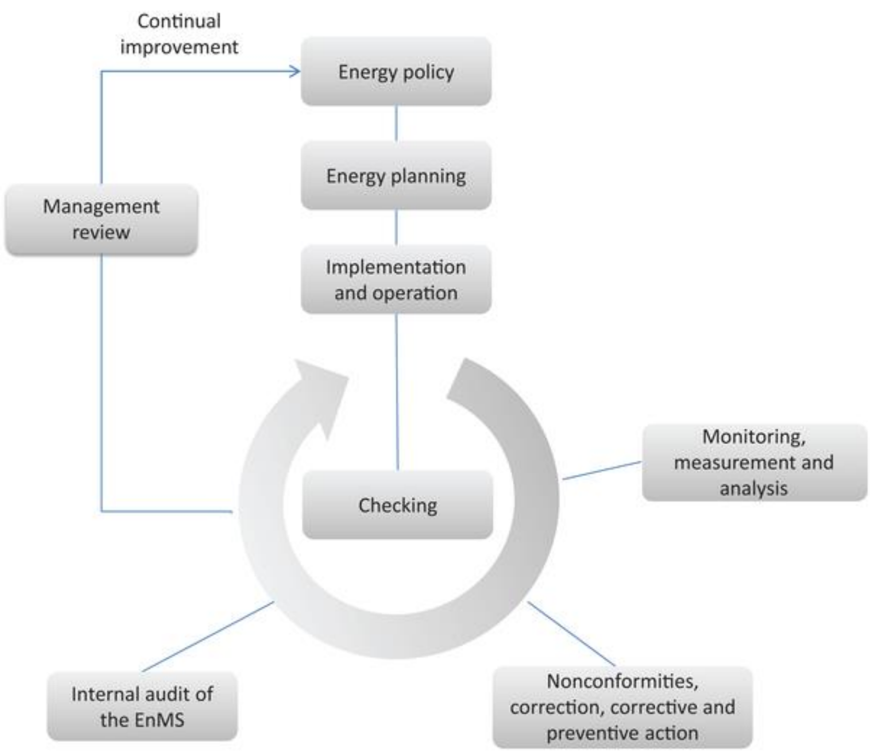

Figure 57: Graphic: Energy management system model for ISO 50001

This International Standard is based on the 'Plan - Do – Check - Act' (PDCA) continual improvement framework and incorporates energy management into everyday organizational practices, as illustrated in the above figure. In addition, ISO/TC 242, has developed additional standards regarding energy.

ISO 14001 environmental management system

The 14001 pays only limited attention to energy related topics, so the additional module ISO 14051 is needed to qualify for exemption. Therefore, an ISO 14001 certificate only exempts an organisation from the obligation to perform an energy audit if the MFCA, described in the ISO 14051 module, is included.

3.15.3.5 Environmental Liability

Environmental liability holds a polluter responsible for any environmental impact he has caused. First, liability serves to compensate parties who have suffered injury or damage, which can include both individuals and society. Second, as liability creates a cost for causing harm, it provides a direct incentive not to pollute and to reduce corporate environmental risks (Comm.2000, GTZ 1995, von Seth/Ott 2000).[404] [405]

3.15.3.6 Environmental Control and Enforcement

Environmental control and enforcement include activities to inspect companies whether they comply with regulations, standards, and laws. They therefore include:

- permissions by authorities,
- inspection of companies,
- checking of emissions and environmental impacts,
- control information submitted to the private sector,
- control of environmental self-control of companies.

[404] «Environmental Liability», s. d., https://environment.ec.europa.eu/law-and-governance/compliance-assurance/environmental-liability_en.

[405] OP US EPA, «Guidelines for Preparing Economic Analyses», Other Policies and Guidance, 21 April 2014, https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses.

3.15.3.7 Economic Instruments

Environmental taxes

Environmental taxes (eco-taxes) strive for early positive environmental impact. They are collected from businesses, consumers, and different organisations. Environmental taxes can be applied on emissions, on product tax, on natural resources, etc.[406] [407]

Certificate trading

In certificate trading systems, authorities allow certificate holders a maximum quantity of emissions into the environment or the use of environmental records up to a defined maximum. Certificates can be traded among firms. The maximum quantity of emissions in the environment is fixed. Procedures and rules for trading need to be set. Emissions need to be measured and reported.[408]

Environmental financing

Environmental financing is an instrument used for promoting environmentally beneficial measures through financial institutions or independent funds. Loans and/or grants are provided to fully or partially finance those measures which are beneficial to the environment on more favourable terms than those in the prevailing market. Such measures are usually initiated through programmes of governments or credit lines of donor agencies with the necessary resources to provide the financial resources for such a scheme.[409]

Green public procurement

Green public procurement usually means that the acquisition of goods or services by the public sector considers environmental elements. The aim of the Green public procurement is to encourage the market to produce and sell more environmentally sound products and services and thus to reduce their prices through economies of scale.[410]

[406]«To Be Assisted in the Ecodesign of Your Products | Ecosystem», Ecosystem, s. d., https://www.ecosystem.eco/en/category/ecodesign-approach.

[407]«Soöruz rewarded for its innovative and eco-responsible approach - EuroSIMA», *https://www.eurosima.com/* (blog), s. d., https://www.eurosima.com/sooruz-recompense-pour-sa-demarche-innovante-et-eco-responsable/.

[408]« Home IETA», s. d., https://www.ieta.org/.

[409]«Home ADEME - the French Agency for Ecological Transition», The French Agency for Ecological Transition, s. d., https://www.ademe.fr/en/frontpage/.

[410]Systemadmin_Umwelt, «Umweltfreundliche Beschaffung», Text, Umweltbundesamt (Umweltbundesamt, 22 August 2013), https://www.umweltbundesamt.de/themen/wirtschaft-konsum/umweltfreundliche-beschaffung.

3.15.3.8 Findings

Energy and Environment management systems aim to provide guidance to companies on how to improve their energy use continuously. They are not trying to provide solutions for a characterisation of a company directly. Accordingly, the audits and certifications provided only concern the energy management of the companies.[411]

CSR performance ladder

The CSR (Corporate Social Responsibility) performance ladder is an internationally renowned certification scheme for companies to demonstrate their social responsibility. The system is based on the ISO 26 000 standard, which is not a management system standard and is not intended for certification purposes. The CSR performance ladder is certifiable. It originated in the Netherlands but is increasingly internationally accepted as proof of social responsibility related to people, planet, and profit.

To assess the performance of companies, the Global Reporting Initiative (GRI) has been set up. A set of indicators allows comparing the performance in the field of sustainability of various companies worldwide.[412]

According to the website, the standard offers a structural approach to sustainable business performance building on the CSR Performance Ladder:

- The CSR Performance Ladder has proven its value since June 2010.
- 194 certificates were issued in the Netherlands and Belgium in the 3 last years.
- The standard is accepted by the Dutch government in quotations and specifications.
- The standard is already transformed to the High-level Structure from the Annex SL/2012.
- Acceptance of the accreditation for the standard is offered to the Dutch accreditation body, which does confirm that certification of a CSR management system is possible.

CO2 performance ladder

The purpose of the CO2-performance ladder is to make companies aware of their CO2 emissions and that of their suppliers, to seek possibilities to reduce the emissions, and to work together with various actors for this purpose. It originated at the Dutch railroad maintenance company ProRail

[411]«ISO - ISO 50001 — Energy Management», ISO, 20 October 2021, https://www.iso.org/iso-50001-energy-management.html.
[412]«GRI - Standards», s. d., https://www.globalreporting.org/standards/.

who used the scheme to stimulate tender contestants to act sustainably, and actively work on the reduction of greenhouse gas emissions. Currently it is available for all companies.

An important aspect of the tool is the reduction of energy use.[413]

The CO_2 performance ladder has five levels (with the 5th being the highest). Each level has set requirements to the company's CO_2 performance. These requirements stem from four perspectives: understanding, reducing emissions, transparency, participation.

The level of a company is determined by the highest level at which it meets all the requirements.

EU eco-design directive

The Eco-design Directive provides consistent EU wide rules for improving the environmental performance of products. The directive sets out the minimum mandatory requirements for the energy efficiency of these products. A stakeholder consultation forum is guiding the implementation of the directive. The consultation forum includes representatives from EU countries, the industry, and civil society.

The aim of the Eco-design Directive is that at the design stage, manufacturers of energy-using products will be obliged to reduce the energy consumption and other negative environmental impacts of products. While the Directive's primary aim is to reduce energy use, it is also aimed at enforcing other environmental considerations including materials use, water use, polluting emissions, waste issues and recyclability.

The Eco-design Directive is a framework directive, meaning that it does not directly set minimum ecological requirements. These are adopted through specific implementing measures for each group of products in the scope of the Directive. The implementing measures are adopted through the so-called comitology procedure. Implementing measures are based on EU internal market rules governing which products may be placed on the market. Manufacturers who begin marketing an energy-using product covered by an implementing measure in the EU area must ensure that it conforms to the energy and environmental standards set out by the measure.

Eco-design has proven to be a highly politically feasible instrument that is accepted by a wide range of stakeholders. Evidence suggests that the Directive has contributed not only to improve environmental performance of products but has also yielded positive effects on competitiveness of the EU industry. This is obviously the reason for the requirement to propose an energy characterisation for companies coherent with the EU eco-design provisions.

[413]«Home CO2 emissiefactoren», CO2 emissiefactoren, s. d., https://www.co2emissiefactoren.nl/.

Technically, the Eco-Design Directive is based on the Methodology for the Eco-design of Energy-using Products (MEEuP) and its successor, the Methodology for the Eco-design of Energy-related Products (MEErP) which extends the first methodology (MEEuP) from energy-using to energy-related products. MEErP is developed to investigate eco-design requirements appropriate for the products that are covered under the Eco-Design Directive such as heating equipment, cooking equipment (i.e., ovens and furnaces), machine tools, refrigerating and freezing equipment, sound and imaging equipment, transformers, and ventilation systems.

Energy labelling directive

The EU Energy Labelling Directive complements the requirements of the Eco-Design Directive with mandatory labelling requirements. The Directive[414] establishes a framework for the harmonisation of national measures on end-user information, particularly by means of labelling and standardising product information, on the consumption of energy and where relevant of other essential resources during use, and providing supplementary information concerning energy-related products, thereby allowing end-users to choose more efficient products.

The energy efficiency of the appliance is rated in terms of a set of energy efficiency classes from A to G on the label, A being the most energy efficient. The labels also give other useful information to the customer as they choose between various models. The information should also be given in catalogues and included by internet retailers on their websites.

This statement could well be taken as an indication of a possible position of this industry, which is a major part of the metal mechanical manufacturing industry in Europe, towards any potential, obligatory energy characterisation of companies since the latter would be even more challenging than labelling professional equipment.

The latter would strongly point towards implementation of any such approach under a voluntary scheme. Besides the basic criteria of such energy characterisation scheme, hence the potential implementation modalities will also be an issue for further clarification through stakeholder consultation.

EU ecolabel

Other than the Energy Label, the EU Ecolabel[415] is a voluntary scheme, aiming to identify products and services that have a reduced environmental impact throughout their life cycle, from the extraction of raw material through to production, use and disposal. Voluntary means that

[414] Directive 2010/30/EU of the European Parliament and of the Council of 19 May 2010

[415] http://www.ec.europa.eu/environment/ecolabel

producers, importers, and retailers can choose to apply for the label for their products. The EU Ecolabel scheme is hence a commitment to environmental sustainability; it can be used as a promotional instrument for more environmentally sustainable products. The criteria have been developed and agreed upon by scientists, NGOs, and stakeholders to create a credible and reliable way to make environmentally responsible choices.

Life cycle assessment and life cycle costing

Life Cycle Thinking (LCT) is about going beyond the traditional focus and production site and manufacturing processes to include environmental, social, and economic impacts of a product over its entire life cycle.

The main goals of LCT are to reduce a products resource use and emissions to the environment as well as improve its socio-economic performance through its life cycle. This may facilitate links between the economic, social, and environmental dimensions within an organization and through its entire value chain.

Looking at the industrial sector, taking LCT as an approach means going beyond the narrower traditional focus on a company's production facility. A product life cycle can begin with the extraction of raw materials from natural resources in the ground and the energy generation. Materials and energy are then part of production, packaging, distribution, use, maintenance, and eventually recycling, reuse, recovery, or final disposal.

Figure 58: Life Cycle

In each life cycle step, there is the potential to reduce resource consumption and improve the performance of products.

Life cycle assessment (LCA)

The concepts that later became (environmental) LCA first emerged in the 1960s (Baumann et al., 2004). Until the early 1990s, studies that undertook an assessment of the material, energy and waste flows of a product's life cycle were conducted under a variety of names – including the resource and environmental profile analysis (REPA), Eco balance, integral environmental analyses, and environmental profiles. In 1990, SETAC hosted workshops with the aim of developing a standardized method of (environmental) LCA, which was to serve as the basis for the ISO 14040 series.

ISO 14000 life cycle analysis standard

LCA standards ISO 14040 and 14044 belong to the ISO 14000 family concerning various aspects of environmental management. On a national level, only two standardisation organisations have developed their own LCA standards before ISO 14040 was enacted: AFNOR (Association Française de Normalisation, France) and CSA (Canadian Standards Association, Canada).

To date, a singular internationally accepted standardisation is aimed at promoting international communication, and this is why France and Canada have stepped into the ISO process.

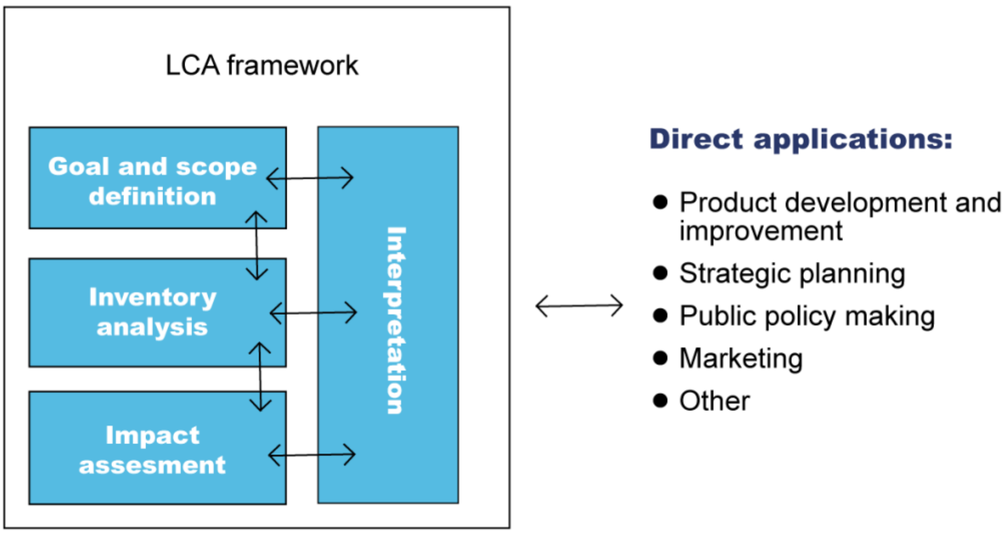

Figure 59: LCA phases according to ISO 14040:1997/2006.

Life cycle costing (LCC)

Life cycle costing (LCC) is the oldest of the three life cycle techniques. Developed originally from a strict financial cost accounting perspective, in recent years LCC has gained new importance. The origins of LCC go back to 1933, when the United States of America General Accounting Office (GAO) requested an assessment of the costs of tractors that considered a life cycle perspective in a Request for a Tender.

Social life cycle assessment (S-LCA)

A social life cycle assessment (S-LCA) is described as ‘a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle’ (UNEP/SETAC, 2009a). These aspects assessed in S-LCA are those that may, directly or indirectly, affect stakeholders. The impacts may be linked to the behaviours of companies, to socio-economic processes, or to impacts on social capital.

Life cycle inventory analysis (LCI)

In the second phase, all emissions released into the environment and resources extracted from the environment along the whole life cycle of a product are grouped in an inventory. The inventory is a list of elementary flows as shown in Fig. 61.

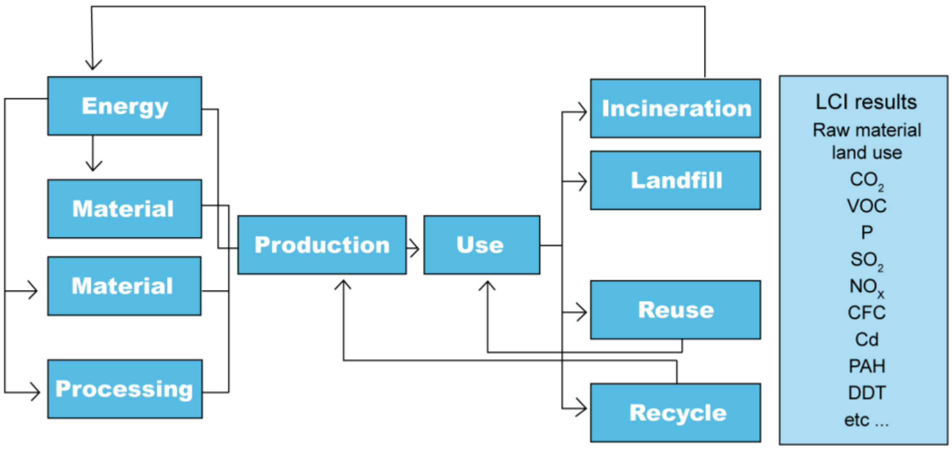

Figure 60: Flows of information needed for a cycle inventory.

Life Cycle Impact Assessment (LCIA)

In the third phase – life cycle impact assessment (LCIA) – the LCI results or indicators of environmental interventions are translated, with the help of an impact assessment method, into environmental impacts. Impacts may be assessed at the midpoint or endpoint level. In a 'classification' step, elementary flows are assigned to midpoint impact categories such as 'climate change' or 'human toxicity', thereby organizing the information to allow for a further processing and meaningful interpretation. In this ISO 14040-termed 'characterization' step, all elementary flows within the same category are converted to a common unit of assigned elementary flows. This step is accomplished by using characterization factors (see Glossary). At the endpoint, environmental LCIA aims to link emissions and resource demands with damages to human health, ecosystem quality and the resource base. Several characterization models can be used to link the inventory results with the midpoint and endpoint categories of impact: the choice of model depends on the goal and scope of the study and on the stakeholders affected by the outcome.

Normalization, aggregation, and weighting are optional LCIA steps, according to ISO 14040 (2006) and ISO 14044 (2006). While the first provides the contribution of each impact category in comparison to a reference by converting differing units into a common and dimensionless format, aggregation and weighting allow the conversion (using numerical factors based on value-choices) and the possible aggregation of indicator results across impact categories.

Life cycle interpretation

A life cycle interpretation is carried out in the last phase. This is necessary for identifying, quantifying, checking, and evaluating information from the results of the LCI and/or the LCIA. This interpretation phase should generate a set of conclusions and recommendations. It should also (according to ISO 14040) raise significant environmental issues, including an evaluation of the study considering completeness, sensitivity and consistency checks, and limitations.

Life cycle sustainability assessment (LCSA)

Life cycle sustainability assessment (LCSA) refers to the evaluation of all environmental, social, and economic negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle.

LCSA = (environmental) LCA + LCC + S-LCA

Life cycle management (LCM)

Life cycle management (LCM) is a product management system aimed at minimizing the environmental and socio-economic burdens associated with an organization's product or product portfolio during its entire life cycle and value chain. LCM supports the business assimilation of product policies adopted by governments. This is done by making life cycle approaches operational and through the continuous improvement of product systems (UNEP/SETAC, 2007).

3.15.3.9 Conclusions

Life Cycle Assessment is a useful theoretical and practical framework for selecting and evaluating indicators for green industry and products. Its growing application is promising to bring greater clarity to the concept of "green industry". It is in this context that the EED requires building energy audits, whenever possible, on life-cycle cost analysis (LCCA) instead of Simple Payback Periods (SPP) in order to take account of long-term savings, residual values of long-term investments and discount rates.

Principle problems with the approach relate for instance to decisions that have to be taken without scientific basis, such as whether three tonnes of emitted sulphur are more or less harmful than the emission of just a few pounds of a more toxic pollutant, which are necessarily subjective.

Other examples are:

- How can one compare heavy energy demand with heavy water use, which imposes greater environmental burden?
- How should the use of non-renewable mineral resources like oil or gas (the ingredients of plastics) be compared with the production of softwoods for paper?
- How should the combined impacts of the landfilling of wastes (air and groundwater pollution, transport impacts etc.) be compared with those produced by the burning of wastes for energy production (predominantly emissions to air)?

Another main drawback to the application of life cycle-based instruments is the extensive data gathering and expensive analysis requirements, which have hampered a wider use particularly in SMEs. In addressing this issue, for instance the ERDF funded and developed a Life Cycle based Energy Audit (LiCEA) aiming especially at SMEs. The LiCEA tool calculates only three environmental indicators according to the LCA approach:

- Global warming potential - GWP (in kg CO2, according to IPCC 2007, 100a).
- Cumulative energy demand – CED (in MJ, incl. non-renewable and renewable energy).
- Blue virtual water (in m^3).

Such simplified approaches could provide a practical solution to energy characterisation, under the provision that they really allow meaningful comparisons. This has to be further analysed in subsequent work.

®Ecosystem[416] guides companies to prevent the impacts of a product's end of life with the same rigour as it does at the development and supply phases. This approach is an important lever for

[416] «To Be Assisted in the Ecodesign of Your Products | Ecosystem».

waste prevention, natural resources conservation and the reduction of recycling's environmental impact.

Their eco-design approach of a product involves manufacturing it with the aim of improving its environmental performance throughout its whole life cycle. ®Ecosystem assists companies in addressing all issues related to a stage or the end of life, to anticipate materials, substances and assembly choices when designing a product, and thus improve the quality of recycling. Integrating material from recycled equipment into new products is part of this virtuous approach.

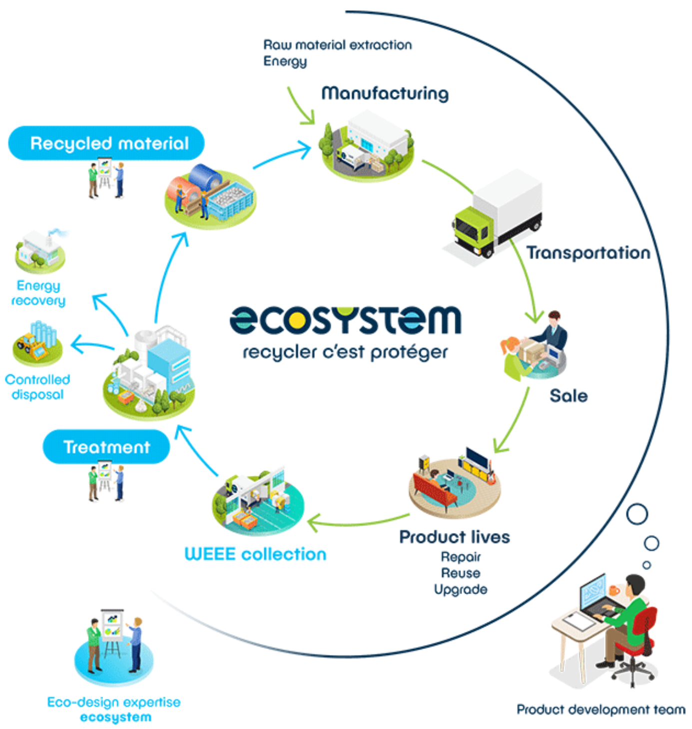

Figure 61: ® Ecosystem

®Ecosystem has developed two databases, that allow to quantify the environmental impacts and benefits of:

- The end-of-life management of your electrical and electronic equipment
- The production of plastics recycled from waste electrical and electronic equipment (WEEE).

To ensure good data representativity, ecosystem has modelled the overall process of equipment's end-of-life based on field data collected from more than 50 WEEE decontamination and treatment facilities and considered about fifteen disposal or recovery sectors.

®Ecosystem has also developed REEECYC'LAB[417], an educational simulator developed specifically by ®Ecosystem for its members in order to understand, assess and improve the recyclability of new products.

For (advanced) manufacturing, MEMAN[418] approach was developed inside a H2020 European project from 2015 to 2018.

The MEMAN project aims to maximise resource saving potentials of the metal mechanical sector through integral material and energy flow management. MEMAN addresses the complete manufacturing value chain, from casting and machining to surface finishing – for which it develops tools for practical decision-making, and new collaborative business models to benefit all companies in the value chain, from cradle to grave.

This present document beneficiated a lot from MEMAN work, about methodology and Energy and Material contents.

The MEMAN project supports European companies in the metal mechanical sector in their efforts to maximise their resource saving potential and increase competitiveness. The project is based on an innovative approach that addresses optimisation of whole manufacturing value chain, from cradle to grave, instead of isolated single company or process optimisation, and includes energy, raw materials, and other supplies.

This was done through:

- Validating new business models via collaboration of different companies along the whole value chain.
- Providing tools for practical decision-making support by combining Material and Energy Flow Analysis (MEFA) and Life Cycle Analysis (LCA).
- Defining requirements for energy certifications at company and whole value chain levels.
- Providing a set of 3 full business cases that demonstrate the effectiveness of the tools and business models.

In this way, MEMAN provided an approach to achieve **major cost reductions, reduce emissions and improve environmental performance, as well as improve regulatory compliance**. At the same time the project methodology supports the incorporation of **smart manufacturing innovations** as solutions for integrated value chain optimisation. All the results of

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[417]«REEECYC'LAB by Ecosystem», Ecosystem, s. d., https://reeecyclab.ecosystem.eco/?locale=en.

[418] MEMAN - Home», MEMAN, s. d., http://www.meman.eu/.

the project are presented in the MEMAN final publication **"Unlocking the resource saving potential of the metal-mechanic sector".**[419]

EU strategy for resource efficiency and Ecological Transition are in large development in Europe, in parallel of Industry 4.0 technologies' implementation.

The Eco-design Directive, which provides consistent EU wide rules for improving the environmental performance of products, also plays a key role in EU energy policy. It has proven to be a highly politically feasible instrument, which is accepted by a wide range of stakeholders. The Directive has contributed not only to improve environmental performance of products but has also yielded positive effects on competitiveness of EU industry.

Statement 1: Though aimed at product characterisation so far, the Eco-design approach could serve as the blueprint for energy characterisation for companies. Especially since the Eco-design Directive is a framework directive, meaning that it does not directly set minimum ecological requirements. Minimum requirements are adopted through specific implementing measures for each group of products defined by means of a so-called comitology procedure. The latter involves all relevant stakeholders.

Statement 2: The development of appropriate, and well accepted, indicators for Industry 4.0's impact on the supply chain and Ecological transition, and more generally for product manufacturing throughout the entire life cycle could support the implementation of Industry 4.0 technologies inside the supply chain, to achieve the sustainability targets.

Statement 3: The main finding is that the supply chain is a completed process from beginning till the end, and modifications to one part of the process can positively or negatively affect the overall results. We have to understand the entire life cycle process well to optimize the process itself and the end products.

Statement 4: Experience from the implementation of the EU Energy Labelling Directive on the one hand, and the EU Ecolabel initiative on the other hand, suggests that any approach towards Industry 4.0 technologies' implementation in Companies should best be implemented under a voluntary scheme.

This could for instance follow the examples of existing Voluntary Agreements or the various Corporate Social Responsibility reporting schemes implemented at national and international levels. An according voluntary energy, and resource efficiency, characterisation scheme would

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419 «MEMAN Virtual visit», MEMAN, s. d., https://umotique.fr/meman-project/.

also very well complement these global CSR approaches and Voluntary Agreement schemes for energy and resource efficiency.

Regarding the technical implementation of the Industry 4.0 technologies' implementation inside companies, this could lean on the implementation of the Eco-Design Directive, which is based on the 'Methodology for the Eco-design of Energy-related Products' (MEErP).

3.16 DIGITAL FACTORY: SIMULATION OF MANUFACTURING PROCESSES IN VOCATIONAL TRAINING

3.16.1 Simulation of Manufacturing Processes

Simulation of manufacturing processes is the use of computer-aided tools to imitate real-world manufacturing processes in a virtual environment. This technique has become increasingly popular in the manufacturing industry as it provides an efficient way to design, optimize, and analyse manufacturing processes. The purpose of this report is to provide an overview of simulation in manufacturing processes, its applications, benefits, challenges, and limitations, and its connection with vocational education.

3.16.1.1 Basics of Simulation

Simulation is the process of modelling a real-world system or process to predict its behaviour under different conditions. In manufacturing processes, simulation is used to create a virtual representation of a manufacturing system, which can be used to identify and optimize process parameters, reduce production time, and improve product quality. There are different types of simulation used in manufacturing processes, including discrete event simulation, continuous simulation, and agent-based simulation. Each type of simulation has its advantages and limitations, depending on the application.

3.16.1.2 Applications and Benefits

Simulation can be used in various applications in manufacturing processes, including virtual prototyping and product design, process optimization and performance analysis, training and education of personnel, and quality control and inspection. Virtual prototyping and product design allow engineers to test and validate the design of a product in a virtual environment before producing it. Process optimization and performance analysis help to identify bottlenecks, reduce cycle time, and improve process efficiency. Training and education of personnel can be enhanced through simulations that provide realistic scenarios that trainees can interact with. Quality control and inspection can be improved by simulating the inspection process, reducing the need for physical inspection, and improving the accuracy of inspection.

Simulation provides numerous benefits to manufacturing processes, including cost savings and time efficiency, reduction of errors and waste, and increased product quality and innovation. Simulation can reduce the need for physical prototypes and testing, reducing material and labour costs. Simulation can also help reduce the time needed to develop and optimize a manufacturing process, reducing time-to-market. By reducing errors and waste, simulation can improve product quality and reduce the number of defective products produced. Finally, simulation can help drive innovation by allowing engineers to explore new designs and concepts quickly and cost-effectively.

3.16.1.3 Challenges and Limitations

While simulation has numerous benefits, there are also challenges and limitations that need to be addressed. Some of the challenges include data acquisition and management, integration with existing systems and processes, and costs and expertise. Data acquisition and management are essential to ensure the accuracy of the simulation. Integration with existing systems and processes can be a challenge, especially if there are complex legacy systems in place. Finally, costs and expertise can be a barrier to adopting simulation, as it requires specialized software and personnel.

3.16.2 Conclusion

Simulation technology is a powerful tool that can help manufacturers optimize their production processes, reduce costs, and improve efficiency. While there are challenges to implementing simulation technology, the benefits are numerous, and the future prospects are promising. Additionally, simulation technology is becoming an increasingly important part of vocational education, providing students with the skills necessary for a successful career in manufacturing. To fully leverage the capabilities of simulation technology, it is important for manufacturers and vocational schools to invest in simulation software and ensure that their students have the skills necessary to succeed in the manufacturing industry.

3.16.2.1 Connection with Vocational Education

Simulation has a vital role to play in vocational education, providing students with a practical and realistic learning experience that is difficult to achieve through traditional methods. By incorporating simulation into vocational education, students can gain practical experience and skills, which can be transferred to real-world manufacturing processes. Simulation can be used to train students in different manufacturing processes, from assembly line production to CNC machining. Simulation can also be used to teach safety protocols and practices, which are essential in the manufacturing industry.

3.16.2.2 Recommendations and Next Steps

To fully leverage the capabilities of simulation in vocational education, several recommendations and next steps should be considered.

1. Develop and implement simulation-based training programs: Vocational education institutions can design and implement simulation-based training programs that enable students to gain hands-on experience in manufacturing processes without the risk of damaging equipment or harming themselves. Such programs can be customized to the needs of the students and the industry they will be working in.
2. Collaborate with industry partners: Vocational education institutions should collaborate with industry partners to design and develop simulation models that reflect real-world manufacturing processes. Such collaboration can also help ensure that the training programs are aligned with the latest industry trends and practices.
3. Encourage lifelong learning: Vocational education institutions should encourage students to engage in lifelong learning by providing access to additional training programs and resources that allow them to stay up to date with the latest technological advancements in manufacturing processes.
4. Invest in technology: Vocational education institutions should invest in the latest simulation technology to create realistic and immersive learning environments that replicate actual manufacturing processes. This can help students to develop the skills needed to operate and maintain the latest manufacturing equipment and technology.
5. Evaluate and improve the effectiveness of simulation-based training programs: Vocational education institutions should evaluate the effectiveness of their simulation-based training programs regularly to identify areas for improvement. This can help ensure that the training programs are effective in preparing students for the demands of the industry.

3.17 DIGITAL FACTORY: VIRTUAL / MIXED REALITY

3.17.1 NVIDIA OMNIVERSE and Advanced Manufacturing

3.17.1.1 Introduction

Nvidia Omniverse [420] is the metaverse of NVIDIA, the largest high-end graphic card manufacturer in the world. Recently they have published a new advance in the metaverse which will have a direct impact on Advanced Manufacturing in VET. Some quick points:

- NVIDIA has presented the new IA and XR technology in their Omniverse environment.
- The main problem for the metaverse was the emptiness or lack of continuous interaction. The new development will help with that.
- Omniverse is not only an XR but also a desktop-like environment so this hybrid approach will reduce onboarding costs.
- AR manufacturers will get all the benefits of the metaverse.

3.17.1.2 Contextualisation

For the past two years, the metaverse has been the preferred topic, with companies like Meta introducing huge changes, and suffering staggering losses. Companies like the NVIDIA have been investigating as well.

In their most recent exhibition at NVIDIA GTC 2023[421], NVIDIA has delved into their metaverse tools that they call the NVIDIA Omniverse. Focused on AI and without abandoning the protoverses, this company facilitates the creation and interaction of the three basic components that facilitate teaching in Advanced Manufacturing within vocational training:

- An increasingly competent AI that serves as the main basis for interacting in metaverses
- An integrated environment where programming the behaviour of machines for advanced manufacturing does not require deep programming knowledge
- A powerful yet simple graphical environment for graphical representation (including diagrams) of machine tools.

[420] «GTC 2023: #1 AI Conference», NVIDIA, s. d., https://www.nvidia.com/gtc/.

[421] «GTC 2023: #1 AI Conference», NVIDIA, s. d., https://www.nvidia.com/gtc/.

3.17.1.3 Objectives / Research Question / Problem Statement

The primary goal is for Advanced Manufacturing to be integrated into omniverse-type environments with the support of XR immersion and with the AI support that NVIDIA has.

Objectives: Microsoft has closed its metaverse this year for being essentially a desert. Its main attraction, a fluid interaction, has failed due to lack of actors. AI could come into play at this level. A permanent AI trainer to help us with advanced manufacturing experiences would be the best approach. Other companies such as SEAT have already opted for this type of technology with different results[422].

Research question: The first question to be solved is how much will it cost for Advanced Manufacturing teachers in VET to start with the integration of these tools? Are there alternatives? Are companies interested in this?

Problem statement: The implementation of new technologies always implies uncertainty, losses but also benefits. The human factor, including the fear of losing teachers' jobs, can have a negative impact on the adoption of new technologies. In the case of NVDIA , the costs associated with the platform are high.

3.17.1.4 Findings

The adoption of tools like NVIDIA's Omniverse is going to be slower than desired. Although the integrated development environment is straightforward and many companies are linking up with NVIDIA, teachers need more training to be able to deploy effectively.

3.17.1.5 Conclusions

There is unlimited potential use, but without enough computing power in the local servers or training, it is difficult to apply such technology on a large scale. That said, it is a technology with a promising future, and we cannot lose sight of it.

[422]«How SEAT Applies VR | SEAT», s. d., https://www.seat.com/company/news/cars/virtual-reality-car-manufacturing.html.

3.17.2 Remote Assistant Using MR for Advanced Manufacturing

Mixed reality devices for improving remote assistance of the operators using TeamViewer technology are saving time and reducing logistic issues with people ubiquity problems. Invelon[423] has created a technology that makes this kind of operations, which should be taught in VETs.

3.17.2.1 Introduction

Remote assistants using MR help solving Advanced Manufacturing maintenance without the inconvenience of travelling. Teaching our VET students about this technology in the two sides of the holo-conference (the guider and the operator) will make their work easier in the future.

3.17.2.2 Contextualisation

Figure 62: Logo TeamViewer call using hololens2[424]

Sending expert technicians to different parts of the planet every time a specialized machine-like advanced manufacturing breaks down is expensive and unproductive. Having a machine stopped by a query that is solved "knowing which screw to tighten" is something that telepresence can help solve. Through videoconferencing technologies, much progress has been made but we can go further through MR and holographic projection.

[423]«Teamviewer Fontline XPick Vision Picking for Logistics and Warehousing | Invelon Technologies», invelon, s. d., https://www.invelon.com/en/teamviewer-xpick/.

[424]N. V. Vijayakumar, «TeamViewer Brings Workflows to TeamViewer Pilot, Adds Microsoft HoloLens 2 Support - The NFA Post», *NFA Post* (blog), 3 December 2020, https://thenfapost.com/teamviewer-brings-workflows-to-teamviewer-pilot-adds-microsoft-hololens-2-support/, https://thenfapost.com/teamviewer-brings-workflows-to-teamviewer-pilot-adds-microsoft-hololens-2-support/.

3.17.2.3 Objectives / Research Question / Problem Statement

This sub-report is highlighting the convenience of VET entry of MR-type holographic telepresence tools thanks to Microsoft Hololens2 hardware and its technology partner TeamViewer.

Objectives: To demonstrate that the use of telepresence and its training in VET saves costs and speeds up repairs in AM.

Research question: How expensive is an MR deployment? What are the connectivity limitations?

Problem statement: Hardware is expensive, and global 5g mobile network connectivity is still limited. Without a reliable communications network, videoconferencing or holoconferencing will fail and there will be no way to support the learner or operator.

Figure 63: Hololens2[425] with security helmet

Off-line operations do not meet the objective of remote assistance discussed in this sub-report.

[425] «Tecnología de realidad mixta para empresas», Microsoft HoloLens, s. d., https://www.microsoft.com/es-es/hololens.

3.17.2.4 Findings

There are several alternatives presented in this report, but all require a paradigm shift for technical support companies and adapted training for students.

3.17.2.5 Conclusions

We conclude that the use of MR for telecare is already implemented in some companies, but that training within VET to assist in Advanced Manufacturing problems is expensive and not widely applied.

3.17.3 Advanced Manufacturing training in XR Environments

This sub-report is about the collaborative XR training[426] for teachers and VET students and the safest and more cost-effective way to provide Advanced Manufacturing training.

3.17.3.1 Introduction

The Basque Vocational Training System is committed to immersive collaborative virtual reality experiences as the best system to train our VET students safely and with reduced costs.

3.17.3.2 Contextualisation

Figure 64: Collaboration in Advance Manufacturing and Assembling[427]

[426]«The Virtual Reality Company», Virtualware, s. d., https://www.virtualwareco.com/.

[427]«The Enterprise VR Platform powered by Virtualware | VIROO®», The VR Enterprise Platform, s. d., https://www.virtualwareco.com/viroo/.

Once the virtual reality market is mature in terms of hardware and software, it is time to apply it in VET. The idea of FP Euskadi is that the students trained under this environment can spearhead companies to bet on this type of technology.

3.17.3.3 Objectives / Research Question / Problem Statement

Expand the use of collaborative VR designed by teachers in VET.

Objectives: Only few VET teachers have knowledge of integrated development environments such as Unity or Unreal or modelling skills with Blender or Maya. This prevents them from developing their own VR experiences and collaboration. The goal is for teachers to be able to create ad-hoc exercises for their students in a versatile way.

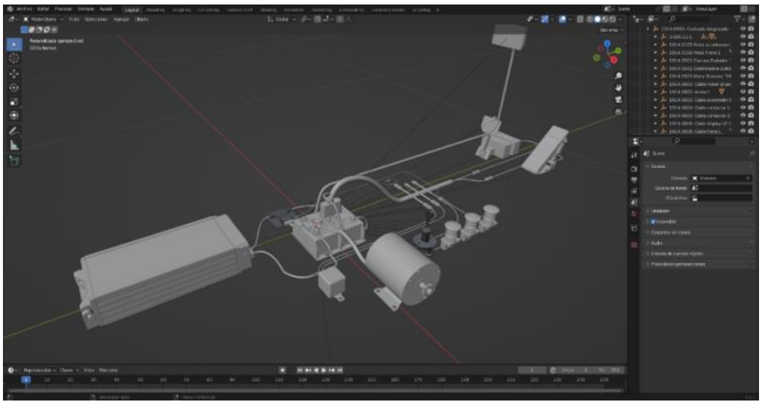

Figure 65: Blender modeling an electric car[428].

Research question: How many hours of training do inexperienced teachers (in VR development) need to be able to create a useful collaborative experience?

Problem statement: All technology needs a time of development and learning, and the tool we choose has to enable a very fast training time.

3.17.3.4 Findings

The tool of the company VIRTUALWARE allows creation of scenes or collaborative rooms by VET teachers. Within a 20-hour training session and with the support of TKNiKA and VIRTUALWARE, the teachers have been able to create a collaborative room to simulate a complex machine. From

[428] «Tknika», *Tknika* (blog), s. d., https://tknika.eus/en/.

this experience (a CNC machine and its start-up) different Advance Manufacturing machines will be created to make the training of the students safer.

3.17.3.5 Conclusions

Training in collaborative VR with materials created by inexperienced teachers in 3D development is possible and was demonstrated through the experience created by the Miguel Altuna centre.

3.17.4 Conclusion

Statement 1: Integration of ergonomic principles and digital technologies into vocational education and training programs: By incorporating ergonomic principles and digital technologies into vocational education and training programs, students can learn the skills and knowledge necessary to thrive in a rapidly changing manufacturing landscape. This includes training in ergonomics, human factors, and digital technologies, as well as hands-on experience with digital workstations and equipment.

Statement 2: Investment in infrastructure and equipment: To fully leverage the capabilities of digital workplaces and ergonomics in vocational education, institutions must invest in the necessary infrastructure and equipment. This includes providing access to state-of-the-art digital workstations, equipment, and software, as well as ensuring that the physical environment is designed with ergonomics in mind.

Statement 3: Prioritization of worker health and safety: While digital workplaces and ergonomics can provide many benefits, they also present new challenges related to worker health and safety. Institutions must prioritize worker health and safety by incorporating ergonomic principles into the design of work environments, providing training in ergonomic practices, and ensuring that workers have access to the necessary tools and resources to maintain their health and well-being.

3.18 DIGITAL FACTORY: PREDICTIVE MAINTENANCE

3.18.1 Introduction

In the age of advanced manufacturing, there is not just one but several maintenances. Historically, the correct operation of equipment was first carried out in a corrective manner (triggered by the malfunctioning or, worse, the breakdown of the machine) and then evolved, thanks to the use of statistics, towards preventive maintenance.

Among other indicators, the history of average times between breakdowns made it possible to "anticipate the occurrence" of a breakdown and to plan the replacement of parts before the machine was forced to stop during the production phase. However, there was no guarantee that the timing of the "repair" was always ideal, and that the equipment would not have been able to carry out other production cycles without problems before a degraded operating mode or a breakdown.

The analysis of profitability, increased competition, but also the awareness of environmental costs and many other aspects, gradually forced a new questioning and pushed the decision-makers to find a solution more adapted to the context of the 2000s. Predictive maintenance then appeared, with the main objective of not suffering a breakdown, but also of not changing a part too soon while guaranteeing the optimal functioning of an equipment and extending its useful life under the best conditions.

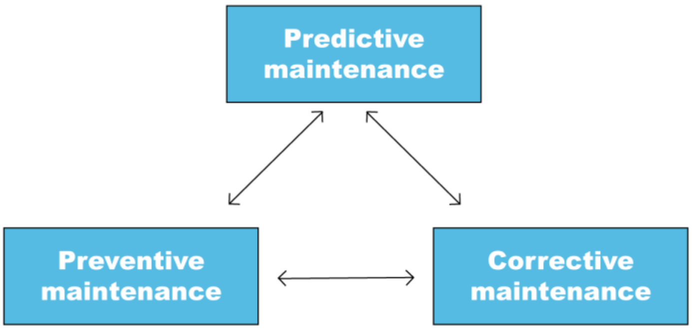

Figure 66: Predictive maintenance - Different types of maintenance

While it has already been favoured for more than 20 years, in the last few years, the technological evolutions linked to digitalisation have made it possible to improve its efficiency with the combined use of several technological trends such as IoT, big data, CPS (M2M & MES) etc.

Another positive point is that thanks to the pooling of infrastructure, tools, and specialised human resources (such as IT development), SMEs have been able to use this technique which was previously difficult to implement.

Already in 2019, the use of IoT was seen as a solution for the future. Even today, although its use is already widespread, it seems like it will spread more and globally in the next 6 years.

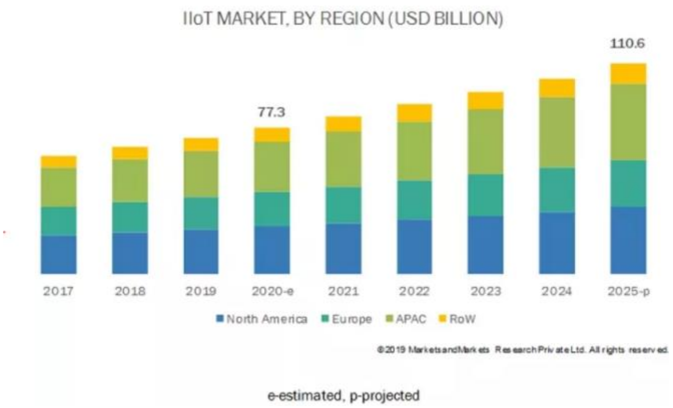

Figure 67: Predictive maintenance - The global IoT market[429]

3.18.2 Contextualisation

What is predictive maintenance and what are its benefits?

The first obvious answer is that it allows the condition of assets to be monitored and their malfunction or failure to be prevented.

The other effect, which is less obvious to predict, is that it encourages exchanges[430] between departments that previously communicated little, or nothing.

[429] Future Market Insights, « Market Research & Business Intelligence | Future Market Insights », Market Research & Business Intelligence | Future Market Insights, 2019, https://www.futuremarketinsights.com/.

[430] GL EVENTS, « Maintenance industrielle : arme de compétitivité pour la productivité », Industrie online, 15 September 2021, https://www.industrie-online.com/p/actualite-2/actualites/maintenance-industrielle-arme-de-competitivite-pour-la-productivite.

Shell uses the IoT for pipeline monitoring[431]

«Oil company Shell is taking advantage of an internet of things (IoT) connectivity solution to improve the company's monitoring capabilities for its operations in Nigeria. Last year, U.S. IoT connectivity provider Ingenu and Croatian producer of industrial electronics and power electronics devices Končar - INEM delivered an IoT connectivity solution to provide digital oilfield capabilities to the Shell Nigeria pipeline facility.

The Digital Oilfield (DOF) solution provides pipeline surveillance and wellhead monitoring capabilities to remote infrastructure in the Niger Delta.»

Lockheed Martin uses big data to maintain the F-35[432]

«Lockheed Martin turned to 3D technology and big data to streamline the diagnostics and maintenance processes for its F-35 and F-22 fighter planes, according to a case study provided by the Industrial Internet Consortium.»

SIMAP: Intelligent system for predictive maintenance[433]**: Application to the health condition monitoring of a wind turbine gearbox**

«SIMAP is the abbreviated name for the Intelligent System for Predictive Maintenance. It is a software application addressed to the diagnosis in real-time of industrial processes. It considers the information coming in real-time from different sensors and other information sources and tries to detect possible anomalies in the normal behaviour expected of the industrial components. The incipient detection of anomalies allows for an early diagnosis and the possibility to plan effective maintenance actions. Also, the continuous monitoring performed allows for an estimation in a qualitative form of the health condition of the components. SIMAP is a general tool oriented to the diagnosis and maintenance of industrial processes, however the first experience of its application has been at a windfarm. In this real case, SIMAP can optimize and to dynamically adapt a maintenance calendar for a monitored wind turbine according to the real needs and operating life of it as well as other technical and economic criteria. In particular this paper presents the

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[431]Juan Pedro Tomás, «Industrial IoT Case Study: Shell Uses the IoT for Pipeline Monitoring», *RCR Wireless News* (blog), 26 April 2017, https://www.rcrwireless.com/20170426/fundamentals/industrial-iot-case-study-shell-pipeline-monitoring-tag23-tag99.

[432]Phillip Tracy, «Case Study: Lockheed Martin Uses Big Data for F-35 Maintenance», *RCR Wireless News* (blog), 19 April 2023, https://www.rcrwireless.com/20160902/uncategorized/big-data-lockheed-martin-tag31-tag99.

[433]Mari Cruz Garcia, Miguel A. Sanz-Bobi, et Javier del Pico, «SIMAP: Intelligent System for Predictive Maintenance: Application to the Health Condition Monitoring of a Windturbine Gearbox», *Computers in Industry*, E-maintenance Special Issue, 57, nº 6 (1 August 2006): 552-68, https://doi.org/10.1016/j.compind.2006.02.011.

application of SIMAP to the health condition monitoring of a wind turbine gearbox as an example of its capabilities and main features.»

Predictive analysis with ODiN[434] - Bosch

«ODiN is a cloud-based service, which includes analysis via the ODiN platform, operation of the user interface (account), monitoring, support with reporting and provision of advice and recommendations. This system was set up, within the framework of a PhD student's thesis, to ensure the maintenance of a hydraulic press for a company based in Morocco. The figures in 2019: 11 countries, 27 connected sites (with about 100 being currently equipped), 11 million measurements per day on one site, and maintenance time divided by 2»

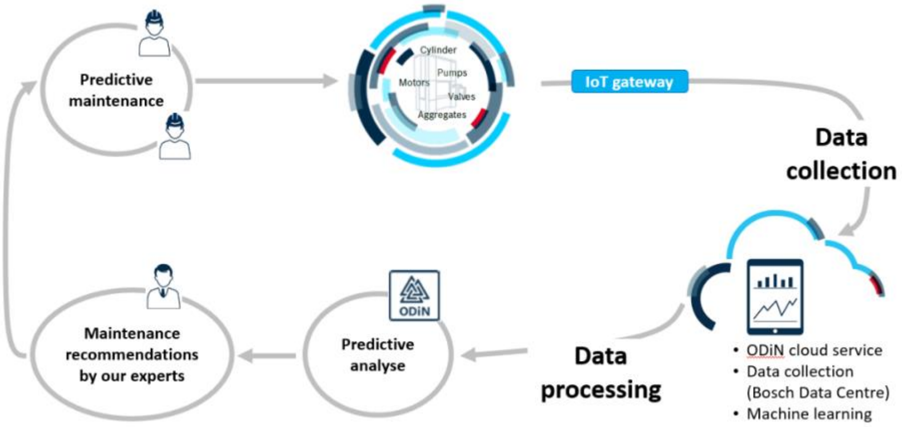

Figure 68: Predictive maintenance - Industrial solution Rexroth - Bosch

Technician on site before the lift breaks down[435]

«This is the case, for example, of the lift and escalator manufacturer KONE. To offer a predictive maintenance system, KONE has gone to great lengths. The artificial intelligence platform chosen by this manufacturer is IBM's Watson, which has proved its effectiveness, for example, with highly reliable medical diagnoses.

As for the connected sensors in its lifts, they record more than 200 critical parameters - opening and closing of doors, lights, automatic stop, distance and duration of trips, noise level, vibrations, temperature, air pressure, humidity, etc. - transmitted in real time!

[434]Bosch Rexroth France, «Brochure - Maintenance prédictive ODin», calameo.com, s. d., https://www.calameo.com/bosch-rexroth-france/books/00410823653cf456c4521.

[435]Usine Digitale, «Maintenance prédictive : comment peut-on réparer avant la panne?», 25 juillet 2019, https://www.usine-digitale.fr/article/maintenance-predictive-comment-peut-on-reparer-avant-la-panne.N866955.

On this technical basis, KONE has developed its "24/7 Connected Services". As soon as the artificial intelligence anticipates a fault in a lift, the technicians receive a service order and a diagnosis. If a critical anomaly is detected, technicians can immediately order the necessary parts and schedule a rapid intervention. The repair will take place even before the failure and unavailability of the lift. But this intervention is scheduled wisely: the AI platform also assesses the degree of urgency of the intervention. The customer will not be disturbed by a minor fault, which will wait for the next maintenance operation on site.»

New tools to boost automated manufacturing[436]

«Within the three-year research project IMPROVE[437], 13 leading players from academia, industry, and software development from across Europe have joined forces to find innovative solutions for the manufacturing industry. Responding to the changing needs and challenges faced by manufacturers and production facilities in times of Industry 4.0, the project has developed novel tools in the field of simulation and optimization, condition monitoring, alarm management, and quality prediction.

The self-learning condition monitoring solution allows forecasting maintenance needs based on a data-driven machine learning approach. Up to now, only experienced operators were able to perform condition monitoring efficiently. The new IMPROVE solution is revolutionary due to its precise predictions. The tool protects producers from unexpected breakdowns or product degradation and can be translated into different software options.

The alarm management solution supports the machine operator in case of an alarm flood. The innovative algorithm is based on data-driven similarity learning as well as case-based reasoning and integrates expert knowledge. It particularly assists the operator in finding the root cause for the alarm and taking the right action.

With the decision support app for quality monitoring, IMPROVE helps the machine operator to predict the quality of the production by using data-driven models based on machine parameters. As the new app enables an exact quality prediction, it ensures the best possible quality for the whole production process.»

[436] Cordis, «New Tools to Boost Automated Manufacturing | News | CORDIS | European Commission», Cordis, 31 August 2018, https://cordis.europa.eu/article/id/123839-new-tools-to-boost-automated-manufacturing.

[437] IMPROVE, «Innovative Modelling Approaches for Production Systems to Raise Validatable Efficiency», IMPROVE, 31 August 2018, https://improve-vfof.eu/.

[L'instant tech] With Cetim, the SAB group goes to the end of the optimization of its foundry[438] - From automation to data analysis

«After robotization and automation, it is time to analyse large quantities of data, to measure the carbon impact of the manufacturing of parts and to use additive manufacturing to optimize moulds. The SAB group joined the DeCISIFF[439] project, led by Cetim and CTIF (Technical Centre for Foundry Industries), alongside four other automotive foundry manufacturers.»

The industry of the future at the heart of excellence industry's innovation[440]

«The Excellence Industrie consortium, a union of six regional economic players located in the Campus Région du Numérique in Charbonnières, is working on decarbonation, digital transition, the factory of the future and the circular economy.

The consortium includes EDF, Bosch Rexroth, Vicat, SNCF, Hef and the Serfim group. It operates on four major themes: the circular economy, decarbonisation, the factory of the future and the digital transition. One of the topics addressed by Excellence Industry is the connected ring. With this project, the consortium wants to create a solution to predict the maintenance of rings on construction equipment and infrastructures undergoing significant stress.

Thanks to the PEL 4.0 connected ring, the user can obtain traceability information, on the state of the ring thanks to numerous sensors and on the need to replace it... The ring benefits from a technology adapted to all types of machines. It is weather resistant. It can communicate via a wireless system and without batteries. According to Richard Brunet, president of Bosch Rexroth SAS, the project is aimed at companies wishing to benefit from support.»

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[438] Léna Corot, «[L'instant tech] Avec le Cetim, le groupe SAB va au bout de l'optimisation de sa fonderie», *L'usine Nouvelle*, 2 mars 2023, https://www.usinenouvelle.com/editorial/l-instant-tech-avec-le-cetim-le-groupe-sab-va-au-bout-de-l-optimisation-de-sa-fonderie.N2104391.

[439] Cetim, «DeCISIFF : un projet structurant pour la fonderie», Cetim, 27 April 2022, https://www.cetim.fr/actualites/decisiff-un-projet-structurant-pour-la-fonderie/.

[440] FactoryFuture, «L'industrie du futur au cœur de l'innovation d'Excellence Industrie», *FactoryFuture* (blog), 26 janvier 2023, https://www.factoryfuture.fr/lindustrie-futur-coeur-innovation-excellence-industrie/.

3.18.3 Objectives / Research Question / Problem Statement

Thanks to the analysis and exploitation of collected data, predictive maintenance makes it possible to identify warning signals to be able to intervene on the machines before the occurrence of operating anomalies or breakdowns.

«PdM[441] can reduce the time taken to schedule maintenance by 20-50%, increase equipment availability and uptime by 10-20% and reduce overall maintenance costs by 5-10%».

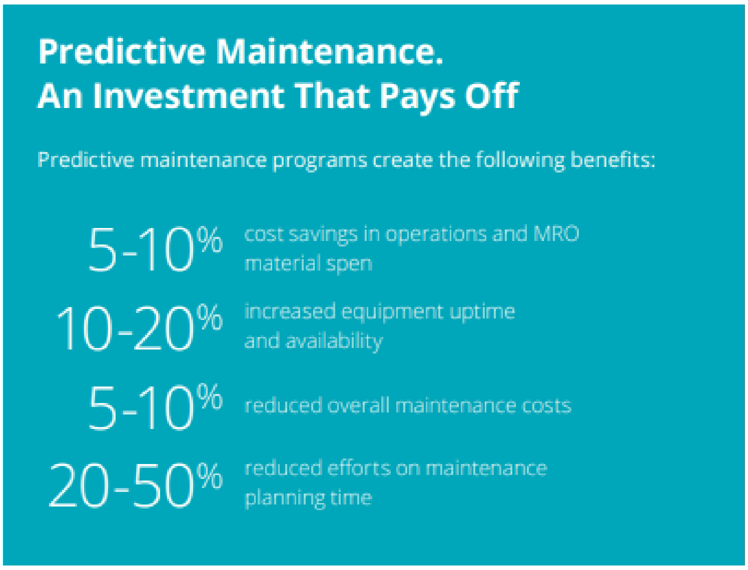

Figure 69: Predictive maintenance - Benefits in figures[442]

Objectives: The major advantage of predictive maintenance is that it is carried out in real time, continuously and especially during the production phase of the equipment. The monitoring of parameters and the comparison of these with warning thresholds can allow intervention before the breakdown or malfunction.

The difficulty of such maintenance varies according to the sector of activity, but it also lies in the diversity and interweaving of the technologies used. From technologies directly correlated to the

[441] Chris Coleman et al., «Making Maintenance Smarter», Deloitte Insights, 9 May 2017, https://www2.deloitte.com/content/www/us/en/insights/focus/industry-4-0/using-predictive-technologies-for-asset-maintenance.html.

[442] «Deloitte_Predictive-Maintenance_PositionPaper.pdf», 10, s. d, https://www2.deloitte.com/content/dam/Deloitte/de/Documents/deloitte-analytics/Deloitte_Predictive-Maintenance_PositionPaper.pdf.

method such as IoT, big data, MES/CSP and technologies linked to the cloud context such as cybersecurity.

Research question: Optimisation of the predictive model, thanks to learning: the more data the database contains, the better the performance of the analysis, which implies an infrastructure that some SMEs are not able to provide. Moreover, they do not necessarily have the technical and IT knowledge required to implement and maintain such a solution. These constraints, among others, explain why this technique is not always within the reach of SMEs.

Another line of research, in recent years, has been devoted to the automatic creation of models. At present, it can be said that although we are not yet in the pure domain of AI, we are getting closer.

In February 2023, the software publisher AVEVA presents the latest version of its AVEVA Predictive Analytics software[443], dedicated to the predictive monitoring of industrial assets involved in process management and manufacturing. The new version facilitates the deployment, validation, saving and interpretation of results.

The evolution of the software is characterised by a new feature that manages the automation of the construction and deployment of predictive models. Through the combined use of digital twin technologies and artificial intelligence, it has been possible to automate the creation of predictive models. These steps, which are carried out prior to implementation, have the double advantage of considerably reducing errors and the time required for deployment.

Unified predictive maintenance system

UPTIME[444] is a predictive maintenance platform, created within the framework of the Horizon 2020 programme. A dozen partners from 5 European countries have participated in its development, in collaboration with 3 end-users from the steel, aeronautics and household appliance industries.

Real-time and historical data enables companies to manage all their connected assets. Maintenance scenarios assist and support users in their decision making to implement optimal and timely maintenance actions. Risk mitigation minimises maintenance costs and improves their Overall Equipment Effectiveness (OEE).

[443] Christian GLADIEUX, «L'IA au service de l'analyse prédictive», *Cad Magazine* (blog), 27 février 2023, https://cad-magazine.com/lia-au-service-de-lanalyse-predictive/.

[444] https://www.uptime-predictive-maintenance.com/

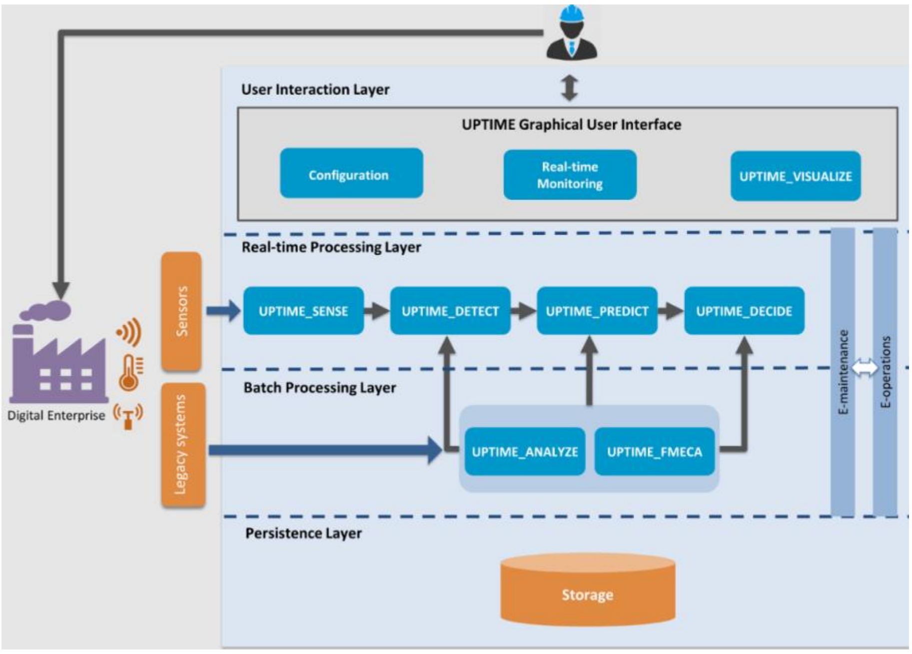

Figure 70: Predictive maintenance - UPTIME Platform[445]

UPTIME facilitates maintenance activity. Control screens allow managers to view real-time asset status, correlation analysis and actionable plans based on collected data analysis. Operators receive real-time alerts and notifications. Over time, they take responsibility for performing maintenance and those most involved can provide feedback to validate or improve the models in place.

The settings allow the tool to be adapted to the needs and data but also to the company's processes, with the aim of rendering the result of the analysis on different screens. The processing of the collected data returns actions and information to the different stakeholders to improve the maintenance of the assets.

Through six main modules, the architecture of the UPTIME platform offers all the functionalities allowing the interaction of the components as well as the integration and communication between all the functional elements of the system to ultimately provide a unified maintenance solution.

At the start of the project, most of the main modules of the UPTIME platform had already reached TRL5 with the final goal of TRL7, including the new ANALYZE module then under development. By 2022, with the main modules having reached TRL8, which is the right level of maturity before launching a product on the market, the whole UPTIME platform was "qualified".

[445]Cordis, «UNIFIED PREDICTIVE MAINTENANCE SYSTEM | UPTIME Project | Fact Sheet | H2020 | CORDIS | European Commission», 28 février 2021, https://cordis.europa.eu/project/id/768634.

The new clients, in addition to the financing, will make it possible to achieve a generalized TRL8 thanks to their specificities and their own challenges.

UPTIME differs from most of its competitors in that it has higher level intelligence functions, which requires strong vertical customisation and more complete integration with existing systems.

3.18.3.1 Problem Statement

Predictive analysis is only effective if it is based on a very large amount of data that must be stored, visualised and analysed. Based on this data, the development of predictive models or schemes allows for real-time monitoring of parameters and the reporting of any potential malfunctions.

Setting up models

From this data, the preliminary work will be to determine the operational patterns, and the unusual patterns likely to indicate a malfunction.

This learning phase creates libraries that are then used to process the incoming data and define the diagnosis in real time.

The efficiency of the system lies in the large amount of data and its quality. It is in fact the machine equivalent of the experience and competence of the operators, with the advantage that it is and will remain accessible to all.

At the gateway to AI

While the monitoring of patterns is automated, their creation today requires human intervention, so we are not yet in the domain of pure AI.

In March 2022 the DeCISIFF project proposed to use AI to automate the creation of these patterns[446], in March 2023 the SAB group wants to achieve this optimisation in the manufacturing process of aluminium parts in its foundry.

Despite several years of know-how and a very good knowledge of the production parameters, 3 to 4% of rejects (incomplete parts, porosity, broken cores) are due to "many hazards in the casting process". This project aims to take a new step towards increased performance and better quality.

During the production of a part, some fifty sensors collect information (aluminium temperature, cooling time, air flow, water flow, mould temperature, etc.). One of the challenges, piloted by

[446] Corot, «[L'instant tech] Avec le Cetim, le groupe SAB va au bout de l'optimisation de sa fonderie».

Cetim[447], remains to cross this information with the quality data, to clean the data sets, to collect the missing parameters, to carry out descriptive statistics and to model the behaviour of the process, with an aim of predicting if the part will be good or bad. Good quality parts are compared to scrap to understand what went wrong and to take corrective action.

The company hopes to have an industrial demonstrator by the end of 2024.

In 2023 AVEVA, introduced the new version[448] of its AVEVA Predictive Analytics tool that automates model building. This new functionality allows new predictive models to be deployed autonomously in a single action. While ensuring consistency in model development, this release facilitates large-scale deployment of the predictive maintenance solution.

Perhaps in the future, the automation of this first phase using AI could be generalised throughout the industry, eventually reaching the SME.

Interconnection of highly specialised profiles

Since always, operators and managers have had to adapt to new ways of working, and this is even more true today where evolutions (or even revolutions) are constant during one's career. Another important parameter of I4.0 is the interweaving of technologies that call on a variety of skills, the effectiveness of which is directly correlated to the ability of everyone to understand and integrate the general constraints and to know how to explain those of his or her field. In short, the greater the collaboration, the better the result.

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[447] Cetim, «DeCISIFF».

[448] Communiqué de Aveva, «AVEVA fait progresser l'analyse prédictive grâce à l'IA», Decideo - Actualités sur le Big Data, Business Intelligence, Data Science, 23 février 2023, https://www.decideo.fr/AVEVA-fait-progresser-l-analyse-predictive-grace-a-l-IA_a12915.html.

Observation

France is facing a lack of candidates, the cause of which is still unclear, is it due to a lack of training[449]?

Although the process of predictive maintenance is now well known and well established, the evolution of the technological means used, and their interweaving require an adaptation of the people in charge of their implementation and follow-up as well as the training provided to them.

For example, the IoT calls on several professions such as mobile and embedded software development, server management, but also robotics and electronics. All these profiles must work together, and their areas of expertise are increasingly complex and broad.

The needs must be clarified, and the positions[450] listed, because the generalisation of 5G will further enable the development of this field and the associated technologies.

Proof of this poor adaptation is the difficulty of recruiting suitable profiles[451] and the strength of these profiles which impose their will. Another factor that explains this observation is that even if there are training courses, they are less than 10 years old, and the people trained are just beginning to have the experience required (about 5 years) by employers for experienced profiles.

Normally this should improve in the coming years, but we will have to remain vigilant about the quality and adaptation of training.

Cybersecurity

Of course, cybersecurity constraints must be integrated into the thinking and tested during each phase of the process and thus guarantee security and prevent malicious attacks.

[449] Raphaële Karayan et Usine Digitale, «La France manque de formations en IoT et en robotique», 31 janvier 2023, https://www.usine-digitale.fr/article/la-france-manque-de-formations-en-iot-et-en-robotique.N2095261.

[450] «GEN_RapportObsGENScan_A4_Light.pdf», s. d, https://www.grandeecolenumerique.fr/sites/default/files/GEN_RapportObsGENScan_A4_Light.pdf.

[451] Usine Digitale, «Métiers du numérique : "Les candidats sont devenus des rockstars"», 10 June 2022, https://www.usine-digitale.fr/editorial/metiers-du-numerique-les-candidats-sont-devenus-des-rockstars.N2014017.

3.18.4 Findings

The first step, which is the collection of data, is done by different types of sensors depending on the piece of equipment to be monitored:

Infrared thermography analysis

This non-invasive technology is widespread because it is versatile. It allows the monitoring of the temperature evolution of sensitive parts of an equipment and thus to anticipate malfunctions before they occur.

Fluid analysis

Analysis of lubricants and coolants can determine the presence of contaminants (water, and other debris) that may indicate wear or part defects. Viscosity change is an alert to the change in lubricant required for the proper functioning of certain parts.

Sonic and ultrasonic acoustic analysis

Acoustic monitoring can detect noises from gas emissions, liquids or surface leaks, the change in the sound pattern can be a warning signal. The cheaper sonic technology is more common, while the more expensive ultrasonic technology is dedicated to electrical equipment that emits more subtle sounds.

Vibration analysis

Wear and tear on certain parts can cause slight changes in the vibration of the machine. With constant surveillance, and appropriate monitoring, a trained professional can be alerted and anticipate an imbalance, shift or failure by planning a re-setting of the machine or replacement of defective parts as soon as the alert threshold is exceeded.

Other technologies

Some industries can also monitor laser alignment, electrical circuits, cracking or corrosion to complete the monitoring picture.

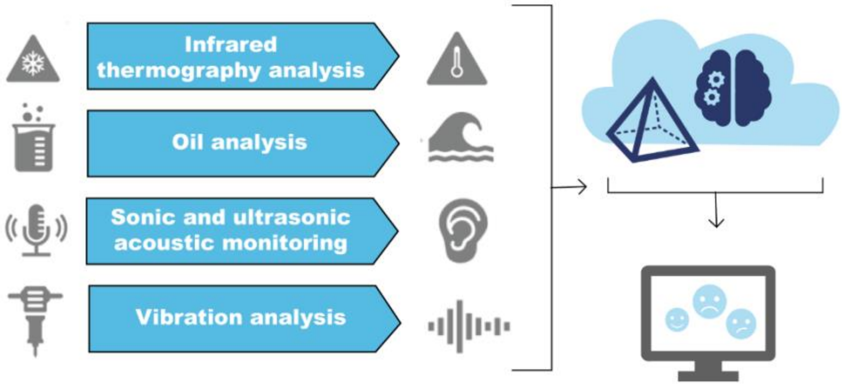

Figure 71: Predictive maintenance - Sensor types

The new generation of sensors, thanks to machine to machine (M2M) technologies, allow the transmission of data without human intervention. We can then talk about real-time transfers that are based on fully automated routines.

Once the data has been collected, the relevance of the data must be determined and the methods of analysis to be implemented in the MES must be defined.

The MES (Manufacturing Execution System) is a tool for steering and optimising the industry of the future. It is the software part, the brain of the predictive maintenance procedure which exploits and analyses the data to send the result of the analysis to the control centre or directly to the workstation.

The effectiveness of MES depends on the quality of the data collected, so key elements of the entire design chain must be scrutinised, from order to production to delivery. This very often involves interfacing with other company management systems such as ERP, CAPM ...

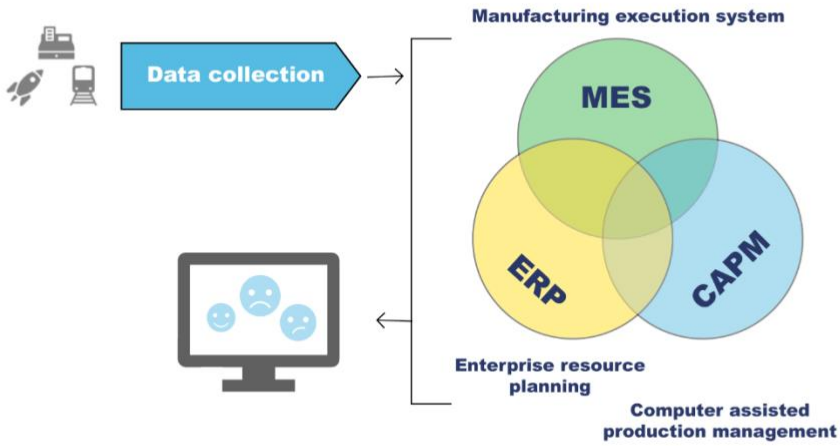

Figure 72: Predictive maintenance - MES interconnections

This is where the human factor comes into play, it is necessary to define the key elements to be traced and for this to be familiar with all the problems encountered by all the departments involved in the company's activity. The analysis phase prior to the definition of the model should not forget anyone and will guarantee the good integration of the MES in the manufacturing process.

Each problem reported will be an avenue of research. Answering the questions of how to detect it and what are the solutions to be implemented to solve it will be the elements on which it will be necessary to rely.

As seen above, current research focuses on the automation of this step using artificial intelligence.

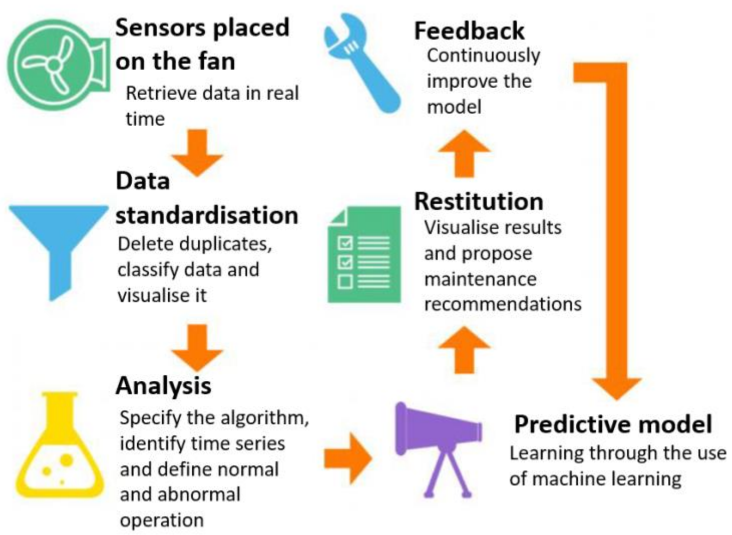

Figure 73: Predictive maintenance - Stages of the model[452]

[452] 3T Industry 4.0, «3T Industry 4.0 & iET4.0 Training», Trainings, 3T Industry 4.0, c s. d, https://3tindustry40training.eu/.

Other benefits of MES[453]

A complete MES, well integrated, collects and analyses all the sensitive phases of the process to advise and assist all the actors of all the departments. An alert generated by one department will very often find its solution through the intervention of another department.

It can improve overall communication within the company, by understanding the role of each person, it can encourage exchanges between departments that previously hardly communicated.

MES brings together all the links in the manufacturing chain around a common objective: the optimisation of quality production.

It is at the heart of what is known as Smart Manufacturing. It connects all the tools, equipment and trades for totally digitised processes, where the data ensures that the activity is maintained and adapted to new constraints.

Each company has its own needs and requirements, and the MES, in addition to controlling predictive maintenance, will aim to meet these specific needs. For example, in sectors (such as medical, food processing, biotechnology, etc.) subject to strict regulations, it will allow the control and recording of the elements necessary for quality assurance.

It will be used to manage all or part of the following elements:

- Optimised production monitoring
- Improved traceability
- Faultless quality control and regulatory compliance
- Management of preventive and corrective maintenance
- Optimisation of output
- Improved customer satisfaction
- Reduced manufacturing cycle and time to market
- Increased visibility into the supply chain
- Contribution to a paperless factory
- Etc.

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[453]GL EVENTS, «Le MES : outil de pilotage et d'optimisation de l'industrie du futur», Industrie online, 23 novembre 2021, https://www.industrie-online.com/p/actualite-2/actualites/le-mes-outil-de-pilotage-et-d-optimisation-de-l-industrie-du-futur.

Predictive maintenance technologies (the cloud)[454]

This last section outlines the various storage and communication possibilities between equipment, MES and control screens.

	Public cloud	Private cloud	Hybrid cloud
Environment	Publicly shared computer resources	Private computer resources	Combining public and private resources
Self-evolution	High	Can be limited	High
Security	Good, but depends on provider security	Most secure: all data is stored in a private data centre	Very secure: sensitive data is stored in a private data centre
Reliability	Medium: depends on Internet connectivity and availability of service providers	High: all equipment is on site or hosted by a dedicated private cloud provider	Medium to high: partly dependent on the service provider
Cost	Low: pay-per-use model and does not require onsite storage or infrastructure	Medium to high: may require onsite resources such as a data centre, electricity and IT staff	Moderate: combination of pay-per-use model and on-site resources
Who is it for?	Companies wanting to take advantage of the latest SaaS applications and the elasticity of IaaS while keeping costs low	Government agencies, healthcare providers, banks and any company handling large amounts of sensitive data	Companies that want to keep their critical applications and data confidential while still using public cloud services

Table 6: Predictive maintenance: The cloud

Whichever mode is chosen, the centralised management system, to which the sensors and control screens are connected, is interfaced with the company's resource planning and production management tools (ERP, CAPM, etc.) to rely on a single database.

This complete system involves a whole chain of technologies, each of which plays a role that guarantees the cohesion of the whole and its ability to adapt automatically.

- **IoT network:** it transmits data between the sensors and the central management system, as well as feedback from the latter to the users.

[454] SAP, «Qu'est-ce que la maintenance prédictive ? | SAP Insights», SAP, s. d., https://www.sap.com/suisse/insights/what-is-predictive-maintenance.html.

- **IoT gateways:** on equipment prior to digital integration, IoT gateway terminals (cameras, microphones and thermometers, etc.) allow the collection and transfer of data.
- **Cloud connectivity:** is the internal or external network through which all elements are connected, and the centralised management system based on a single database.
- **Modern database and ERP system:** The need to reduce response times as the volume of data increases has led to a rethinking of how information is stored. The modern ERP system relies on a fast, responsive, in-memory database with almost unlimited scalability.
- **AI and Machine Learning:** Machine Learning (a subset of AI), through algorithms, aims to analyse and understand the data to return real-time observations and, if necessary, recommendations when the data are close to dysfunctional patterns.
- **Advanced analytics:** Based on the data collected and the algorithms defined according to the initial schemes, it provides the desired analytical results. The particularity of advanced analytics lies in the desire to create programs that can adapt to optimise their performance over time.
- **Digital twins:** they allow the simulation of real or supposed test cases, without risk or damage to the machine. These experiments reproducing proven or totally unknown cases contribute to the objective of self-learning.

Benefits of predictive maintenance

The various business sectors have remarkably increased their efficiency through the implementation of the predictive maintenance system. Indeed, the integration of Industry 4.0 technologies has revolutionised the method, control and analysis of parameters in real-time have not only improved the maintenance of assets, but have also had favourable effects such as:

- **Reduced maintenance costs** and **improved asset performance:** planning instead of reacting optimises maintenance actions, but also reduces stocks (of spare parts) and then maintains the life of assets, while reducing downtime.
- **Improved staff autonomy:** feedback from the maintenance system has transformed the work of operational staff who, instead of reacting to breakdowns and unforeseen events, can focus on developing and planning action strategies.
- **Better visibility:** the intervention of service providers and other equipment suppliers is facilitated by a better knowledge of the state of the assets.

3.18.5 Conclusions

Four main findings seem to emerge from this study

1. The infrastructure (hardware, technical, software, etc.) and, to a lesser extent, the human resources provided by the platforms facilitate access to predictive maintenance for SMEs, which should make it even more accessible.
2. The creation phase of predictive models, which is about to be fully automated (thanks to AI and more particularly machine learning) could further encourage SMEs to engage in predictive maintenance.
3. Although the process of predictive maintenance is well known and established, the evolution of technology means that in France, the recruitment of qualified people with sufficient experience remains problematic.
4. This is why the effort to set up and adapt training courses must be maintained.

Three remarks to conclude this study

If the predictive maintenance process is now well known and well established, the evolution of the technological means used, and their interweaving require an adaptation of the people in charge of their implementation and of the training made available to them.

"In the environment of Industry 4.0, maintenance should do much more than merely preventing downtimes of individual assets. Predicting failures via advanced analytics can increase equipment uptime by up to 20%."

Figure 74: Predictive maintenance - Key figure of the Deloitte report[455]

But the implementation of MES can generate too much abrupt change which can lead to rejection by the operators but also by the management team. In this case, during the implementation, it is better to limit the model to critical issues and those where the return on investment will be visible and gradually integrate the remaining issues.

And finally, as for all technologies related to Industry 4.0, the major challenge is to guarantee training and certifications that integrate the evolution of techniques to facilitate the adaptation of people to new techniques and thus help companies to offer the right job to the right person, for the good and interest of all.

[455] « Deloitte_Predictive-Maintenance_PositionPaper.pdf », 3.

3.19 DIGITAL FACTORY: DIGITAL TWINS IN VOCATIONAL TRAINING EDUCATION

3.19.1 Introduction

3.19.1.1 Background and Context

Digital twins, virtual replicas of physical assets, systems, or processes, have emerged as a powerful technology in various industries, including manufacturing, aerospace, and healthcare. These digital representations enable real-time monitoring, analysis, and optimization of their physical counterparts, leading to improved efficiency, reduced costs, and better decision-making. The rapid advancement of the Internet of Things (IoT), artificial intelligence (AI), and data analytics has further accelerated the development and adoption of digital twin technology.

3.19.1.2 Purpose of the Report

This report aims to explore the potential of digital twins in the context of Vocational Training Education (VET). It will provide a brief overview of digital twins and their key components, discuss their applications and use cases in vocational training, and analyse the benefits, challenges, and limitations associated with their implementation. Additionally, the report will touch upon future perspectives, highlighting emerging trends and technologies that may shape the role of digital twins in vocational training education.

3.19.2 Digital Twins: An Overview

3.19.2.1 Definition and Key Components

Digital twins are virtual representations of real-world objects or processes, which enable real-time monitoring, analysis, and optimization. They consist of three primary components: a data model, a set of algorithms, and a communication network. The data model represents the physical asset or process, while the algorithms enable the analysis of the data collected from the physical counterpart. The communication network facilitates the exchange of information between the digital twin and the real-world object or process.

3.19.2.2 Connection to IoT, AI, and Data Analytics

The development and adoption of digital twins have been accelerated by advancements in IoT, AI, and data analytics. IoT devices and sensors collect data from the physical world, enabling digital twins to be updated with real-time information. AI and machine learning algorithms are used to analyse the data, identify patterns, and make predictions or recommendations. Data analytics tools help visualize and interpret the data, allowing for better decision-making and improved performance of the physical assets or processes.

3.19.3 Digital twins in Vocational Training Education

3.19.3.1 Applications and Use Cases

Virtual labs and hands-on learning

Digital twins can be used to create virtual labs, providing students with hands-on learning experiences in a safe and controlled environment. These virtual labs allow students to interact with complex machinery, equipment, or processes without the risks and costs associated with physical labs.

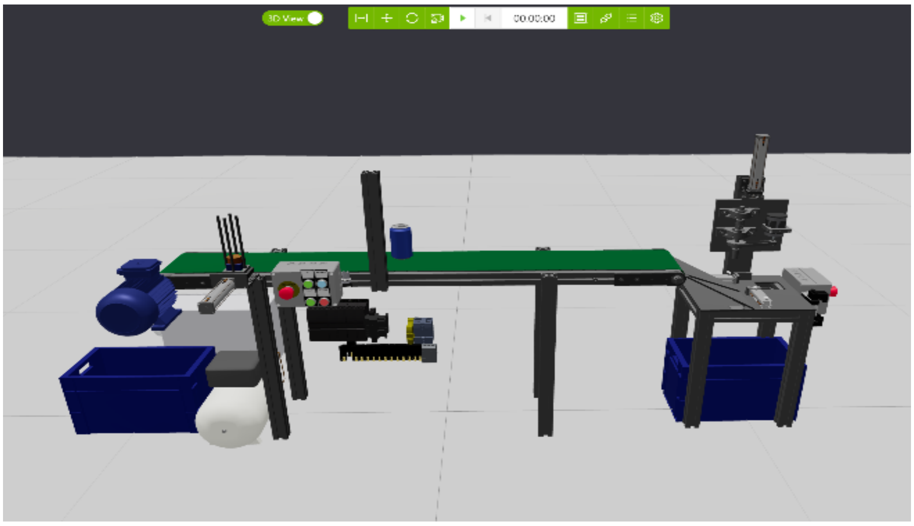

Figure 75: Some of the virtual labs created by instructors in Simumatik as part of the pilot project led by TKNiKA.

TKNIKA, a leading centre for innovation in vocational education and training in the Basque Country, is collaborating with Simumatik, a digital twin platform, to develop virtual labs as part of their pilot project. These virtual labs aim to improve the quality of vocational training by incorporating digital twins and Industry 4.0 technologies into the educational process. This collaboration allows students and instructors to work with realistic simulations of real-world machinery and processes, enhancing the learning experience and better-preparing students for the future workplace.

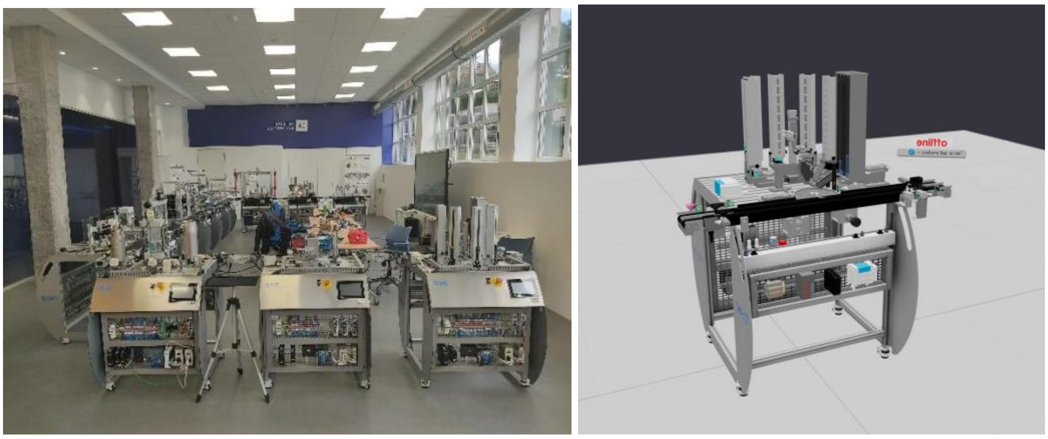

Figure 76: TKNiKA, Industry 4.0 Factory Lab with the Digital Twin of one of the workstations

Remote collaboration and accessibility

Digital twins facilitate remote collaboration and accessibility, allowing students and instructors to work together from different locations. This expands the reach of vocational training programs and provides opportunities for students who may not have access to physical facilities or resources.

During the COVID-19 pandemic, digital twins played a crucial role in maintaining the continuity of education and vocational training. They facilitated remote collaboration and accessibility, enabling students and instructors to work together from different locations. Key benefits included promoting remote learning, providing realistic simulations for practice, reducing costs and resource requirements, and enhancing collaboration and communication. Digital twins allowed students and instructors to adapt to remote learning while preserving the quality of training and access to practical experiences.

3.19.3.2 Benefits and Advantages

Enhanced student engagement and motivation

The use of digital twins in vocational training can lead to increased student engagement and motivation by providing immersive and interactive learning experiences that closely resemble real-world scenarios.

Improved learning outcomes and skill development

Digital twins can help students develop practical skills and apply theoretical knowledge in a realistic context, leading to improved learning outcomes and better preparation for the workforce.

3.19.3.3 Challenges and Limitations

Technological barriers and infrastructure requirements

Implementing digital twins in vocational training may require significant investments in technology and infrastructure, which could be a barrier for some institutions or organizations.

Integration with existing curricula and teaching methods

Integrating digital twins into existing curricula and teaching methods may require a shift in pedagogical approaches and educator training, presenting another challenge for the successful implementation of digital twins in vocational training education.

3.19.4 Future Perspectives

3.19.4.1 Emerging Trends and Technologies in Digital Twins and Vocational Training:

The landscape of digital twins and vocational training is constantly evolving. Emerging trends and technologies, such as augmented and virtual reality, edge computing, and 5G connectivity, could further enhance the capabilities of digital twins in education. These advancements may lead to more immersive and interactive learning experiences, more accurate simulations, and improved real-time data processing and communication.

3.19.4.2 Potential New Applications and Opportunities

As digital twin technology continues to develop, new applications and opportunities may arise within vocational training education. For instance, digital twins could be integrated with adaptive learning systems to create personalized learning experiences tailored to individual students' needs and progress. Additionally, digital twins could be used to simulate real-world scenarios in industries that are difficult to access or hazardous.

3.19.5 Conclusion

3.19.5.1 Recap of the Importance of Digital Twins in Vocational Training Education

Digital twins hold great potential for transforming vocational training education by providing immersive, hands-on learning experiences, personalized learning paths, and effective training for complex tasks. Despite existing challenges, such as technological barriers and the need for integration with current curricula, the benefits of digital twins in this field are substantial and warrant further exploration and investment.

3.19.5.2 Recommendations and Next Steps

To fully leverage the capabilities of digital twins in vocational training education, the following recommendations and next steps are suggested:

1. Foster collaboration: Encourage cooperation among educational institutions, industry partners, and policymakers to share knowledge, resources, and best practices related to digital twins in education.
2. Invest in research and development: Support ongoing research and development to advance digital twin technology and explore innovative applications in vocational training education.
3. Address infrastructure needs: Ensure that educational institutions have the necessary technological infrastructure and support to effectively implement and utilize digital twins in their programs.
4. Develop training programs: Create training programs for educators and trainers to equip them with the necessary skills and knowledge to effectively use digital twins in their teaching.
5. Assess and iterate: Continuously evaluate the impact of digital twins on student outcomes, skill development, and overall educational experiences, and refine the implementation strategies accordingly.

3.20 DIGITAL FACTORY: DIGITAL WORKPLACES, ERGONOMICS IN VOCATIONAL TRAINING

3.20.1 Introduction

3.20.1.1 Background and Context

The emergence of Industry 4.0 has brought significant changes in the manufacturing sector, including the increasing adoption of digital technologies and automation systems. As a result, the nature of work has also evolved, creating new challenges and opportunities for workers and companies alike. In this context, digital workplaces and ergonomics play a crucial role in ensuring that workers can adapt to the changing work environment and perform their tasks safely and efficiently.

Digital workplaces refer to the use of digital technologies to enable employees to perform their work remotely or on-site, using digital tools and platforms. These technologies include mobile devices, cloud-based applications, collaborative software, and virtual reality tools, among others. Digital workplaces can help companies improve productivity, reduce costs, and increase employee satisfaction and engagement (Kossek et al., 2017).

Ergonomics, on the other hand, is the science of designing work environments, tools, and systems to fit the physical and cognitive abilities of workers. Ergonomic design aims to optimize human performance, prevent injuries and health problems, and improve well-being and satisfaction at work (Karwowski, 2006). In the context of smart manufacturing and Industry 4.0, ergonomic design is critical to ensure that workers can adapt to new technologies and work processes without experiencing physical or mental strain.

Vocational education plays a crucial role in preparing workers for the changing work environment in smart manufacturing and Industry 4.0. Vocational education and training (VET) programs can provide workers with the necessary skills and competencies to operate digital technologies and work in ergonomic environments. VET programs can also help companies identify and address the challenges and opportunities of digital workplaces and ergonomic design (Cedefop, 2020).

3.20.1.2 Purpose of the Report

In summary, digital workplaces and ergonomics are critical components of smart manufacturing and Industry 4.0, and vocational education is essential to prepare workers for the changing work environment. The following chapters of this report will provide an overview of digital workplaces and ergonomic design in smart manufacturing, and discuss the benefits, applications, challenges, and limitations of these concepts. We will also examine the best practices for integrating digital workplaces and ergonomics in smart manufacturing, and the implications for future research and practice.

3.20.2 Ergonomics in Smart Manufacturing

Smart manufacturing is transforming the industrial landscape by integrating advanced technologies such as the Internet of Things (IoT), big data analytics, and artificial intelligence (AI). While these technologies bring significant benefits to manufacturers, they also present new challenges related to ergonomics in the workplace.

3.20.2.1 Benefits and Advantages

The benefits of incorporating ergonomics into smart manufacturing are significant. By ensuring the health and safety of workers, companies can reduce the risk of workplace injuries and accidents, improve worker satisfaction and well-being, and increase productivity and efficiency.

The benefits of incorporating ergonomics into smart manufacturing are significant. By ensuring the health and safety of workers, companies can reduce the risk of workplace injuries and accidents, improve worker satisfaction and well-being, and increase productivity and efficiency.

3.20.2.2 Challenges and Limitations

There are also challenges and limitations to incorporating ergonomics into smart manufacturing. For example, there may be a lack of knowledge and awareness of ergonomic principles among workers and management. Additionally, the cost of implementing ergonomic solutions and training programs can be a barrier for some organizations.

Another challenge is the need for interdisciplinary collaboration between engineers, designers, and ergonomics experts to ensure that ergonomic considerations are incorporated into the design and development of products and systems.

3.20.2.3 Applications and Use Cases

Ergonomics is critical to the success of smart manufacturing. It ensures the health and safety of workers and promotes their productivity and well-being. Some of the applications and use cases of ergonomics in smart manufacturing include:

1. Designing workstations and equipment that are ergonomic and user-friendly.
2. Incorporating sensors and wearables to monitor workers' health and well-being.
3. Providing workers with real-time feedback on their posture and movements
4. Using data analytics to identify ergonomic risks and optimize workflows.
5. Incorporating virtual and augmented reality technologies to simulate work environments and train workers in safe and ergonomic practices.

3.20.2.4 Future Perspective

As smart manufacturing continues to evolve, ergonomics will play an increasingly important role in ensuring the health and safety of workers and promoting their well-being and productivity. New technologies such as wearables and AI will provide new opportunities for monitoring and optimizing ergonomic conditions in the workplace.

Furthermore, the integration of ergonomic principles into the design and development of products and systems will become an essential factor in the success of smart manufacturing, driving innovation and improving customer satisfaction.

3.20.3 Digital Workspaces in Smart Manufacturing

3.20.3.1 Definition and Types

Digital workplaces are a fundamental aspect of smart manufacturing. They are defined as a combination of physical and virtual environments where workers use digital tools and platforms to carry out their work. The use of digital workplaces allows companies to optimize their operations, enhance their productivity, and provide employees with more flexibility in their work activities.

There are several types of digital workplaces, including:

1. Mobile workplaces: These are workplaces where workers can use mobile devices such as smartphones or tablets to perform their tasks. Mobile workplaces enable employees to work from anywhere and at any time, increasing their productivity and flexibility.

2. Cloud-based workplaces: These are workplaces where workers use cloud-based applications to access and share data and documents. Cloud-based workplaces allow employees to collaborate in real time and access their work from anywhere with an internet connection.
3. Collaborative workplaces: These are workplaces where workers use collaborative software to communicate and collaborate on projects. Collaborative workplaces promote teamwork, knowledge-sharing, and innovation.
4. Virtual workplaces: These are workplaces where workers use virtual reality tools to simulate work environments and carry out their tasks. Virtual workplaces provide workers with a safe and immersive environment to learn and practice new skills.

3.20.3.2 Benefits and Advantages

The adoption of digital workplaces in smart manufacturing can bring several benefits and advantages, such as:

1. Increased productivity: Digital workplaces can help workers perform their tasks more efficiently, reducing the time and effort required to complete them.
2. Enhanced flexibility: Digital workplaces can enable workers to work from anywhere and at any time, providing them with more flexibility in their work activities.
3. Improved communication and collaboration: Digital workplaces can facilitate communication and collaboration among workers, improving teamwork, knowledge-sharing, and innovation.
4. Enhanced employee satisfaction and engagement: Digital workplaces can provide workers with a better work-life balance and increase their job satisfaction and engagement.

3.20.3.3 Challenges and Limitations

Despite the benefits and advantages of digital workplaces, their adoption in smart manufacturing can also pose several challenges and limitations, such as:

1. Cybersecurity risks: Digital workplaces can expose companies to cybersecurity threats, such as data breaches or hacking attacks.
2. Skill gaps: The adoption of digital workplaces requires workers to have specific digital skills and competencies, which may not be available in the current workforce.
3. Resistance to change: The adoption of digital workplaces can face resistance from workers who may be reluctant to change their work habits or learn new technologies.
4. Costs: The adoption of digital workplaces may require significant investments in digital technologies and infrastructure, which may be a barrier for some companies.

3.20.3.4 Applications and Use Cases

Digital workplaces can be applied in several areas of smart manufacturing, such as:

1. Digital supply chain: Digital workplaces can help companies manage their supply chain more efficiently, by enabling real-time tracking and monitoring of products and materials.
2. Digital production: Digital workplaces can help companies optimize their production processes, by providing real-time data and insights on the performance of machines and equipment.
3. Digital maintenance: Digital workplaces can help companies improve their maintenance processes, by enabling real-time monitoring and diagnosis of equipment and systems.
4. Digital training: Digital workplaces can provide workers with immersive and interactive training experiences, using virtual reality tools and simulations.

3.20.3.5 Future Perspective

The adoption of digital workplaces in smart manufacturing is expected to continue growing in the coming years, driven by the increasing demand for productivity, flexibility, and innovation. However, the successful implementation of digital workplaces will require companies to address the challenges and limitations posed by these technologies and invest in the necessary skills and competencies of their workforce.

3.20.4 Conclusion

3.20.4.1 Recap of the Importance of Digital Workspaces and Ergonomics in Vocational Training Education

In the context of smart manufacturing and Industry 4.0, digital workplaces and ergonomics play a critical role in promoting worker health and safety, productivity, and innovation. The integration of digital technologies into work environments has created new opportunities for flexibility, mobility, and collaboration, but also presents new challenges related to ergonomics that must be addressed.

This report has explored the importance of digital workplaces and ergonomics in smart manufacturing, including their applications and use cases, benefits and advantages, challenges and limitations, and future perspective. It has been shown that by incorporating ergonomic principles into digital work environments, companies can promote worker health and safety, reduce the risk of injuries and accidents, and improve productivity and efficiency. Furthermore, digital technologies can enhance the usability and functionality of workstations and equipment, improving the overall user experience and driving innovation and competitiveness.

In the context of vocational education, the integration of digital workplaces and ergonomics in smart manufacturing can also play a critical role in preparing the workforce for the jobs of the future. By incorporating ergonomic principles and digital technologies into vocational education and training programs, students can learn the skills and knowledge necessary to thrive in a rapidly changing manufacturing landscape.

However, the integration of digital workplaces and ergonomics in smart manufacturing also presents challenges, such as the need for significant investments in infrastructure, training, and support. Additionally, the use of digital technologies may lead to increased sedentary behaviour and decreased physical activity, which can have negative impacts on worker health.

To overcome these challenges and fully realize the potential benefits of digital workplaces and ergonomics in smart manufacturing, organizations and vocational education institutions must prioritize the implementation of ergonomic practices and technologies, invest in infrastructure and training, and prioritize worker health and safety.

In conclusion, the integration of digital workplaces and ergonomics in smart manufacturing is a critical factor in the success of Industry 4.0, promoting worker health and safety, productivity, and innovation. By prioritizing ergonomic considerations and investing in digital technologies and infrastructure, organizations and vocational education institutions can improve worker satisfaction and well-being, drive innovation, and prepare the workforce for the jobs of the future.

3.20.4.2 Recommendations and Next Steps

To fully leverage the capabilities of digital workplaces and ergonomics in vocational training education, the following recommendations and next steps are suggested:

1. Integrate ergonomic principles and digital technologies into vocational education and training programs: By incorporating ergonomic principles and digital technologies into vocational education and training programs, students can learn the skills and knowledge necessary to thrive in a rapidly changing manufacturing landscape. This includes training in ergonomics, human factors, and digital technologies, as well as hands-on experience with digital workstations and equipment.
2. Invest in infrastructure and equipment: To fully leverage the capabilities of digital workplaces and ergonomics in vocational education, institutions must invest in the necessary infrastructure and equipment. This includes providing access to state-of-the-art digital

workstations, equipment, and software, as well as ensuring that the physical environment is designed with ergonomics in mind.

3. Prioritize worker health and safety: While digital workplaces and ergonomics can provide many benefits, they also present new challenges related to worker health and safety. Institutions must prioritize worker health and safety by incorporating ergonomic principles into the design of work environments, providing training in ergonomic practices, and ensuring that workers have access to the necessary tools and resources to maintain their health and well-being.
4. Foster collaboration and innovation: Digital workplaces and ergonomics can enhance collaboration and innovation by providing workers with the tools and technologies necessary to work together effectively and efficiently. Institutions can foster collaboration and innovation by creating a culture of openness, collaboration, and continuous learning.
5. Continuously evaluate and improve vocational education programs: To ensure that vocational education programs remain relevant and effective, institutions must continuously evaluate and improve their programs. This includes soliciting feedback from students, employers, and industry experts, and incorporating that feedback into the design of programs.

By following these recommendations and taking these next steps, institutions can fully leverage the capabilities of digital workplaces and ergonomics in vocational education, preparing students for the jobs of the future and driving innovation and competitiveness in the manufacturing industry.

3.21 IMPACT OF DIGITAL TRANSITION ON ADVANCED MANUFACTURING: ASSISTED JOBS (SAFETY-ERGONOMICS RELATED)

3.21.1 Introduction

Since the appearance of Unimate, the first industrial robot, in 1961 in a General Motors factory in the United States, scientists, designers and other researchers have never ceased to find solutions to make people's work easier, safer and more effective. At the time, the idea was to replace humans for tedious, dangerous and repetitive tasks.

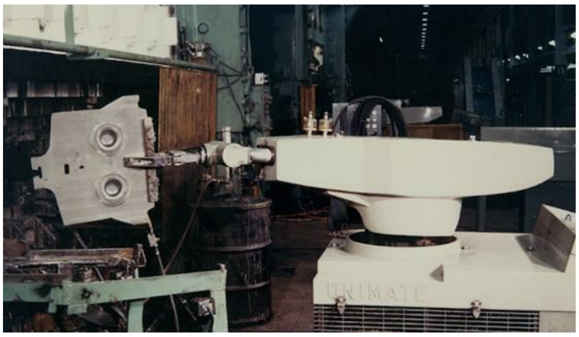

Figure 77: Assisted Jobs - Robots and cobots

After an active phase of partial or full automation of the production line in 2019, the number of industrial robots per 10,000 employees[456] was 346 in Germany, 277 in Sweden, 212 in Italy, 191 in Spain and 177 in France, but those numbers seem small compared to Japan's rate of 855 robots per 10,000 employees. While the effort was maintained to roll out automation, sometimes the solution was not appropriate.

This is why, among other reasons, in recent years thought has also been given to the facilitation of collaboration between man and machine in order to assist and ensure the safety and health of people at their workplaces.

The concepts of cobots (collaborative robots) and collective protective equipment / personal protective equipment (CPE/PPE) were created. The former is meant to replace, but also assist

[456]PULSA Bols Vibrants, «Automatiser une ligne de production - Se poser les bonnes questions», *PULSA Bols Vibrants* (blog), 2019, https://www.pulsafrance.com/automatiser-une-ligne-de-production/.

people. The latter intends to bring fixed collective protection aimed at removing or isolating from a risk (electricity, heat, etc.) or provide individual protection which complements the CPE to protect against risks such as:

- Mechanical: shocks, cuts, particle projections.
- Electrical: contact with live conductors.
- Biological: inhalation of biological agents.
- Chemical: inhalation of chemical agents, hand contact with chemicals.
- Auditory: constant and loud noise
- etc.

Fixed or mobile robots perform tasks to assist operators at their workstations. On demand, planned or not, they bring tools or materials, they take care of moving parts and other packages. But the major revolution is that they adapt to their environment and stop their activity as soon as someone enters their field of action. Collaboration is becoming increasingly important.

Regarding safety, the evolution of PPE with exoskeletons[457], which has been booming in recent years, represents a solution for the future to reduce the risks of musculoskeletal disorders (MSD) and worker fatigue[458].

3.21.2 Contextualisation

It is in industry, and more specifically on workstations with very heavy handling, that equipment is currently used the most.

Assisted handling[459]

«The repetitive nature of physical work can become disabling for the worker, even if the load is light. And the manual handling of heavy or bulky loads involves risks that can cost the employee and the employer dearly.

In a context where well-being at work crucial, a main factor of keeping employees, the question of health and safety should not be taken lightly.

[457] INRS, «Exosquelettes. Foire aux questions - Risques - INRS», INRS, s. d., https://www.inrs.fr/risques/exosquelettes/faq.html.

[458] Centre canadien d'hygiène et de sécurité au travail Gouvernement du Canada, «CCHST: Exosquelettes», 5 April 2023, https://www.cchst.ca/oshanswers/safety_haz/exoskeletons.html.

[459] Pedlex, «Vers une manutention plus ergonomique», 1 December 2019, https://www.pedlex.com/index.php?route=extension/d_blog_module/post&post_id=50.

When we think of a production plant, what comes to mind in terms of it might be automation, robotization, and assisted handling. Lifting and handling systems such as overhead cranes, chain hoists and jib cranes are part of the industrial environment as we know it. But there are other high-performance systems: vacuum tube lifting systems that significantly reduce the workload. This is called assisted handling.

The actual capacities of the system vary depending on the nature of the load (sealed or porous product), the condition of the surface (cleanliness, roughness), the effective surface of the suction cup, the shape (dimensions) of the product and the deformation of the suction cup (influenced by the level of vacuum, the force exerted, the shape of the suction cup, the material of the suction cup).

Designed for use in high production, this vacuum lifting aid is ergonomic, as it respects the natural fluidity of the operator's movements. In addition, it considerably reduces the risk of injuries related to manual handling.»

Novel exoskeleton chair supports factory workers[460]

«Workers no longer must stand all day. A new chair straps to the body and is available for support as needed. Workers in manufacturing and other industries routinely work long hours in a standing position. Standard office chairs may not be permitted because they can dangerously impede workers and machinery.

Although occasionally working standing up benefits health, standing for entire shifts has the opposite effect.

Specifically, it can cause injury, various kinds of strain including lower back pain, and hypertension. Furthermore, demographic, and social changes mean that an increasing proportion of factory workers are of an older age group, especially unsuited to standing all day.

To combat these problems, the EU-funded Chairless Chair project developed an exoskeleton chair for the creation of ergonomic, age-neutral, and low-fatigue workplaces in industry and for the reduction of physical strains in the ageing workforce. Conventional industrial exoskeletons are worn on the upper body and augment workers' strength. The Chairless Chair is the first designed to be worn on the lower body to support workers' weight.

The current version, Chairless Chair 2.0 is the third product generation. It has been refined in collaboration with automobile manufacturers. The refinement has reduced the weight by more

[460] Cordis, «Novel Exoskeleton Chair Supports Factory Workers | Chairless Chair Project | Results in Brief | H2020 | CORDIS | European Commission», 31 October 2020, https://cordis.europa.eu/article/id/429162-novel-exoskeleton-chair-supports-factory-workers.

than 25 %, extended the height adjustment from 1.5 to 2 metres, and slimmed the design. The product has been optimised for fit. The newer version is safer and offers more freedom of movement. The straps, vest and seat pads have been redesigned and feature new textile materials. Such changes make the product more comfortable and durable.

The team has established the Chairless Chair as a well-known brand, especially among German car manufacturers. Next, researchers will be further refining the product in subsequent versions, while also seeking new markets.

The product benefits older workers but is not intended for them exclusively. It will benefit any worker having to stand all day, reducing the health consequences and lost productivity resulting from this mode of work.»

A robot to protect the lives of motorway company employees developed in the Cantal[461]

«The company Europe Service[462], based in Aurillac (Cantal - France), is developing a robotic cone picker to improve the safety conditions of motorway company agents.

A robotic arm will place and remove cones and road signs from a construction site, without the need for an agent.

In collaboration with the motorway company APRR, Europe Service is currently developing "an E-cone carrier", says Aurélien Lafon. This is a truck that the CEO of this SME wants to run on electricity, with a robotic arm, which places and removes cones and road signs on a site without the need for an agent.»

Robotic technology for ship inspection[463]

«Faster, cheaper and safer robotic and autonomous systems such as drones and crawlers are an attractive solution for ship inspections. The EU-funded ROBINS project set out to certify these systems and help establish them as a standard tool for ship surveyors.»

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[461] La montagne, «Un robot pour protéger la vie des agents des sociétés d'autoroutes développé dans le Cantal - Aurillac (15000)», 4 June 2023, https://www.lamontagne.fr/aurillac-15000/actualites/un-robot-pour-proteger-la-vie-des-agents-des-societes-d-autoroute-developpe-dans-le-cantal_14289670/.

[462] *E-Cône -Ramasseuse de cônes robotisée*, 2022, https://www.youtube.com/watch?v=tK6SumDEXCg.

[463] Cordis, «Robot-Assisted Ship Inspections Sail towards Certification | ROBINS Project | Results in Brief | H2020 | CORDIS | European Commission», Cordis, 30 June 2021, https://cordis.europa.eu/article/id/435257-robot-assisted-ship-inspections-sail-towards-certification.

Laser-assisted machining of challenging metals[464]

«To offer sheet metal forming in titanium- and nickel-based materials for heavy-duty aero engine components and other demanding applications, EU-funded scientists have set new boundaries in metal spinning.»

Robotic extraction of asbestos fibres from buildings[465]

«Europe has paid a high price for asbestos, with over 100 000 asbestos related deaths. First in line in the fight to free buildings from asbestos contamination, workers in the construction sector could soon find a helping hand in the form of an AI-piloted robotic system.»

Safer human-robot collaboration for workplaces of the future[466]

«The next generation of robots could be entering the workplace alongside humans, but this first needs some collaborative principles to be established. SYMBIO-TIC has developed a system for such a safe, dynamic, intuitive and cost-effective working environment.

Factories of the future will depend on the development of safe, cost-effective, hybrid assembly/packaging arrangements based on human-robot collaboration. However, the European manufacturing industry faces implementation challenges, which could be summarised as a lack of adaptability, flexibility and vertical integration.

The team have already recorded active collision avoidance for worker protection and are currently developing a demonstrator, to be ready by mid-March 2019, which integrates all the modules and sub-systems together to showcase the full solution. This demonstrator will be located at Volvo Cars in Sweden, where it will assemble a mass balancing system (MBS) within a car, but outside of the regular production environment.

After this, the team will seek out new partners to advance the technology to a market-ready state.

The system will also maintain product quality, with humans remaining ultimately responsible for inspections and the necessary adjustments.»

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[464] Cordis, «Laser-Assisted Machining of Challenging Metals | EASYFORM Project | Results in Brief | FP7 | CORDIS | European Commission», Cordis, 28 February 2015, https://cordis.europa.eu/article/id/159598-laserassisted-machining-of-challenging-metals.

[465] Cordis, «Robotic Extraction of Asbestos Fibres from Buildings | Bots2ReC Project | Results in Brief | H2020 | CORDIS | European Commission», Cordis, 30 November 2019, https://cordis.europa.eu/article/id/418003-robotic-extraction-of-asbestos-fibres-from-buildings.

[466] Cordis, «Safer Human-Robot Collaboration for Workplaces of the Future | SYMBIO-TIC Project | Results in Brief | H2020 | CORDIS | European Commission», Cordis, 31 mars 2019, https://cordis.europa.eu/article/id/251213-safer-humanrobot-collaboration-for-workplaces-of-the-future.

COMAN+ takes human-robot interaction to the next level[467]

«Imagine a humanoid robot able to help industry workers carry heavy objects around or to assist doctors in their physiotherapy sessions. Such versatile robots will soon be a reality thanks to work under the EU-funded CogIMon[468] project.»

Technology-wise, the scaled-up humanoid robot COMAN+ strengthens the world-leading position of European research in the development of variable impedance actuation and compliant humanoid robots. We have also developed engineering tools for the simulation and control of such robots and made them open-source. Finally, we have created the technology to run robot controllers in VR and open new avenues for mixed-reality applications.

Thanks to new soft capture methods, the CogIMon project has made it possible for the first time for:

- 2 humanoid robots to carry objects.
- The collaboration of a human with four robotic arms to lift and move heavy loads.
- Developing a physiotherapy application, enabling patients to practise catching balls thrown by a robot.

Industrial applications:

For the time being, the project remains in the field of fundamental research. Despite growing interest, there has been little feedback on concrete use in the industry. Thanks to the collaboration with an SME, the project is exploring the combined use of VR-robotic mixed reality with a view to industrial applications.

In the medical field, the COMAN+ units currently on the market are being evaluated in a physiotherapy applicatio

[467]Cordis, «COMAN+ Takes Human-Robot Interaction to the next Level | Interview | CORDIS | European Commission», Cordis, 15 October 2022, https://cordis.europa.eu/article/id/124821-coman-takes-humanrobot-interaction-to-the-next-level.

[468]Cognitive Interaction in Motion

3.21.3 Objectives / Research Question / Problem Statement

Objectives: Research is now moving towards real collaboration between humans and robots in order to carry out a job together and where the robot will facilitate the human's task. As far as PPE is concerned, exoskeletons are going to be democratised and probably improved. For more conventional PPE, the latest developments tend to use the IoT to enhance personal safety.

Research question: It seems that the new technologies linked to digitalisation and big data will allow significant advances regarding both the field of cobots and safety at work. However, it will be necessary to be careful not to be too intrusive (particularly for PPE), and to ensure that standards evolve at the European level, to guarantee the proper functioning and legality of this new equipment.

Problem statement: Will the future be 'intelligent'?[469]

“Personal protective equipment (PPE) is reinventing itself. Innovative equipment, capable of interacting with the wearer and the environment, and becoming true intelligent personal protection systems (IPPS), is multiplying on the market. But what are we talking about? And how can we distinguish between a genuine prevention solution and something that is not?”

Intelligent personal protection systems (IPPS)

The legal classification of a personal protection system as PPE requires a CE marking, and an instruction manual, but above all, it is subject to a declaration of conformity to EU Regulation 2016/425.

When the equipment only alerts to risks and does not have the function of protecting against risks to the health or safety of the wearer, it cannot be called PPE, but simply IPS. Furthermore, collective protection measures must always be given priority, and the individual protection solution is only adopted when collective protection is not effective. Individual protection must be the ultimate solution.

T2S, the manufacturer of high-visibility personal protective equipment has integrated electronics into its high-visibility waistcoat. In addition to being better seen and seeing better, thanks to waterproof LEDs, the connected waistcoat helps avoid collisions between vehicles and pedestrians. As soon as the safety distance between the machine and the pedestrian is no longer

[469] «Visionneuse - Travail et Sécurité», Travail et Sécurité, October 2022, 26-27, https://www.travail-et-securite.fr/ts/pages-transverses/liseusePDF.html.

respected, the latter is alerted, while a box placed in the machine warns the driver. This non-intrusive system leaves the driver in total control of the vehicle.

IPPS are subject to the regulations on radio equipment (RED - 2014/53), the Electromagnetic Compatibility Directive (EMC - 2014/30), the Machinery Directive (2006/42), and the General Data Protection Regulation (GDPR - 2016/67). In view of the very broad prospects for future use, it would seem appropriate to consider standardisation, through the creation of a European structure, with the aim of validating the real effectiveness of the equipment and also reassuring users.

The range of uses envisaged or already under study is very broad:

- Waistcoat: equipped with LEDs to be more visible, and with sensors that warn of a risk of collision.
- Textile (trousers or jacket): producing heat.
- Safety footwear: enabling geolocation, signalling a loss of verticality or prolonged immobility, or warning of entry into a dangerous area.
- Caps: capable of detecting fatigue signals.
- Safety glasses: providing real-time information about the workspace.
- Gloves: which change colour in the presence of toxic products.

3.21.4 Findings

The use of IoT will take PPE to a new level. Increased interaction between the wearer and the environment will enhance risk and accident prevention.

Tomorrow, connected and multifunctional PPE[470]

The use of connected objects, which is already widespread, should take PPE and other work clothing into a new era. Either in the research phase, or for the most advanced in the test phase, projects are transforming clothing to fight against extreme temperatures, or report incidents and even warn the emergency services. They are expected to be available within a few years.

A number of developments are expected to be available in the next few years.

[470] Print and Prod, «Les EPI nouvelle génération - Comment évoluent-ils?», Les EPI nouvelle génération - Comment évoluent-ils ?, 2 mars 2020, https://www.printandprod.com/epi-nouvelle-generation-evolution.html.

For example, on building sites where men work around moving machinery, an anti-collision parka will vibrate and light up if the pedestrian is less than ten metres from a vehicle, whose driver will have been warned of the danger by an audible alarm.

Another line of research is the alerting of the team leader, who will be able to use his or her smartphone to geolocate a person whose "intelligent" parka has reported a problem. The parka, which can be seen from 250 metres away, can also warm the wearer up if necessary.

For the time being, this equipment works thanks to batteries, recharged every night, and functional for a day's work. But the project to use fibres capable of producing energy should perhaps eventually allow the garment to be recharged while it is being worn.

The new generation of collaborative robotic systems has already brought humans and machines closer together, but tomorrow this collaboration should be increased.

Multitasking robots work hand-in-hand with operators[471]

ColRobot offers a new generation of collaborative robotic systems to the automotive and aerospace industries. These two sectors have to adapt to a growing need for flexibility, while managing large order books. There is no longer a one-size-fits-all production line; each product must be customised with the options chosen by the customer. This requires organisation, which led first of all to a high degree of automation of production lines where operators were totally absent. The latest developments in this field are moving towards better collaboration between robots and humans, who share their workspace.

TRL7[472] and beyond

By 2018 the ColRobot project had reached TRL7, so Professor Gibaru thought it would take another two to three years of development before the consortium could deliver a usable product.

"The cost of the solution is still very high from a hardware and software point of view, and adaptations and modifications to the demonstrator are needed before any industrial deployment can be considered.

At the same time, Thales Alenia Space and Renault were already considering integrating ColRobot solutions into new industrial applications.

[471]Cordis, «Multitasking Robots Work Hand-in-Hand with Operators | ColRobot Project | Results in Brief | H2020 | CORDIS | European Commission», Cordis, 31 January 2019, https://cordis.europa.eu/article/id/251212-multitasking-robots-work-handinhand-with-operators.

[472]Technology Readiness Levels

To date, the industrial applications of the ColRobot project include:

- Electronic component assembly: the robotic systems developed in the project have been used to assemble electronic components efficiently and accurately, using force sensors to ensure the quality of the assembly.
- Industrial maintenance: collaborative robots were used to perform maintenance and repair tasks in hazardous or difficult-to-reach industrial environments, reducing the risk to human workers.
- Quality control: robotic systems have been used to inspect the quality of finished products, using vision sensors and image processing algorithms to detect defects and anomalies.

These industrial applications of the ColRobot project demonstrate the potential of collaborative robotic systems to improve the efficiency and safety of production processes in the manufacturing industry.

Horizon 2020: New robotics projects 2021[473]

In the Brochure linked below, the 24 new robotics projects launched in January 2021 are presented. These new Horizon 2020 projects work on robotics in application areas. They have been selected from various call topics:

- ICT-46-2020: Robotics in Application Areas and Coordination and Support
- ICT-47-2020: Research and Innovation boosting promising robotics application.
- DT-ICT-12-2020: AI for the smart hospital of the future
- Full brochure[474]

Extract from this brochure, the DARKO project[475] (Dynamic Agile production Robots that learn and optimise Knowledge and Operations)

- Call: H2020-ICT-2018-20
- Duration: 1 January 2021 – 31 December 2024
- Project: ID 101017274

[473]Cordis, «Nouveaux projets de robotique dans le cadre du programme Horizon 2020 2021 | Bâtir l'avenir numérique de l'Europe», Cordis, 14 April 2021, https://digital-strategy.ec.europa.eu/fr/library/horizon-2020-new-robotics-projects-2021.

[474]Cordis, «Horizon 2020: New Robotics Projects 2021», 2021, https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=75587.

[475]Ibid, 7.

Objectives

O1: Time/energy efficient manipulation through pick & place in motion and throwing objects with inherently elastic manipulators and flexible end-effectors.

O2: Efficiency and safety in human-robot coproduction through human motion prediction, learning and exploiting activity patterns, mutual communication of intent and riskware planning.

O3: Efficient deployment through failure-aware and failure-resilient mapping and localisation, semantic mapping and information transfer from heterogeneous map priors.

O4: Risk-aware operation for safety and efficiency by principled, local and global risk assessment through predictive models that account explicitly for risk probabilities.

Figure 78: Assisted Jobs - DARKO (Horizon 2020 – New project 2021)

Expected impact

I1: Improved technical capabilities E.g.: AI-enabled 3D perception and scene understanding and dynamic manipulation capabilities for agile production, healthcare, agri-food, etc.

I2: Demonstration of applications in logistics and agile production at TRL6 Integration and demonstration of DARKO in realistic settings: at a BSH (Bosch Siemens Home Appliances) warehouse and a permanent demonstrator at ARENA2036 (Stuttgart).

I3: Lowering of technical barriers within logistics and agile production. Particularly: greater dependability, higher efficiency, increased safety in dynamic environments, planning considering predictions of people and other dynamics and risks.

3.21.5 Conclusions

These are the directions in which the latest trends in the field of work assistance are being integrated and generalised.

1. **The use of IoT will take PPE to a new level. Increased interaction between the wearer and the environment will enhance risk and accident prevention.**
2. **The new generation of collaborative robotic systems has already brought humans and machines closer together, but tomorrow this collaboration should be increased.**

Whether in the field of PPE or cobots, there is still work to be done, as evidenced by the 24 new robotics projects selected in April 2021 under the Horizon 2020 programme.

3.22 CLASSIFICATION, MAPPING OF EU PROJECTS ON INDUSTRY 4.0, AND CLASSIFICATION OF THEIR OUTPUTS IN RELATION WITH LCAMP

3.22.1 The impact of I4.0 in the manufacturing sector and EU-related projects

The manufacturing industry is a crucial component of sustainable economic development in the European Union, generating added value and providing employment to millions of people. Despite the significant role it plays in the economy, European Small and Medium-sized Enterprises (SMEs) still lag behind large organizations in adopting disruptive Industry 4.0 technologies. The fourth industrial revolution refers to the rapid changes occurring in the design, production, operation and service of manufacturing systems and goods, which have a deep impact on productivity and people's lives globally. Industry 4.0 involves the merging of digital technologies and the internet with conventional industry, resulting in a highly integrated value chain where every aspect of the manufacturing process is digitally interconnected. While the expression originated in Germany, similar developments in other European countries are known by various names, such as Smart Factory, Industrial Internet of Things, Smart Industry and Advanced Manufacturing[476]. To ensure that workers and companies can adapt to the technological changes brought by Industry 4.0, appropriate training interventions must be identified and implemented. As highlighted by the World Economic Forum (WEF), 65% of children who started attending primary school in 2018 will be performing jobs that do not currently exist by the time they will finish their education around 2030[477].

New technologies and tools such as robotics and Artificial Intelligence (AI) contribute to transforming European companies and increasing their performance in the frame of globalization. Due to the low-cost workforce in emerging countries, European SMEs need to transform their

[476] Ron DAVIES, « Industry 4.0: Digitalisation for Productivity and Growth | Think Tank | European Parliament », European Parliament - Think Tank, 2015, https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2015)568337.

[477] Chiara Ristuccia, « Industry 4.0: SMEs Challenges and Opportunities in the Era of Digitalization. ZEI Discussion Paper C 252/2019 », Discussion Paper, 2019, https://www.zei.uni-bonn.de/dateien/discussion-paper/DP-C252-Ristuccia.pdf.

manufacturing processes and increase their performances. Indeed, in addition to their workforce optimization, the modernization of their manufacturing processes is essential[478].

The European Union encourages industrial change through its policies, as well as via funding research programmes and infrastructures, in order to support SMEs in their digital transition[479], since companies significantly lag behind large organizations in benefiting from disruptive Industry 4.0 technologies and are still struggling with the initial adoption decisions regarding the digital transformation journey under Industry 4.0[480]. In fact, the expression "Industry 4.0" has proven to be a successful common denominator of the trends that pursue digitalization and innovation in manufacturing processes. It has been widely used by the European Commission and the Governments of the Members States to label public policies aimed at developing innovation and digitalization of European firms, namely SMEs[481].

This chapter includes a non-exhaustive list of EU-funded projects (funded by Horizon 2020 and Europe, Digital Europe, EIT Manufacturing, Erasmus+) related to Industry 4.0 and Advanced Manufacturing, in line with LCAMP's thematic.

[478] Paul-Eric Dossou, Pierre Torregrossa, et Thomas Martinez, « Industry 4.0 concepts and lean manufacturing implementation for optimizing a company logistics flows », *Procedia Computer Science* 200 (8 mars 2022): 358-67, https://doi.org/10.1016/j.procs.2022.01.234.

[479] *Ibid.*

[480] Morteza Ghobakhloo et al., «Drivers and barriers of Industry 4.0 technology adoption among manufacturing SMEs: a systematic review and transformation roadmap », *Journal of Manufacturing Technology Management* 33 (21 April 2022), https://doi.org/10.1108/JMTM-12-2021-0505.

[481] Laurent Probst et al., *Digital Transformation Scoreboard 2018: EU Businesses Go Digital: Opportunities, Outcomes and Uptake* (LU: Publications Office of the European Union, 2018), https://data.europa.eu/doi/10.2826/821639.

AI-MATTERS

AI manufacturing Testing and experimentation network for European industries

January 2023 – December 2027

DIGITAL EUROPE

The AI-MATTERS proposal lays out a consorted approach for the establishment of an impactful European reference Testing and Experimentation Facilities dedicated to the uptake of AI in the European Manufacturing sector. AI in Manufacturing TesTing and experimentation facilities for EuRopean SMEs (AI-MATTERS) is proposed by an agile network of seven nodes and one satellite. The aim is to increase the resilience and flexibility of the European manufacturing sector through the deployment of the latest developments in AI and robotics, and intelligent, autonomous systems for flexible production. Europe needs world-class and impactful reference facilities across the Union to allow SMEs and larger industries to test their AI-enabled concepts and innovative technologies in representative conditions, thereby bringing them closer to deployment. This initiative under the DIGITAL Europe Programme can boost the uptake of innovation within the European manufacturing industries that have suffered during the pandemic crises[482].

SME 5.0

A Strategic Roadmap Towards the Next Level of Intelligent, Sustainable and Human-Centred SMEs

January 2023 – December 2026

HORIZON EUROPE

Digital transformation is all around us. SMEs are no exception. The smallest of businesses can have the biggest potential to integrate digital value chains by adopting digital services. However, the rapid technological changes that define the Fourth Industrial Revolution, or Industry 4.0 are slow in terms of uptake. With the support of the Marie Skłodowska-Curie Actions programme, the SME 5.0 project aims to develop a strategic roadmap for making SMEs digitally savvy, sustainable, resilient and human-centric. In this next level of SME 5.0 factories, humans will play a much more important role. The project's overall goal is to ensure SMEs reap the benefits of Industry 4.0 and reach the next level of Industry 5.0[483].

[482] « AI Matters: AI in Manufacturing for EU Industries », AI Matters, s. d., https://ai-matters.eu/.

[483] « A Strategic Roadmap Towards the Next Level of Intelligent, Sustainable and Human-Centred SMEs | SME 5.0 Project | Fact Sheet | HORIZON | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/101086487.

AI REDGIO 5.0

Regions and (E)DIHs alliance for AI-at-the-Edge adoption by European Industry 5.0 Manufacturing SMEs

January 2023 – December 2025

HORIZON EUROPE

AI REDGIO 5.0 aims at renovating and extending the HORIZON 2020 I4MS AI REGIO alliance between Vanguard EU regions and DIHs for a competitive AI-at-the-Edge Digital Transformation of Industry 5.0 Manufacturing SMEs. AI REGIO outcomes (methods and tools for DIHs governance and cross-DIH collaboration; Data Space and AI for Manufacturing toolkit; Didactic Factories network and TERESA facilities; SME-driven experimentations in 14 Vanguard regions) are i) extended to the I5.0 principles; ii) enabled by the newest trusted technologies along the edge-to-cloud continuum; iii) supported by European open source hw/sw reference implementations, preserving EU values and ethical principles; iv) interconnected with the EDIH network in DEP as well as with the AI TEF nodes and the Data Spaces deployment program[484].

REBOOT Skills

Rebooting manufacturing industry with digitalisation skill development

January 2023 – December 2024

DIGITAL EUROPE

The aim of REBOOT SKILLS is to enable workers who are at present or who wish to be employed in the manufacturing sector to access advanced digital upskilling opportunities that can help them keep pace with the latest developments in Cybersecurity, Robotics, Artificial Intelligence (AI) and the Industrial Internet of Things (IoT). The project brings together a novel mix of EU education providers and professional organizations to deliver a bespoke upskilling model of advanced digital, skill-based, through short training course that will jointly empower workers and the manufacturing industry at this critical time for the European manufacturing industry ecosystem[485].

[484] « Regions and (E)DIHs alliance for AI-at-the-Edge adoption by European Industry 5.0 Manufacturing SMEs | AI REDGIO 5.0 Project | Fact Sheet | HORIZON | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/101092069.

[485] « Rebooting manufacturing industry with digitalisation skill development - REBOOT Skills - MADE », MADE CC, s. d., https://www.made-cc.eu/en/projects/reboot/.

NEPTUNE

New approach to innovative technologies in manufacturing

November 2022 – October 2025

HORIZON EUROPE

Innovation is crucial for any and every industry. In the EU, innovation has driven the implementation of novel solutions. Unfortunately, some EU countries, like Poland, have not been completely successful at accelerating innovation and introducing new ideas. The EU-funded NEPTUNE project, in cooperation with KTH Stockholm, TU Berlin and NTU Athens, aims to offer a solution. It utilises their experience in subjects like innovations in additive manufacturing, VR technology, and others, as well as their connections with multiple universities. The objective is to help Poland and other EU countries to achieve innovative industrial sectors with research and production excellence[486].

Circular TwAIn

AI Platform for Integrated Sustainable and Circular Manufacturing

July 2022 – June 2025

HORIZON EUROPE

The transition towards Industry 5.0 is very much underway, putting the manufacturing industry on a more sustainable and resilient development path. However, the path is lined with challenges, mainly the adoption of sustainable practices in the face of reduced consumption and scarce resources. AI technologies could assist manufacturers in taking this step, but the difficulty of integrating and using them can make them suboptimal for some companies. The EU-funded Circular TwAIn project aims to overcome this issue by developing an innovative AI platform that, supported by data sharing within trusted and effective manufacturing data spaces, utilises digital twin technology to offer stakeholders end-to-end sustainability as well as the adaptability to remain competitive in the coming Industry 5.0[487].

[486] « Objectives - About NEPTUNE », NEPTUNE, s. d., https://www.neptune-project.eu/About-Neptune/Objectives.

[487] « AI Platform for Integrated Sustainable and Circular Manufacturing | Circular TwAIn Project | Fact Sheet | HORIZON | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/101058585.

CAPP_AI4.0

Learning about AI and digitalization for a more efficient computer-aided process planning in Machining 4.0

January 2023 – December 2024

EIT MANUFACTURING

Planning and preparation of the machining process are at the heart of modern machining in the world of industrial production, ensuring precision and quality. Until now, decisions accrued during planning, have been made mainly on the basis of the experience of skilled professionals. New Artificial Intelligence systems can help and support process planning to shorten the time required and get as close as possible to optimal results. This project aims to increase awareness, skills, and application of Artificial Intelligence support systems that can assist trained employees in their activities of planning and preparing machining processes. Courses and workshops (as well as training materials) are to be delivered in order to train employees in the use of these systems, thereby increasing the capacity, productivity and efficiency of SMEs[488].

MIND4MACHINES

Manufacturing industry's novel digitalisation value chains for connecting machines with people, process and technology

June 2021 – September 2024

HORIZON 2020

The manufacturing sector is one of the largest economic sectors in Europe, employing more than 29 million people in the EU. But it is also experiencing a skills gap in areas such as energy and resource efficiency and digitalisation. In this context, the EU-funded MIND4MACHINES project aims to facilitate the cross-sectoral and cross-border support needed by manufacturing SMEs to test and adopt the latest digital technologies for transformation towards smarter, greener, and more resource-efficient manufacturing. Specifically, the project's objective is to establish large-scale demonstrators to test a range of digital solutions. Manufacturing companies are invited to use the Open Innovation Space of MIND4MACHINES to search for solutions for the digitalisation of production processes. The project provides financial support via two Open Calls[489].

[488] « Learning about AI and Digitalization for a More Efficient Computer-Aided Process Planning in Machining 4.0 -CAPP_AI4.0 », *MADE* (blog), s. d., https://www.made-cc.eu/en/projects/project-cappai40/.

[489] « Home - Mind4machines », *MIND 4 MACHINES* (blog), s. d., https://mind4machines.eu/, https://mind4machines.eu/.

PULSATE

Fostering the PAN-European infrastructure for empowering SMEs digital competences in laser-based advance and additive manufacturing

September 2020 – August 2024

HORIZON 2020

Laser-based advanced and additive manufacturing (LBAAM) technologies play an important role in furthering digital production and offer important advantages to the companies that adopt them. However, barriers such as high investment costs, complex technology and system integration and awareness hinder their adoption by SMEs. The EU-funded PULSATE project intends to mitigate these barriers to boost the adoption of LBAAM technologies by SMEs and promote the development of SME-friendly laser-based equipment and solutions. To achieve this, a Europe-wide network to encourage SME participation in LBAAM innovation is to be set up, with the objective to therefore connect digital innovation hubs to support a structure designed to tackle the issues currently hindering LBAAM technology adoption. The project's work aims at helping to increase the competitiveness of European SMEs[490].

Change2Twin

Create and harvest offerings to support manufacturing SMEs to become digital twin champions

June 2020 – May 2024

HORIZON 2020 HORIZON EUROPE

The EU-funded Change2Twin project (part of I4MS) helps to manufacture SMEs in their digitalisation efforts to deploy digital twins. The concept of digital twins is one of the big game-changers in manufacturing and allows companies to significantly increase their global competitiveness. A digital twin is a digital replica of an artefact, process or service that is so accurate that it can be used as a basis for taking decisions. The digital replica is often connected with the physical world by streams of data. Digital Innovation Hubs are important partners in this process and will facilitate the uptake of the latest digital twin technologies across the European Union[491].

[490] « Fostering the PAN-European infrastructure for empowering SMEs digital competences in laser-based advance and additive manufacturing. | PULSATE Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/951998.

[491] « Create and Harvest Offerings to support Manufacturing SMEs to become Digital Twin Champions | Change2Twin Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/951956.

SMART 4.0

Smart manufacturing advanced research training for Industry 4.0

June 2019 – May 2024

HORIZON 2020

The EU-funded SMART 4.0 programme is an inclusive, professional development opportunity for experienced researchers, aimed at creating research leaders of tomorrow in the area of smart manufacturing. SMART 4.0 is implemented by CONFIRM Centre, which constitutes an excellent dedicated smart manufacturing training environment. The programme is academically led and industrially informed, and CONFIRM's industry partners play a key role in ensuring that fellows possess the relevant skills and talent to provide immediate returns to the competitive knowledge economy. SMART 4.0 focuses on providing world-class training and research opportunities and delivering the next generation's smart manufacturing leaders with strong interdisciplinary systems-level thinking. The programme supports increasing Europe's critical mass in the field of smart manufacturing to deliver Industry 4.0[492].

DIGIMAN4.0

DIGItal MANufacturing technologies for zero-defect Industry 4.0 Production

January 2019 – March 2024

HORIZON 2020

Recent advances in digital technologies have created unprecedented possibilities for manufacturing industries. Industry 4.0 identifies a strategy allowing the manufacturing sector to transition towards new ways of production driven by recent innovations. Industry 4.0 consists of essentially nine clusters of key-enabling digital technologies that can radically innovate and disrupt current manufacturing production. The training consists of innovative technological solutions in different domains for high quality, high-throughput, and high-precision production (zero-defect precision mass manufacturing of high-performance products) and validation of diverse digital manufacturing technologies by integration into process chains of advanced components[493].

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[492] « Smart Manufacturing Advanced Research Training for Industry 4.0 | SMART 4.0 Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/847577.

[493] « DIGItal MANufacturing Technologies for Zero-defect Industry 4.0 Production | DIGIMAN4.0 Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/814225.

DE4HUMAN

Developing design driven innovation skills for human centred manufacturing system

January 2023 – December 2023

EIT MANUFACTURING

DE4Human proposes a training course to enhance knowledge of traditional manufacturing with digital and application methods to improve human-centred factories. The course has a focus on manufacturing and engineering design based on three pillars: Design4Empower, Design4Safety, Design4Inclusivity[494].

RECIRCLEMAN

Blockchain technologies to enable circular and recycling business model for manufacturing industry

January 2023 – December 2023

EIT MANUFACTURING

ReCircleMan aims at enhancing the green transition of the manufacturing process by fostering the adoption, tracing and demonstration of sustainable approaches by means of innovative and circular product information management. This is expected to improve the End-of-Life management of production waste, such as electrical and electronic equipment as well as chemicals. To ensure full visibility throughout the value chains, the ReCircleMan solution is to be built upon blockchain technology, providing manufacturing operators, and stakeholders with traceable data to implement end-of-life waste management practices enabling innovative, shared, circular business model[495].

[494] « Developing Design Driven Innovation Skills for Human Centered Manufacturing System - DE4HUMAN », *MADE* (blog), s. d., https://www.made-cc.eu/en/projects/de4human/.

[495] « ReCircleMan – Blockchain technologies to enable circular and recycling business model for manufacturing industry », ReCircleMan, s. d., https://www.recircleman.eu/.

DIGITbrain

Digital twins bringing agility and innovation to manufacturing SMEs, by empowering a network of DIHs with an integrated digital platform that enables Manufacturing as a Service (MaaS)

July 2020 – December 2023

HORIZON 2020

DIGITbrain is an EU innovation program to give SMEs easy access to digital twins. A Digital Twin is a computer-based application/simulation that mimics the real production line of a company and runs in parallel with the real manufacturing process. Using this Digital Twin, companies can rationalise the manufacturing process, make predictions regarding expected machine failures and can predict maintenance needs. This group aims to unite partners of the project, but also likes to add interested people from the outside to its network[496].

DigiPrime

Digital platform for circular economy in cross-sectorial sustainable value networks

January 2020 – December 2023

HORIZON 2020

The EU-funded DigiPrime project aims to develop the concept of a circular economy digital platform in order to create circular business models based on the data-enhanced recovery and reuse of functions and materials. Specifically, it creates and operates a federated model of digital platforms for cross-sector business in the circular economy. DigiPrime is to be validated through several cross-sectoral pilots, further detailed in 20 use cases covering different European industrial sectors (automotive, renewable energy, electronics, textile, construction), and by additional pilots in new sectors, funded through an open call mechanism[497].

[496] « Digital twins bringing agility and innovation to manufacturing SMEs, by empowering a network of DIHs with an integrated digital platform that enables Manufacturing as a Service (MaaS) | DIGITbrain Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/952071.

[497] « Digital Platform for Circular Economy in Cross-sectorial Sustainable Value Networks | DigiPrime Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/873111.

KYKLOS 4.0

An Advanced Circular and Agile Manufacturing Ecosystem based on rapid reconfigurable manufacturing process and individualized consumer preferences

January 2020 – December 2023

HORIZON 2020

In circular manufacturing (CM), manufacturers find ways to eliminate waste by reusing and recycling materials and goods. The EU-funded KYKLOS 4.0 project aims to show how cyber-physical systems, product life-cycle management, life-cycle assessment, augmented reality, and artificial intelligence technologies and methods are able to transform CM. It aims to achieve this through seven large-scale pilot projects that will demonstrate improvements in operational efficiency and deliver solutions for resource reuse. The project's advanced ecosystem can reshape factory processes and services so as to benefit manufacturing throughout Europe European SMEs[498].

SMART4ALL

Selfsustained cross border customized cyberphysical system experiments for capacity building among European stakeholders

January 2020 – December 2023

HORIZON 2020

To create sustainable growth, Europe is building and funding ecosystems for co-creation. Promoting cross-border collaborations between academia and industry and taking knowledge transfer to the next level is essential. The EU-funded SMART4ALL project aims to develop a new paradigm to uncover the so-called hidden innovation treasures in Southeast Europe (SEE). The project introduces the concept of marketplace-as-a-service (MaaS), which can serve as a one-stop-smart shop offering tools, services and platforms based on open-source technology. Overall, the project works to enhance regionality for community building, synchronising European and national development strategies to bring new products and business ideas originated from SEE to the market[499].

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498 « An Advanced Circular and Agile Manufacturing Ecosystem based on rapid reconfigurable manufacturing process and individualized consumer preferences | KYKLOS 4.0 Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/872570.

499 « SELFSUSTAINED CROSS BORDER CUSTOMIZED CYBERPHYSICAL SYSTEM EXPERIMENTS FOR CAPACITY BUILDING AMONG EUROPEAN STAKEHOLDERS | SMART4ALL Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/872614.

FIT-4-NMP

Strategic and targeted support to incentivise talented newcomers to NMP projects under Horizon Europe

January 2021 – December 2023

HORIZON 2020

Nano-sciences, nanotechnologies, material and new production technologies (NMPs) represent a significant group of pervasive technologies; their development can boost the competitive advantage of the European industry. The EU-funded FIT-4-NMP project aims to assist newcomers from underrepresented regions to participate in NMP projects in Horizon Europe, the next EU research and innovation investment programme (2021-2027). Newcomers in this context refer to promising innovation organisations, especially small and medium-sized enterprises that have not participated in the Horizon 2020 NMP. The project organises workshops, facilitates networking and provides training and technology transfer. One of FIT-4-NMP's key strategic surveys aims to analyse the reasons for the non-participation of newcomers in NMP projects[500].

VOJEXT

Value of joint experimentation in digital technologies for manufacturing and construction

July 2020 – December 2023

HORIZON 2020

Robots and autonomous systems that use human-like strategies and knowledge are important components in the development of Europe's industry. Under the vision of Value Of Joint EXperimentation in digital technologies, the EU-funded VOJEXT project aims to provide a business and technological framework that will match and encourage producers and SMEs to adopt cognitive autonomous systems for human-robot interaction, and cobots in particular. To this end, VOJEXT creates cost-effective, market-oriented, and easy-to-repurpose autonomous, mobile and dexterous robotic systems as the main component of a smart, agile and scalable cognitive cyber-physical system for industry. Fifteen new demonstrators are to be integrated during the project through open calls. The VOJEXT project's efforts help to boost science-driven industry approaches for the EU manufacturing and construction industry[501].

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[500] « Strategic and targeted support to incentivise talented newcomers to NMP projects under Horizon Europe | FIT-4-NMP Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/958255.

[501] « Value Of Joint EXperimentation in digital Technologies for manufacturing and construction | VOJEXT Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/952197.

RODIN

Robotics digital innovation network

November 2018 – October 2023

HORIZON 2020

With increasing digitalisation, expansion of the Internet of Things and maturation of Industry 4.0 leadership in robotics will be critical to Europe's future. The European Commission has made the provision of a network of robotics digital innovation hubs (DIHs) a priority. The EU-funded RODIN project is addressing this pressing need, coordinating activities among the DIHs in the four prioritised application areas of healthcare, infrastructure inspection and maintenance, agri-food and agile production. The network of networks created and orchestrated by the project aims to facilitate and accelerate a broad uptake and integration of robotic technologies and support the digitisation of industry through robotics[502].

ASSISTANT

Learning and robust decision support systems for agile manufacturing environments

November 2020 – October 2023

HORIZON 2020

The EU-funded ASSISTANT project aims to develop breakthrough solutions for the manufacturing industry, using artificial intelligence to optimize production systems. One of the keystones of ASSISTANT is the creation of intelligent digital twins. By combining machine learning, optimization, simulation, and domain models, ASSISTANT develops tools and solutions providing all required information to help production managers design production lines, plan production, and improve machine settings for effective and sustainable decisions that guarantee product quality and safety. With 12 Partners involved, ASSISTANT aims to provide a set of AI-based intelligent digital twins that helps process engineers and production planners to operate collaborative mixed-model assembly lines based on the data collected from IoT devices and external data sources. Such a tool aims to help planners to design the assembly line, plan the production, operate the line, and improve process tuning. In addition, the system

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502 « RObotics Digital Innovation Network | RODIN Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/825263.

monitors the line in real-time, ensures that all required resources are available, and allow fast re-planning when necessary. ASSISTANT aims to make cost-effective decisions while ensuring product quality, safety, the well-being of the workers, and managing the various sources of uncertainties. The resulting intelligent digital twin systems will be data-driven, agile, autonomous, collaborative, explainable, and safe but reactive[503].

AI REGIO

Regions and DIHs alliance for ai-driven digital transformation of european manufacturing SMEs

October 2020 – September 2023

HORIZON 2020

The AI REGIO project aims at filling 3 major gaps currently preventing AI-driven DIHs from implementing fully effective digital transformation pathways for their Manufacturing SMEs: at the policy level the Regional vs. EU gap; at the technological level the Digital Manufacturing vs. Innovation Collaboration Platform gap; at the business level the Innovative AI (Industry 5.0) vs Industry 4.0 gap. AI REGIO is following the 4 steps for VANGUARD innovation strategy (learn-connect-demonstrate-commercialize) by constantly aligning its methods with the AI DIH Network initiative and its assets with I4MS/DIH BEinCPPS Phase II and MIDIH / L4MS Phase III projects. AI REGIO: Industry 5.0 for SMEs[504].

[503] « leArning and robuSt deciSIon SupporT systems for agile mANufacTuring environments | ASSISTANT Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/101000165.

[504] « Regions and DIHs alliance for AI-driven digital transformation of European Manufacturing SMEs | AI REGIO Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/952003.

RIMA

Robotics for Infrastructure Inspection and maintenance

January 2019 – June 2023

HORIZON 2020

Industrial robots can be used to inspect and maintain machines and facilities in industries like energy, transport and civil engineering. Usually done manually, the automation of these operations will increase efficiency. In this context, the EU-funded RIMA project aims to facilitate the uptake of inspection and maintenance technologies. Specifically, it establishes a network of 13 Digital Innovation Hubs on robotics sharing best practices. The project also provides education and training on automated inspection and maintenance operations in order to accelerate growth in the field. Among the expected results is the increased competitiveness of the EU's robotic inspection and maintenance sector[505].

iProduce

A Social Manufacturing Framework for Streamlined Multi-stakeholder Open Innovation Missions in Consumer Goods Sectors

January 2020 – June 2023

HORIZON 2020

Innovation researchers consider the rise of the capability of consumers to innovate for themselves. The democratisation of innovation will benefit EU producers. However, its integration with corporate innovation processes is still underdeveloped. The EU-funded iPRODUCE project aims to technologically advance existing concepts from specific manufacturing fields such as DIY manufacturing, FabLabs and Makerspace and deploy them in connected multi-stakeholder structures under its inclusive concept of collaborative manufacturing demonstration facilities (cMDF). The project intends to activate an open digital platform supported by innovative instruments that will allow stakeholders to interact and cooperate. The platform will be installed, monitored and evaluated in six local environments with diverse experiences, objectives and application areas[506].

[505] « Robotics for Infrastructure Inspection and MAintenance | RIMA Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/824990.

[506] « A Social Manufacturing Framework for Streamlined Multi-stakeholder Open Innovation Missions in Consumer Goods Sectors | iPRODUCE Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/870037.

DIH²

A Pan-European network of robotics DIHs for agile production

January 2019 – June 2023

HORIZON 2020

DIH² network consists of EDIHs/DIHs supporting the local manufacturing industry, especially SMEs in the deployment of the latest Robotics and AI technologies in the Agile Production sector. The network supports its members in their regional digitalization goals in line with the Digital Europe program. Currently, the network has over 90 DIHs as members representing 28 European countries. The network is constantly expanding to reach all regions of Europe. The network members get access to the most advanced technologies in the fields of Robotics and AI, plus access to European funding opportunities which they can bring directly to the SMEs in their region. Through the network, members will have the possibility to provide direct input for the funding programs of the European Commission [507].

DIH-World

Accelerating deployment and matureness of DIHs for the benefit of digitisation of European SMEs

July 2020 – June 2023

HORIZON 2020

SMEs can benefit significantly from adopting digital technologies. However, few have the resources and know-how to do so. The EU-funded DIH-World project, therefore, aims to accelerate the uptake of advanced digital technologies by European manufacturing SMEs. Furthermore, it aims to help these SMEs build sustainable competitive advantages and reach global markets, in this way strengthening the capacities of regional digital innovation hubs (DIHs) across Europe. To do so, it provides DIHs with access to harmonised tools, effective technologies and methodologies, smart investment sources and rich training assets. By accelerating the matureness of DIHs, the project aims to help them capitalise on European DIH networks and leverage their resources and facilities to benefit their local SMEs[508].

[507] « A Pan-European Network of Robotics DIHs for Agile Production | DIH² Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/824964.

[508] « DIH-World - Accelerating deployment and matureness of DIHs for the benefit of Digitisation of European SMEs | DIH-World Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/952176.

BEYOND4.0

Inclusive futures for Europe BEYOND the impacts of Industrie 4.0 and digital disruption

January 2019 – June 2023

HORIZON 2020

BEYOND4.0 aims to help deliver an inclusive European future by examining the impact of the new technologies on the future of jobs, business models and welfare. We use a multidisciplinary research approach undertaken by a top-tier consortium with stakeholder engagement throughout the project. BEYOND4.0 has five objectives: 1. Provide new, scientific insight into technological transformation; 2. Provide new, scientific insight into company strategies dealing with technological transformation; 3. Examine the impact of technological transformation on: a. quality, content, and distribution of work; b. skill needs; c. education and training; d. value creation by companies; 4. Identify policy options for: a. fiscal policy (e.g. robot taxes); b. welfare policy (e.g. basic income); 5. Identify social investment approaches and tools for inclusive growth[509].

Gazelle Accelerator

January 2021 – March 2023

EIT MANUFACTURING

Gazelle Accelerator is a European project which aims to develop Start-ups and SMEs working in industry 4.0. We support them to accelerate their growth through dedicated training and coaching sessions but also connections with end-users and investors. Gazelle Accelerator is about matching manufacturing challenges with innovative solutions, by identifying with industrial corporates in Europe what are their manufacturing needs and challenges[510].

[509] « The project BEYOND 4.0 », BEYOND 4.0, s. d., https://beyond4-0.eu/the-project.

[510] « Gazelle Accelerator - Discover the Project », Gazelle Accelerator, s. d., https://gazelle-accelerator.eu/.

MULTI-IA

Development of a multi-material and multi-defect detection and anomaly prediction system based on machine vision, artificial intelligence and IoT

January 2021 – January 2023

MANUNET (HORIZON 2020)

MULTI-AI addresses one of the more ambitious challenges in industry 4.0: zero-defect manufacturing, by applying cutting-edge information and communication technologies in the development of a multi-material and multi-defect detection and anomaly prediction system. The main innovation regarding the current state-of-the-art is that the system to be developed within this project allows the real-time, simultaneous analysis of multiple types of defects in different materials, without the need to have different inspection stations for each type of defect. This system aims to be scalable and customisable for the quality control of any part manufactured in a production line. The use of IoT technologies for monitoring and real-time sensoring is essential to guarantee obtaining adequate datasets in terms of size, quality and labelling which allow feeding both the defect detection and the anomaly prediction modules, and thus result in a robust and reliable system[511].

TECH2MARKET

Technology to market for competitive manufacturing in Europe

January 2022 – December 2022

EIT MANUFACTURING

Tech2Market aims to create a competition to attract, select and support technological results from R&D projects that potentially pave their way to the market. These tech results were developed in previous R&D activities in the context of H2020, Horizon Europe, or National/Regional programmes. The main goal is been to support IP protection and commercialization, as well as venture creation through training activities, a mentorship program, and initial financial support. The R&D results will be taken by teams from all over Europe[512].

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[511] « Izertis Coordinates MULTI-AI International Project », Izertis, s. d., https://www.izertis.com/en/-/noticias/izertis-coordina-el-proyecto-internacional-multi-ai.

[512] « Technology to Market », EIT Manufacturing, 3 février 2022, https://www.eitmanufacturing.eu/news-events/activities/technology-to-market-for-competitive-manufacturing-in-europe-tech2market/.

HUBCAP

Digital innovation hubs and collaborative platform for cyber-physical systems

January 2020 – December 2022

HORIZON 2020

An increasing number of interacting systems with strong connectivity are being used in both society and industry as computational and physical systems become mainstream. This confluence of the physical and computational worlds has resulted in the so-called cyber-physical systems (CPS). The EU-funded HUBCAP project provides a one-stop-shop to assist European SMEs in joining the CPS revolution. It builds on digital innovation hubs (DIHs) in seven European countries by creating a growing and sustainable European network offering SMEs opportunities to undertake experiments, seek investment, access expertise and training and form new business links. The aim of the project is to lower barriers for SMEs to realise the potential of growing autonomy in CPS by accessing advanced model-based design (MBD) technology, and providing training and guidance[513].

AI4DI

Artificial intelligence for digitizing industry

May 2019 – December 2022

HORIZON 2020

Artificial intelligence plays a central role in societies, economies and industries around the world. However, there has been a lack of AI integration in Europe. As a result, potential users are not sufficiently supported despite the benefits it can provide to all branches of the industry and its digitisation. The EU-funded AI4DI project aims to transfer machine learning (ML) and AI from the cloud to the digitising industry. It uses a seven-key-target approach to evaluate and improve its relevance within the industry. The project plans to connect factories, processes and devices within the digitised industry by utilising ML and AI. Then it collects data on their performance[514].

[513] « DIGITAL INNOVATION HUBS AND COLLABORATIVE PLATFORM FOR CYBER-PHYSICAL SYSTEMS | HUBCAP Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/872698.

[514] « Artificial Intelligence for Digitizing Industry | AI4DI Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/826060.

TRINITY

Digital technologies, advanced robotics and increased cyber-security for agile production in future European manufacturing ecosystems

January 2019 – December 2022

HORIZON 2020

Agile manufacturing refers to the ability of businesses to respond quickly to customer needs with new product development and delivery to market. It is of increasing importance in today's rapidly changing market conditions and will be supported by next-generation robotic technologies and Industry 4.0. The EU-funded TRINITY project is strengthening Europe's position by creating a network of multidisciplinary and synergistic local digital innovation hubs focused on agile production that will include researchers and companies implementing solutions. The network also aims to offer consulting services for business planning and accessing financing, propelling Europe to the forefront of agile manufacturing and robotics[515].

ConnectedFactories2

Global-leading smart manufacturing through digital platforms, cross-cutting features and skilled workforce

December 2019 – November 2022

HORIZON 2020

The ConnectedFactories project establishes a structured overview of available and upcoming technological approaches and best practices regarding the digitalisation of manufacturing. The project identifies present and future needs, as well as challenges, of the manufacturing industries. The project explores pathways to the digital integration and interoperability of manufacturing systems and processes and the benefits this will bring. ConnectedFactories creates insights into important cross-cutting factors and key enablers. ConnectedFactories associates projects and project results, use cases and demonstrators to the pathways and the cross-cutting factors[516].

[515] « Digital Technologies, Advanced Robotics and increased Cyber-security for Agile Production in Future European Manufacturing Ecosystems | TRINITY Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/825196.

[516] « Global-leading smart manufacturing through digital platforms, cross-cutting features and skilled workforce | ConnectedFactories 2 Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/873086.

I4MS4Ts

I4MS tools and technologies for transformation

June 2020 – November 2022

HORIZON 2020

Tech suppliers and public bodies face several challenges when attempting to accelerate digital uptake by European manufacturing SMEs and mid-caps. The EU-funded I4MS4Ts project aims to address these challenges by contributing to the ICT Innovation for Manufacturing SMEs (I4MS) ecosystem's structure and visibility. It, therefore, provides I4MS actions and digital innovation hubs (DIHs) with tools to convey their value proposition and attract manufacturing SMEs and mid-caps. It puts together and shares I4MS DIH demonstrators, services and training programmes. It also provides the I4MS with a strong communication and dissemination platform. The project's work aims to help solve I4MS challenges and encourage national and regional financing entities to dedicate resources to supporting promising applications[517].

Arrowhead

Arrowhead tools for engineering of digitalisation solution

May 2019 – July 2022

HORIZON 2020

From everyday uses to large-scale industrial applications, the Internet of Things (IoT) is expanding at an accelerating speed. The EU-funded Arrowhead Tools project aims to create advanced new digitisation and automation tools for the European engineering industry. These tools bridge the gap that currently prevents total integration of operational technology – for example how efficiently the engineering industry is leveraging IoT and the 'system of systems' into its products. The project is expected to reduce the costs of developing and introducing flexible and secure digitisation and automation solutions by about 20% to 50%. This will make Europe more competitive and create new jobs and business opportunities, while also reducing energy consumption and the environmental footprint[518].

[517] « I4MS Tools and Technologies for Transformation | I4MS4Ts Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/951848.

[518] « Arrowhead Tools for Engineering of Digitalisation Solutions | Arrowhead Tools Project | Fact Sheet | H2020 | CORDIS | European Commission », Cordis, s. d., https://cordis.europa.eu/project/id/826452.

SME 4.0

Industry 4.0 for SMEs - Smart manufacturing and logistics for SMEs in an X-to-order and mass customization environment

January 2017 – June 2022

HORIZON 2020

A great challenge for the future lies in the transfer of Industry 4.0 expertise and technologies in small and medium-sized enterprises (SME). SMEs represent the backbone of the economy and have enormous importance in the development programs of the European Union for strengthening the competitiveness of European enterprises. Although the high potential of Industry 4.0 in SMEs, the main limit lies in a lack of concrete models for its implementation and application in small and medium enterprises. Thus, this research project titled "Industry 4.0 for SMEs - Smart Manufacturing and Logistics for SMEs in an X-to-order and Mass Customization Environment" aims to close and overcome this gap through the creation of an international and interdisciplinary research network. Identifying the needs and enablers for a smart and intelligent SME-Factory, creating adapted concepts and design solutions for production and logistics systems in SMEs and developing suitable organisation and business models are the three main objectives of this research network[519].

SMART-PDM

A smart predictive maintenance approach based on cyber-physical systems

December 2018 – December 2021

ITEA 3 (EUREKA)

Manufacturing is undergoing an immense yet gradual Industry 4.0 transformation with the help of advancements including predictive maintenance. SMART-PDM's objective is to acquire manufacturing data to provide diagnosis and prognosis information while rendering the underlying technology financially feasible. This will result in lower costs of maintenance, waste and parts as well as improvements in quality and throughput. The technological advancements validated by the demonstrators will help enhance the know-how, technologies, solution offerings and toolsets of the partners[520].

[519] « Industry 4.0 for SMEs - Smart Manufacturing and Logistics for SMEs in an X-to-order and Mass Customization Environment », Cordis, s. d., https://cordis.europa.eu/project/id/734713.

[520] « SMART-PDM – A Smart Predictive Maintenance Approach based on Cyber Physical Systems », SMART PDM, s. d., https://smart-pdm.eu/.

EXAM 4.0

Excellent advanced manufacturing 4.0

November 2019 – October 2021

ERASMUS+

The Excellent Advanced Manufacturing 4.0 project is one of the five Platforms of VET Excellence approved for funding by the Erasmus+ programme in 2019 under the Centres of Vocational Excellence (CoVE) pilot initiative launched by the European Commission in 2018. The first project objective is to establish a European platform of excellent advanced manufacturing VET centres, the EXAM 4.0 hub, aiming to become a reference in skills governance in the participating regions/countries and at the European level, setting up European regional skills ecosystems that bring together VET/HVET centres, companies, policymakers and individual lifelong learners. In addition, the project's second objective is to design the main features of the EXAM 4.0 lab, where students can acquire relevant competencies to work in 4.0 environments in the advanced manufacturing sector[521].

BOOST 4.0

Big data value spaces for competitiveness of European connected smart factories 4.0

January 2018 – December 2020

HORIZON 2020

EFFRA recommendations on Factories 4.0 and Beyond (Sept 2016) clearly stated the need for the development of large-scale experimentation and demonstration of data-driven "connected smart" Factories 4.0 to retain European manufacturing competitiveness. BOOST 4.0 addresses this need, by demonstrating in a measurable and replicable way, an open standardised and transformative shared data-driven Factory 4.0 model through 10 lighthouse factories. BOOST 4.0 also aims to demonstrate how European industry can build unique strategies and competitive advantages through big data across all phases of product and process lifecycle (engineering, planning, operation, production and after-market services) building upon the connected smart Factory 4.0 model to meet the Industry 4.0 challenges (lot size one distributed manufacturing, operation of zero defect processes & products, zero break down sustainable operations, agile customer-driven manufacturing value network management and human-centred manufacturing)[522].

[521] « Home EXAM 4.0 », Exam 4.0, 18 mars 2022, https://examhub.eu/.

[522] « Boost 4.0 | Big Data for Factories », Boost 4.0, s. d., https://boost40.eu/.

OPTIMUM

Optimised Industrial IoT and distributed control platform for manufacturing and material handling

November 2017 – June 2021

ITEA 4 (EUREKA)

OPTIMUM supports innovative concepts for engineering, commissioning, control and supervision of Smart Manufacturing and Material Handling. It is in line with European, National and International initiatives towards digital manufacturing, closely related to ongoing activities in working groups around the German initiative Industry 4.0[523].

SHERLOCK

Seamless and safe human-centred robotic applications for novel collaborative workplaces

October 2018 – September 2020

HORIZON 2020

To address the increasing need for flexible manufacturing lines, the manufacturing paradigm has to advance towards hybrid solutions, combining the capabilities of both humans and machines. While there is much attention to the technological improvements of human-robot collaborative (HRC) solutions, the operator's psychological and social well-being remains an overlooked subject, resulting in performance and acceptance issues, dealing with applications and complexity. The EU-funded SHERLOCK project addresses these shortcomings, aspiring to develop flexible, safe human-centred robotic applications for new collaborative workplaces. The project introduces novel robotics technologies, such as high and low-payload collaborative robots, exoskeletons and mobile dual-arm robots, enhanced with smart mechatronics and AI-based cognition to augment human capabilities. The novel SHERLOCK shop floors ensure the safety, acceptance, and well-being of the operators[524].

[523] Johan van der Heide, [at]itea4.org, « ITEA 4 · Project · 16043 OPTIMUM », itea4.org, s. d., https://itea4.org/project/optimum.html.

[524] « Home Sherlock Project », Sherlock Project, s. d., https://www.sherlock-project.eu/.

3.22.2 Conclusions

In the last years, the European Union has made significant investments in research and innovation programs to promote competitiveness and support the digital transition. In this regard, at the start of the EU 2021 - 2027 programming period, a new funding program (Digital Europe) has been launched with a specific focus on cybersecurity and digital skills, as well as with the aim to foster investments in the public and private sectors. In addition, particularly Horizon 2020 and later Horizon Europe funding programs, together with Erasmus+ financing (that funded both EXAM 4.0 and LCAMP projects) and EIT Manufacturing initiatives, play a crucial role in the support of European companies facing challenges related to the transformation of manufacturing processes, optimization of the workforce and increase of performances.

In order to cope with the changes that Industry 4.0 and Advanced Manufacturing are bringing into the labour market, digital skills must be spread alongside investments in new technologies[525]. EU projects listed above demonstrate a significant focus on Digital Transformation and advanced technologies, such as Artificial Intelligence, the Internet of Things, Predictive Maintenance, Digital Twins, Virtual and Augmented Reality, blockchain, and robotics. These initiatives cover various topics, including Smart Manufacturing, human-robot collaboration, Circular Economy, sustainability and waste reduction. They show a strong emphasis on supporting SMEs not only in their digital, but also green, transformation journey through training and support programs, as well as via the integration of different advanced technologies to enable more agile and flexible production processes. Sustainable and circular manufacturing practices are also a focus, demonstrating that nowadays digital and green transitions run in parallel.

[525] Ristuccia, « Industry 4.0 ».

3.23 EXPERTS' EVALUATION RESULTS

We gathered evaluations of the statements regarding future trends from seven national panels of experts, and received responses, including 7 from the French, 9 from the German, 5 from the Italian, 8 from the Slovenian, 8 from the Spanish, 7 from the Turkish and 1 from the Swedish panel.

Each evaluation of a future trend was assigned a value from 1 to 4. To do this, we assigned a numerical value to each answer except for the "no opinion" option:

- Already fulfilled: 4
- Short-term (in a 3-year period): 3
- Mid-term (in a 3 to 10-year period): 2
- Long-term (after 10 years): 1
- It will not happen: 0

3.23.1 Scope of statements

The statements cover a broad spectrum of topics. However, without the experts' opinions, the future trends all seem to be equally pertinent. The experts provide context and urgency to the statements.

The statements:

Megatrends in Advanced Manufacturing	Industry 5.0 paradigm is emerging in Europe towards a more human-centric, resilient and sustainable industry. Transformations are not technology-driven but simultaneously technology and human-centric.
Trends in Advanced Manufacturing and Insights for VET	The Advanced Manufacturing sector is facing a green transition, including energy efficiency, energy neutrality and ecological emphasis. Green skills and circular economy concepts must be included in all the training programmes. Therefore, Green skills need to be defined. A culture for lifelong learning is not developed enough among students and workers. VET centres and companies must place mechanisms towards strengthening Lifelong Learning pathways.
Review of EU projects	The EU's investment in research and innovation programmes, emphasizes the need for digital skills of students and workers as well as

	the adoption of new technologies to adapt to the changes brought by Industry 4.0.
Learning analytics	Learning analytics is the opportunity to identify potential gaps in an organization's skill set and to develop training programmes to address those gaps. Additionally, analytics provide valuable data to help companies assess the effectiveness of their training programs and make necessary adjustments. It is rarely used in Vocational Education and Training (VET) centres.
Sensoring of manufacturing processes	A global deployment of 5G technology, eliminates the need for distributed edge computing, enabling lower costs for data mining and management on servers in the cloud. 5G enables better communication and supports the maturity levels in digital transitions of companies.
Data collection, analysis of data	The application of Artificial Intelligence (AI) techniques in manufacturing has made it possible to formalise complex multivariate knowledge of machine and process conditions. These tools enhance the work of the operator, which also increases his value as a technician. The massive generation of data through the Internet of Things (IoT) is giving AI a huge boost in the industrial sector.
Metal forming and other technologies	The resource efficiency in terms of material saving and reduction of wastes make metal forming processes an attractive alternative to produce complex parts. Furthermore, the improvement of quality and efficiency due to digitalization increases its opportunities.
Cybersecurity	Cybersecurity is strategic for SMEs as a result of the in-depth digital connectivity of all the value chains.
Assisted jobs (robotics)	Collaborative robots (cobots) and autonomous mobile robots (AMR) have already changed the way humans and machines work together, but the use of Cyber Physical Systems (CPS) will take this to a new level. Increased interaction between the worker and the technological environment enhances safety by reducing risk and preventing accidents.
3D printing / selective laser sintering	Metal additive manufacturing, concretely Selective Laser Sintering (SLS) is a growing and developing technology that requires specific skills and knowledge to design parts and operate equipment. The shift to automated manufacturing processes such as SLS requires retraining of existing staff in order to remain employable.

Reverse engineering	3D scanning is a core element in reverse engineering and requires specific equipment and software, through different solutions, and more affordable options to Vocational Education and Training (VET) Centers which are incorporating these training programmes into their courses. This will require more collaboration between trainers and the industry in order to maintain currency in training processes and equipment.
Ergonomics	By incorporating ergonomic principles and digital technologies into vocational education, students learn to thrive in a rapidly changing manufacturing landscape. This includes training in ergonomics, human factors and digital technologies, as well as hands-on experience with digital workstations and equipment.
Predictive maintenance	The creation phase of predictive models, which is fully automated in many cases encourages companies to engage in predictive maintenance.
Virtual reality / artificial Reality / mixed Reality	Collaborative immersive virtual environments are a safe and useful tool for training on complex or risky processes and establishing useful digital twins in advanced manufacturing. In addition, new solutions simplify the process of creating teaching materials, giving teachers and trainers a leading role.
Digital twin	Digital twin (DT) technology is an emerging valuable tool for Vocational Educational Training (VET) as it is used to create digital replicas of physical assets and processes that are monitored and analysed in real-time.

The statements are, with few exceptions, very technological. The human factor is considered mainly regarding training. They lack consideration of design and engineering, as well as inclusion, such as facilitating disabled workers.

Tomorrow's industry must respond to technological challenges, but above all to **environmental and social challenges**. Companies must be concerned about the meaning of their mission and their impact.

Some of the challenges are already implemented in some areas of our industry, but the gap between companies that realise the importance of digitalisation, green production and sustainability and the ones that do not is quite wide and is getting even wider. Education needs to play a role in closing the gap.

The industry must take into account notions of sovereignty and protect itself against geopolitical risks, which can endanger individual companies as well as the economy in the broadest sense (problems of supply of materials, components and energy, with an explosion in lead times and associated costs).

Ultimately, we need to anticipate changes in our business models and rethink them. Tomorrow's industry will either be circular/sustainable, or it won't be. We need to get away from the pattern of exploiting resources to produce waste.

Companies require soft skills from their people: communication, positive behaviour, improvement, self-training ability, and project management. Agile project management must become the rule for projects dealing with uncertainty, commonly used in digital projects.

Many of the above-mentioned topics are already included in European educational programmes. At the moment, the knowledge and competences are included in different subjects and need more structured and integrated approaches.

The main challenge remains how to include these topics in the new curricula, at different educational levels, with a specific scope of competences at each level. In most cases the need for new competences is already recognised although not in a very formal manner.

The effort to create meaningful material and scenarios for learning should not be underestimated. If learners are not picked up correctly, the most magnificent learning environment might only confuse them. The "second" effort one should not forget about, is the effort to guide and mentor the learners. Learners are individual and gain more from an individual learning experience, rather than predefined paths. They need to be able to leave the trail for the moment and sometimes, to be motivated to do so, trainers must challenge them, or even push them a little bit off the track. This requires a lot of competencies on the side of the trainers.Maybe AI/LLM might play a major role in the near future to adapt the learning experience for the learners and support the learning process, without replacing a competent trainer.

Regarding the statements below, they are ordered numerically, but if we would order them by significance, the order would be as follows:

1. Statement 1
2. Statement 2
3. Statement 3
4. Statement 13
5. Statement 9
6. Statement 12
7. Statement 4
8. Statement 5
9. Statement 6
10. Statement 8
11. Statement 14
12. Statement 11
13. Statement 16
14. Statement 7
15. Statement 10
16. Statement 15

3.23.2 Statement 1

Megatrends in Advanced Manufacturing: «Industry 5.0 paradigm is emerging in Europe towards a more human-centric, resilient and sustainable industry. Transformations are not technology-driven but simultaneously technology and human-centric.»

In terms of these challenges, we have to consider the definition of I5.0 aspects, including the I5.0 skills:

- Human-centric skills, resilience skills and sustainability skills?
- What does it mean to move from I4.0 to I5.0?
- How should we update skills frameworks to I5.0?
- How should we update training programs to I5.0?

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
1	Mega Trends in Advanced Manufacturing	2,2	45	2,5	19	2,1	14	2,1	12	2,6	7	2,3	9	2,6	5	1,6	8	2,5	8	2,0	1	2,0	7

Comments on statement 1

Turning I4.0 into I5.0 is confusing customers. Addressing I4.0 and I5.0 has mainly a commercial purpose. It's more about a different interpretation of I4.0. We can see I5.0 as the result of I4.0 as it is or will be, with an added people-centric approach. Industry 5.0 seeks to harness digitization by placing the individual at the centre of industrial activity. We can see that they are using the term I5.0 but that does not always mean a big change (not a revolution). Moreover, in the case of some SMEs, they are still at I3.0.

If changing from 4.0 to 5.0 is not an accepted strep, the concept through it means realizing the real basis of a smart factory and placing Humans at the centre of the factory and technology supporting human activity. It will be necessary to create a framework in which the human is the element that brings added value, and technology must become even more ergonomic and efficient.

People and community awareness are key factors. Marketing this major change inside society will be essential.

I5.0 means to come back at the human aspect of Industry 4.0: the main problem in dealing with the difficulties posed by faster, more efficient and personalized production is not about technology, but about us, people. Legal frameworks, or even constitutions have to be adapted to changing dynamics of technology, economy and society. There's always room for improvement and always the necessity to carry out work; job creation must not be left to the invisible hand of the market, but rather to the wise hand of system designers.

Needed analysis should be carried out with a realistic, planned and professional understanding, and the technological needs determined in line with the results of the analysis should be met with strategic business plans prepared in a professional manner.

The exponential increase in connectivity between people, machines and data is a crucial issue for the competitiveness of businesses and will help them to adapt to change. This notion of 'man/machine' collaboration will help to develop a collaborative culture based on innovation, agility and speed. These elements will need to be integrated into training courses.

Update of management rules to give more responsibility and autonomy, a necessary condition for global performance and full implementation of technologies.

As this change brings new directions and skill requirements, updating skill frameworks becomes necessary. Existing frameworks may need to be expanded or modified to include the people-centred, resilience and sustainability capabilities associated with Industry 5.0. This requires collaboration with industry experts, academia and relevant stakeholders to determine the specific skills and competencies needed for the future workforce.

The cooperation between teachers and engineers from companies in the preparation and implementation of training programs for the respective field is particularly important for an effective transition and adequate training.

A focus on human creativity would be a good thing, with also Human-centred skills, such as ethics and responsibility, since the use of artificial intelligence and the automation of the production process will raise ethical and responsibility issues that must guarantee the proper use of them.

Transversal digital capabilities are highly important, while digital specialization is reserved for specific niches. Skills such as teamwork, problem-solving, and communication, which have been developed thus far, will become increasingly important, alongside concepts such as ‘changing environments' and 'complex problems'.

The advent of AI represents a disruptive change in many aspects. The skills to be developed and the associated competencies will undergo transformation. It is important to analyse its influence on advanced manufacturing and the future competencies required to operate in the new 'intelligent' systems.

The new working model that will emerge with an automated working environment in human-machine (robot) cooperation will require very advanced skills that many people cannot learn; that income inequality could turn into a worldwide crisis; In addition, existing internet security techniques will be insufficient, and this will bring the necessity of international regulations and management to adapt to this rapid change.

We need to upskill existing human forces and prepare our organisations to become more attractive and have a special space for newcomers with new skills. We must leave space for new ways of doing things and to integrate new skills which have also to be promoted.

It is necessary to develop a systemic approach to industrial transformation. As a consequence, it should be necessary to develop the competences for architects of the transformations.

Resilience skills are especially important. Technologies and systems change constantly, and users continually must adapt their skills.

To this end, personal, social, environmental and sustainability skills must play a key role, and it is schools and vocational training centres that can help the business sector and the administration lead this structural change. One could add that future industrial systems more than ever need to utilize existing ones and seek more synergies with their context, e.g. along the life cycle of the product with other industries/sectors and/or their neighbouring environment (like in a city).

3.23.3 Statement 2

Trends in Advanced Manufacturing and Insights for VET «The Advanced Manufacturing sector is facing a green transition, including energy efficiency, energy neutrality and ecological emphasis. Green skills and circular economy concepts must be included in all the training programmes. Therefore, Green skills need to be defined. »

This challenge brings to mind:

- Definition of Green skills
- Inclusion of Green skills in current training programmes
- Energy efficiency, energy saving, reuse
- Circular economy skills

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
2	Trends in Advanced Manufacturing and Insights for VET	2,6	44	2,5	19	2,8	13	2,6	12	2,7	7	2,9	9	2,8	5	2,1	7	2,8	8	3,0	1	2,3	7

Comments on statement 2

The Global Warning requires a global societal change, an everyday and short-term action plan. Training programs are needed urgently for quick action to include Green skills.

We understand that the sustainability of the planet depends on the sustainability of its activities. Manufacturing activities need to conduct a thorough analysis with the aim of being sustainable themselves and contributing to the sustainability of other activities.

The analysis should start by considering how advanced manufacturing will be influenced by the challenge of sustainability. What will be demanded from a sustainable perspective in terms of materials, manufacturing processes, end products, …

Ecology begins and ends with real values that the individual defends and also puts into practice. Personal maturity, honesty, consistency, willingness to give up oneself at the expense of others, respect for fellow human beings and natural resources in such a way, that we do what is right and not what might suit us at the moment due to a sense of comfort. Ecology is also from this point of view, a natural and logical process, if it is based on the stated foundation. Otherwise, it can only become a convenient tool used for abuse for the realization of narrow interests that do not guarantee real sustainability. Therefore, the integration of green skills into educational content must be designed to solve the real and most pressing challenges of the local and regional environment.

Digitalization and sustainability: These two megatrends are the current view. Green skills are involved in the second one but affect the first one. CO_2 emissions will be a competitive tool for the industry. Apart from energy saving in terms of money, efficiency, etc., we expect regulations by law that will enforce to make our production centres greener. We can see a priority for existing facilities to become more efficient and to ask for more efficient facilities in case of investment. Training centres need to be adapted to this new reality.

From the perspective of vocational training (VET), we must define ecological competencies. Some will be cross-cutting, while others will be specific to each program. An analysis should be conducted based on the requirements or changes that will occur in Advanced Manufacturing and differentiate within the VET environment which programs it would correspond to and at what stage of development the competency development should take place in each related program cycle.

Updating and incorporating green skills into existing training programs is essential to equip the workforce with the necessary knowledge and skills. This may include integrating modules or courses that specifically focus on sustainable practices, energy efficiency, circular economy principles and other related topics. Collaborating with experts in sustainability and incorporating industry best practices can help ensure that training programs are aligned with the latest requirements and developments. To add a more generic concept of Company Viability: its ability to stay alive and profitable for a long time. I would as well enlarge the concept of Energy efficiency to Resource Efficiency.

To sum up, green skills are an absolute must for all students who will become academicians and professionals of the future, for all subject matters, and it should encompass a holistic body of knowledge that covers.

3.23.4 Statement 3

Trends in Advanced Manufacturing and Insights for VET «A culture for lifelong learning is not developed enough among students and workers. VET centres and companies must place mechanisms towards strengthening Lifelong Learning pathways.»

What this challenge means:

- Defining the skills for lifelong learning
- Identifying effective methods for upskilling
- Enhancing motivation for lifelong learning among learners
- Fostering the use of Collaborative learning Factories (CLF) to Enhance lifelong learning activities

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
3	Trends in Advanced Manufacturing and Insights for VET	2,2	45	2,4	19	2,2	14	2,0	12	2,7	7	2,1	9	2,4	5	2,5	8	2,0	8	1,0	1	2,0	7

Comments on Statement 3

Lifelong learning is a process that requires target-specific planning, investment, patience and time with professional adult education experts.

This challenge includes not only VET/HVET but also the companies which need to identify competencies which will support and enhance their future operations. The lifelong learning chain consists of three main partners: the company, the individual being trained, and the training centre. Additionally, this chain can be lubricated with the assistance of administration.

The importance of collaboration within training programs, but also between training organizations, to meet the challenges ahead. The basic skills of process analysis, problem-solving with people from different knowledge backgrounds, and defining a common set of goals becomes more important than absolute detailed knowledge. Identify methods and tools for measuring the up-/re-skilling. Favouring and incentivising the formalisation of tacit knowledge among generations.

The definition of these skills on the other hand shall be led by experts and co-developed by society. Infrastructure doesn't need to be factories; they can also be laboratories, venues for experimentation, culture houses and similar.

Flexibility and availability of vocational training, along with a dose of innovation in methodologies and curriculum design, are essential.

People are not already aware of the necessity of lifelong learning. The main problems are accessibility and the costs of upskilling measures. It is not sufficient to motivate learners but there has also to be a change in business culture to allow room for lifelong learning.

3.23.5 Statement 4

Review of EU projects: «The EU's investment in research and innovation programmes, emphasizes the need for digital skills of students and workers as well as the adoption of new technologies to adapt to the changes brought by Industry 4.0»

What these challenges mean:

- Proposing/adopting a skill Framework for digital manufacturing
- Updating advanced manufacturing curriculums with digital skills
- Enhancing digital literacy of the workforce.

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
4	Review of EU Projects	2,7	43	2,6	18	2,6	14	2,7	11	3,0	6	2,4	8	2,8	5	2,9	8	2,9	8	1,0	1	2,3	7

Comments on Statement 4

We are not digital yet. but we need to be. The level of digital literacy is developing very rapidly. But the most important factor that provides this development is the technological innovations that are rapidly applied in social life. People have to keep up with these developments in their lives.

It is important to separate the learning pathways of students from workers. Different methods, different tools, and different ways to assess the results: the adoption of digital skills will be different in time and form for students or the workforce.

Every company needs to have internal capabilities for building a digital framework and improving it continuously.

From the vocational training perspective, there should be greater flexibility in modifying curricula. Specifically, in the realm of digitalization, a reflection should be made for each cycle and module on the level of digitalization required by the industry (both currently and in the future), contrasting it with what is currently provided through the existing curriculum. Once the analysis is conducted, the desired scenario can be defined, and modifications to the learning paths can be proposed.

First of all, activities should be planned to raise awareness. It is also important to consider the training of teaching staff and the associated resource needs.

Gamification of training sessions allows the workforce to experiment with digital tools; provide hands-on digital training sessions; include augmented and mixed-reality training scenarios.

Another major trend that must be taken into account is the rise of distance learning, according to which we must recreate our curriculums. More videos, even maybe with VR-AR functionality shall be embedded into everyday learning and +Adaptive learning for Artificial Intelligence in the daily life of manufacturing. This may include the use of design software, automation systems, data analytics tools and other digital tools. Curriculums should be updated based on industry standards and industry needs.

To add: a focus on projects dealing with inclusion.

3.23.6 Statement 5

Learning analytics: «Learning analytics is the opportunity to identify potential gaps in an organization's skill set and to develop training programmes to address those gaps. Additionally, analytics provide valuable data to help companies assess the effectiveness of their training programs and make necessary adjustments. It is rarely used in Vocational Education and Training (VET) centres. »

What these challenges mean:

- Raising the understanding of the benefits of learning analytics in companies and education to improve the skills provision
- Capacity building for VET centres in learning analytics
- Improving interoperability between Learning analytic systems

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
5	Learning Analytics	2,1	40	2,0	18	1,8	12	2,5	10	1,3	3	2,1	9	2,2	5	2,3	7	1,9	8	1,0	1	2,4	7

Comments on Statement 5

Learning Analytics is still in its infancy. This is going to drive any learning pathway. Learning analytics enable the content of a training course to be constantly improved. They are an excellent source of information about how training is progressing, and provide an objective basis on which to build. But, especially in Europe, the guidelines concerning data protection are very strict. Using learning analytics also means understanding how this can be done in legal ways. This is also important regarding the acceptance by users.

Learning analytics can provide us with valuable information about training processes, allowing us to improve them. It uses data mining techniques to examine patterns, among others. The training of Vocational Training centres can provide 'local' information, which can be enhanced by adding information through networks of Vocational Training centres that share data. Learning analytics can be an additional service that complements the definition and development of company training plans.

To add: Potential mistakes and/or shortcuts in estimating gaps in skill sets, mostly due to using technology for the sake of it, not geared for solving a major problem.

Analytics and analytical thinking are essential in correct decision-making in all walks of life; surely true also for learning. For the correct estimation of skill-set gaps, the right KPIs and standards for measurement have to be put in place. VET centres can lead the way to train both the workforce and decision-makers who will be in charge of learning analytics.

As long as the learning analytics in vocational education is created in accordance with the investment and production targets and commercial strategies of the companies, results will be obtained in a short time with professional coordination and corporate communication.

Learning analytics helps companies and educational institutions make their learning processes more effective and efficient. However, to fully realize this potential, it is important to create greater awareness among companies and educational institutions about the benefits of learning analytics. This can be done by sharing examples and case studies, highlighting how learning analytics can be used and the value it provides.

Learning analytics may encounter resistance from some companies. Large companies surely have implemented it or will do, while SMEs struggle to find skilled workers at all. On the one hand, there will be a low willingness to have internal skills analysed by someone externally and on the other hand there will be difficulty in understanding the potential of these analyses by companies.

We need a system like the ISO 9001, not for quality, but for learning quality on all levels.

3.23.7 Statement 6

Sensoring of manufacturing processes: «A global deployment of 5G technology, eliminates the need for distributed edge computing, enabling lower costs for data mining and management on servers in the cloud. 5G enables better communication and supports the maturity levels in digital transitions of companies. »

What these challenges mean:

- Integrating 5G industrial application in an educational environment to learn/research the technology
- Creating training/programmes on 5G

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
6	Sensoring of Manufacturing Processes	2,1	39	2,1	16	1,8	13	2,4	10	2,2	6	1,9	7	1,0	3	2,4	7	2,6	8	2,0	1	1,7	7

Comments on Statement 6

No special comments.

3.23.8 Statement 7

Data collection, analysis of data: «The application of Artificial Intelligence (AI) techniques in manufacturing has made it possible to formalise complex multivariate knowledge of machine and process conditions. These tools enhance the work of the operator, which also increases his value as a technician. The massive generation of data through the Internet of Things (IoT) is giving AI a huge boost in the industrial sector.»

What these challenges mean:

- Defining the competences/skills of AI-supported technicians
- Defining the job transitions driven by the integration of AI into manufacturing
- Fostering the use of Collaborative Learning Factories (CLF) to enhance AI applications and their relationship to data analysis

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
7	Data Collection, Analysis of Data	2,4	41	2,3	18	2,8	12	2,3	11	2,5	6	2,6	8	2,0	4	1,9	7	2,8	8	3,0	1	2,4	7

Comments on Statement 7

The application of AI in manufacturing is revolutionizing the way machines and industrial processes are managed. These tools have enabled the formalization and utilization of complex knowledge about machine conditions and manufacturing processes.

But, AI is not correct, nor adapted. In main applications, we use processes of data science such as data crunching, data mining ... We cannot speak only about AI which can afraid people.

Ethical concepts behind some AI applications could be a field which students could think about as a way to encourage the development of soft or transversal skills. AI acceptance is still in progress in society. So, Experts are and will be required for the modelling and design of rules for AI before spreading in every process. It is necessary to be aware of the ethical and moral aspects of using AI.

To note: Data Science is most important and urgent. AI will follow

Collaborative learning factory (CLF) is a sort of experimental production line, whereby developments can be tested against results. AI applications are notoriously hard to predict, thus CLF is essential for practical real-world success.

3.23.9 Statement 8

Metal forming and other technologies: «The resource efficiency in terms of material saving and reduction of wastes make metal forming processes an attractive alternative to produce complex parts. Furthermore, the improvement of quality and efficiency due to digitalization increases its opportunities. »

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
8	Metal Forming	2,5	35	2,6	14	2,4	12	2,7	9	2,8	6	2,8	6	3,5	2	2,4	7	2,4	7	1,0	1	2,2	6

Comments on Statement 8

Important sectors such as automotive and aerospace are increasingly committed to sustainability, which results in stricter requirements downstream in the production processes of their components made through forming. These requirements will impact materials, component design, and processes.

Additionally, we must not overlook other manufacturing processes such as additive manufacturing, which serves as a great ally for producing components for forming parts. Molds, models, prototypes, and tools will increasingly be produced using this type of process, which, while not matching the production rate of forming, can provide additional agility and flexibility. Therefore, I believe that these auxiliary technologies should be considered a challenge for the industry.

To work on a digitalisation standard that allows the exchange of information between the different mechanical manufacturing workshops and between the technicians working in different companies."

In addition to the change in the work processes and in the skills/competences of the technicians, it will also be necessary to define the necessary changes in the current manufacturing means vs. the new ones.

Incentives and investments support regulations that require revision to motivate the reduction of waste and the reuse of metals. Experience of traditional workshops adds more value than digital training.

3.23.10 Statement 9

Cybersecurity: «Cybersecurity is strategic for SMEs as a result of the in-depth digital connectivity of all the value chains. »

What these challenges mean:

- Integration of cybersecurity skills in all the training programmes

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
9	Cybersecurity	2,7	42	2,8	18	2,6	13	2,5	11	2,9	7	2,8	8	2,8	4	3,0	7	2,9	8	0,0	1	2,0	7

Comments on Statement 9

it would be useful to define training programmes adapted to students and the workforce respectively.

Cyber security is a crucial issue for companies of all sizes; SMEs being especially susceptible to loss of product, quality and brand value. This subject has to be a priority at all times, from the start, and has to be taken into account at all stages of AI and IoT-based process flows.

Cybersecurity should be a transversal skill in manufacturing processes. Students should be aware of the risk of connected systems and machines. It is a major/cultural topic, like machine safety from a hardware point of view.

The main objective is to create awareness that certain security measures are there for reasons and should not be omitted in favour of laziness.

3.23.11 Statement 10

Assisted jobs (robotics): «Collaborative robots (cobots) and autonomous mobile robots (AMR) have already changed the way humans and machines work together, but the use of Cyber Physical Systems (CPS) will take this to a new level. Increased interaction between the worker and the technological environment enhances safety by reducing risk and preventing accidents. »

About these challenges, we have in mind:

- Develop skills on Cobots and AMR
- Pilot practical implementation of cobots and AMRs in Vocational Education and Training (VET) labs
- Foster the use of Collaborative Learning Factories (CLF) to enhance the use of Cobots and AMRs

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
10	Assisted Jobs (Robotics)	2,3	41	2,5	18	2,2	14	1,9	9	2,6	7	2,0	6	2,4	5	2,1	7	2,2	8	2,0	1	2,3	6

Comments on Statement 10

No special comments

3.23.12 Statement 11

3D metal printing / Selective laser sintering: «Metal additive manufacturing, concretely Selective Laser Sintering (SLS) is a growing and developing technology that requires specific skills and knowledge to design parts and operate the equipment. The shift to automated manufacturing processes such as SLS requires retraining of existing staff in order to remain employable. »

What these challenges mean:

- Defining specific skills and knowledge for Vocational Education and Training (VET)
- Creating curricula for (Metal) Additive manufacturing competences
- Linking to existing initiatives in metal additive manufacturing

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
11	Selective Laser Sintering / 3D Metal Printing	2,5	35	2,7	15	2,7	10	2,0	10	2,7	6	2,8	5	2,3	3	2,4	7	2,4	7	1,0	1	2,7	6

Comments on Statement 11

Too narrow scope: SLS is not the only one process in additive manufacturing way. We should be aware not to reduce the spectrum of possible processes. The development of additive manufacturing needs also to thing and redefine the value chains and economic models.

Additive manufacturing (AM) as a whole, not only SLS but also other techniques, are fast becoming mature technologies that companies are getting comfortable with using. It is especially useful for fast-cycle product development, eliminating time-consuming and costly prototypes. Another major use-case for Advanced Manufacturing is the manufacturing of jigs & fixtures which are expensive and with traditional metal forming techniques. Sectors like automotive, plastic injection and other types of discrete manufacturing are the main beneficiaries.

To add: Design for Additive. Meaning that only a complete change of paradigm on how objects are conceptualized with additive in mind could foster the growth of additive.

3.23.13 Statement 12

Reverse engineering: «3D scanning is a core element in reverse engineering and requires specific equipment and software, through different solutions, and more affordable options to Vocational Education and Training (VET) Centers which are incorporating these training programmes into their courses. This will require more collaboration between trainers and industry in order to maintain currency in training processes and equipment. »

What these challenges mean:

- Finding financial resources to use 3D scanning systems in education

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
12	Reverse Engineering	2,6	39	2,6	16	2,8	13	2,5	10	2,7	6	2,8	8	2,7	3	2,9	8	2,9	7	2,0	1	2,0	6

Comments on Statement 12

3D scanning is not just for reverse engineering which is too narrow in scope: reverse engineering is one the numerous use of 2D/3D scanning combined with image processing. As far as we can observe, besides the high upfront cost of hardware, the value of reverse engineering has not been fully appreciated yet in the industry. Spare parts management can be greatly hastened and enhanced with quick dimensional analysis. This will bring much value to sectors like process industries where downtime costs a lot and maintenance teams have to keep everything up and running with spare parts ready and in good shape. Other beneficiaries will be product designers who still prefer working with real-life models over CAD models.

To find financial resource is not sufficient for reverse engineering. Learners should know about problem solving, lateral thinking, meta cognitive skills etc., to understand what they are facing off.

3.23.14 Statement 13

Ergonomics: «By incorporating ergonomic principles and digital technologies into vocational education, students learn to thrive in a rapidly changing manufacturing landscape. This includes training in ergonomics, human factors and digital technologies, as well as hands-on experience with digital workstations and equipment. »

What this challenge means:

- Setting-up digital workstations in VET labs
- Defining the skills and competences and their assessment methods for the field

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
13	Ergonomics	2,9	43	3,2	17	2,6	14	2,7	12	2,9	7	3,2	9	3,0	5	2,8	8	2,7	7	2,0	1	2,7	5

Comments on Statement 13

Ergonomics is crucial in all sectors that design products, therefore technicians and engineers shall be well-equipped in this respect and embed ergonomics principles into product design.

We are still not holistic enough in ergonomics. Health for older people, and younger persons with specific needs will grow rapidly. We have not enough awareness about that. We should be able to live longer, but we do a few by ergonomy.

Companies should implement more awareness programs about human-oriented work. This issue should be addressed in workplace design.

Laboratories that offer real-world experience to students using digital technologies should be created. These labs allow students to gain practical experience by enabling the application of skills and abilities related to ergonomics and digital workstations.

The challenge now is to incorporate human-machine interfaces, human related competences in order to facilitate to work in a collaborative/better way.

To add in training programmes: create non-ergonomic and ergonomic situations to make the benefits learn through experience.

This item will also help to deconstruct certain representations of manufacturing trades and can help to attract women to join the industry.

3.23.15 Statement 14

Predictive Maintenance: «The creation phase of predictive models, which is fully automated in many cases encourages companies to engage in predictive maintenance. »

What these challenges mean:

- Training programs on AI-driven predictive maintenance
- Integrating AI-driven predictive maintenance systems in Vocational Education and Training (VET) labs

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
14	Predictive Maintenance	2,6	43	2,7	18	2,5	14	2,5	11	2,7	7	2,8	8	2,2	5	2,6	7	2,6	8	3,0	1	2,4	7

Comments on Statement 14

No special comments

3.23.16 Statement 15

Virtual Reality/Artificial Reality/Mixed Reality: «Collaborative immersive virtual environments are a safe and useful tool for training on complex or risky processes and establishing useful digital twins in advanced manufacturing. In addition, new solutions simplify the process of creating teaching materials, giving teachers and trainers a leading role»

What these challenges mean:

- Integrating Virtual Reality/Artificial Reality/Mixed Reality in Vocational Education and Training (VET) labs for advanced manufacturing processes

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
15	Virtual Reality / Artificial Reality / Mixed Reality	2,3	43	2,4	19	2,3	14	2,2	10	2,9	7	1,6	8	2,8	5	2,3	7	2,4	8	2,0	1	2,1	7

Comments on Statement 15

No special comments

3.23.17 Statement 16

Digital Twin: «Digital twin (DT) technology is an emerging valuable tool for Vocational Educational Training (VET) as it is used to create digital replicas of physical assets and processes that are monitored and analysed in real time.»

What these challenges mean:

- Promoting methods to implement DT in VET labs
- Scaling-up the implementation of Digital twins in VET labs
- Finding financial resources to us DT solutions in VET

		45		19		14		12		7		9		5		8		8		1		7	
		Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
16	Digital Twin	2,5	43	2,5	19	2,6	13	2,5	11	2,3	6	2,6	9	2,8	5	2,4	7	2,9	8	3,0	1	2,0	7

Comments on Statement 16

Particularly important subject. Especially the definition. Digital Twin is more than a 3D representation of reality. Quite often it is well prepared data to better analyze the processes.

Digital twins are a very suitable support for both managing an active process, as they assist in continuous supervision and monitoring, and for the development of a new project, as they help simulate all the interactions and variables involved.

Digital twin is a good solution that we use in the incorrect way. It should be integrated in the design process. This means, to use digital twin tools to design and simulate the product before making it real. However, we use it as a simulator, as a substitute for the real product. We design the digital twin after we validate the physical part. This is what we understand should be changed. Any case, digital twins are a simplified version of the reality. It is a good complement but still, for the VET environment, will be needed the real part of the machine-system-process. Those how use digital twins as low-cost substitutes of real models are missing many interactions. This applies to Learning Factories.

This spectrum of utilities implies that different actors will interact with digital twins. For example:

- Production programmers will need to work with defined systems and propose solutions for different scenarios.

- Maintenance managers will need to monitor the status of production equipment.
- Mechanical designers will need to collaborate with automation specialists to develop new solutions under these systems for testing before installation.

Financial resources are essential for implementing digital twins in VET laboratories. The hardware and software requirements of this technology should be financed and laboratories should be provided with adequate resources. This enables digital twin solutions to reach a wider audience and allow more students to learn about this technology. Consequently, the implementation of digital twins in VET laboratories enables students to gain practical experience and simulate real-world scenarios. This helps students develop their skills and develop into a better workforce. However, it is important to provide adequate financial resources for this purpose.

4 CONCLUSION

4.1.1 Overview

This first report on the LCAMP Observatory is based on the analysis of several topics on advanced manufacturing. It focuses on the first of the four main pillars of the Observatory: (1) Technology trends in advanced manufacturing. The upcoming reports will cover (2) The impact of technology on industry, (3) Existing qualifications and educational offers, and (4) Employability, including the most in-demand jobs and skills. To dedicate enough time and focus to each topic, we decided to divide the reports into four separate releases.

4.1.2 Report

The report has been created by 16 writers from the LCAMP consortium coming from seven different countries. The topics covered:

- Topic 1.1 Mega trends in Advanced Manufacturing
- Topic 1.2 Classification, mapping of EU projects
- Topic 1.3 Trends in industry about digitalization, (green & digital)
- Topic 1.4 Digitization of manufacturing processes
- Topic 1.5 Robotics
- Topic 1.6 Additive Manufacturing
- Topic 1.7 Digital Factory

The analysis covers a technology-driven approach: a descriptive part followed by an analysis of the presence of technology trends within VET study programs. The impact of technologies on jobs and skills is partially covered, although a more thorough analysis will be undertaken in the next reporting period.

4.1.3 Findings

We are providing short 'Future Trends' statements for each of the topics. We selected sixteen 'Future Trends' statements for further analysis. For each 'Future Trend', the LCAMP consortium identified potential impacts, including challenges it might pose. In the table below, we are presenting the statements on 'Future Trends' and their corresponding challenges.

No	Statements related to the analysed research topics	Challenges linked to the statements
1	Industry 5.0 paradigm is emerging in Europe towards a more human-centric, resilient and sustainable industry. Transformations are not technology-driven but simultaneously technology and human-centric	• Definition of I5.0 aspects, including the i5.0 skills: Human-centric skills, resilience skills and sustainability skills • What does it mean to move from I4.o to I5.0? • How should we update skills frameworks to i5.0? • How should we update training programmes to i5.0?
2	The Advanced Manufacturing sector is facing a green transition, including energy efficiency, energy neutrality and ecological emphasis. Green skills and circular economy concepts must be included in all the training programmes. Therefore, Green skills need to be defined	• Definition of Green skills. • Inclusion of Green skills in current training programmes • Energy efficiency, energy saving, reuse. • Circular economy skills.
3	A culture for lifelong learning is not developed enough among students and workers. VET centres and companies must place mechanisms towards strengthening Life Long Learning pathways.	• Define the skills for lifelong learning Identify effective methods for upskilling. • Enhance motivation for lifelong learning among learners. • Foster the use of Collaborative Learning Factories (CLF) to enhance lifelong learning activities.
5	Learning analytics is the opportunity to identify potential gaps in an organization's skill set and to develop training programmes to address those gaps. Additionally, analytics provide valuable data to help companies assess the effectiveness of their training programs and make necessary adjustments. It is rarely used in VET centres.	• Raise the understanding of the benefits of learning analytics in companies and education to improve the skills provision. • Capacity building for VET centres in learning analytics • Improve interoperability between Learning analytic systems.
6	A global deployment of 5G technology, eliminates the need for distributed edge computing, enabling lower costs for data mining and management on servers in the cloud. 5G enables better communication and supports the maturity levels in digital transitions of companies.	• Integrate 5G industrial applications in an educational environment to learn/research the technology. • Create training/programmes on 5G.
7	The application of Artificial Intelligence (AI) techniques in manufacturing has made it possible to formalise complex multivariate knowledge of machine and process	• Define the competences/skills of AI-supported technicians. • Define the job transitions driven by the integration of AI into manufacturing.

No	Statements related to the analysed research topics	Challenges linked to the statements
	conditions. These tools enhance the work of the operator, which also increases his value as a technician. The massive generation of data through IoT is giving AI a huge boost in the industrial sector.	• Foster the use of Collaborative Learning Factories (CLF) to enhance AI applications.
8	The resource efficiency in terms of material saving and reduction of wastes make metal forming processes an attractive alternative to produce complex parts. Furthermore, the improvement of quality and efficiency due to digitalization increases its opportunities.	• Define job transitions in metal forming processes due to the digitalization. • Define the new competences/skills for technicians in metal forming.
9	Cybersecurity is strategic for SMEs as a result of the in-depth digital connectivity of all the value chains.	• Integration of cybersecurity skills in all the training programmes.
10	Collaborative robots (cobots) and autonomous mobile robots (AMR) have already changed the way humans and machines work together, but the use of Cyber Physical Systems (CPS) will take this to a new level. Increased interaction between the worker and the technological environment enhance safety by reducing risk and preventing accidents	• Develop skills on Cobots and AMR. • Pilot practical implementation of cobots and AMRs in VET labs. • Foster the use of Collaborative Learning Factories (CLF) to enhance the use of Cobots and AMRs.
11	Metal additive manufacturing, concretely Selective Laser Sintering (SLS) is a growing and developing technology that requires specific skills and knowledge to design parts and operate equipment. The shift to automated manufacturing processes such as SLS requires retraining of existing staff in order to remain employable.	• Define specific skills and knowledge for VET. • Create curricula for (Metal) Additive manufacturing competences. • Link to existing initiatives in metal additive manufacturing.
12	3D scanning is a core element in reverse engineering and requires specific equipment and software, through different solutions, and more affordable options to VET Centers which are incorporating these training programmes into their courses. This will require more collaboration between trainers and industry in order to maintain currency in training processes and equipment.	• Find financial resources to use 3d scanning systems in education.

No	Statements related to the analysed research topics	Challenges linked to the statements
13	By incorporating ergonomic principles and digital technologies into vocational education, students learn to thrive in a rapidly changing manufacturing landscape. This includes training in ergonomics, human factors and digital technologies, as well as hands-on experience with digital workstations and equipment.	• Set up digital workstations in VET labs. • Define the skills and competences and their assessment methods for the field.
14	The creation phase of predictive models, which is fully automated in many cases encourages companies to engage in predictive maintenance.	• Training programs on AI-driven predictive maintenance. • Integrate AI-driven predictive maintenance systems in VET labs.
15	Collaborative immersive virtual environments are a safe and useful tool for training on complex or risky processes and establishing useful digital twins in advanced manufacturing. In addition, new solutions simplify the process of creating teaching materials, giving teachers and trainers a leading role.	• Integrate Virtual Reality/Artificial Reality/Mixed Reality in VET labs for advanced manufacturing processes.
16	Digital twin (DT) technology is an emerging valuable tool for Vocational Educational Training (VET) as it is used to create digital replicas of physical assets and processes that are monitored and analysed in real time.	• Promote methods to implement DT in VET labs. • Scale up the implementation of Digital twins in VET labs. • Find financial resources to us DT solutions in VET.

Table 7: Statements extracted from the observation topics and challenges for LCAMP

Next to the statements, there are some remarkable findings from the main results we find worth sharing. We found that the twin-, digital- and green transitions have an impact on Advanced Manufacturing companies.

The requirement to digitalise production and organisational processes and the new normative framework to support the green transition are pushing companies to implement new technologies and are affecting the skills required for the job market. That includes skills for newly created jobs as well as existing jobs the task for which have been transformed. The twin transition is widening the gap between companies, with some of them leading the twin transition and others (mainly SMEs) facing challenges to adopting new technologies, adapting to the new regulations, and keeping up with the newly in-demand skills.

The main points from our observation:

- The demand for digital skills is increasing, for both general digital skills (to be able to operate in a digitalised environment but without being an expert) and specialised digital skills (like programming, developing applications, or managing and maintaining networks).
- The need for digital skills does not substitute occupation-specific skills and other soft skills.
- The challenges posed by the transitions make us propose two time-related strategies: a short-term strategy for successful transitioning (digitalised work environments, CO2 reduction, energy efficiency, etc.) and a long-term strategy, for which we will need to develop new paradigms. In the short term, if we want to meet the goals set by the European Commission, up- and re-skilling will be necessary. This will push VET systems' training to become shorter, more accessible, more flexible in terms of delivery, and more specific to the skill needs of workers. In this sense, micro-credentials are especially relevant, and here to stay.
- We need a cautious approach to the effects of the twin transition, especially digitalisation. The predictions range from job-disappearance and the substitution of human labour by machines, to the full opposite. The future scenarios range from extreme optimism to apocalyptic situations. It is difficult to predict any of the above with confidence.
- There is a need for common frameworks and definitions in many aspects. There is no common internationally agreed definition of a 'skill', of 'Industry 4.0', 'advanced manufacturing', or even 'digitalisation'. There is, therefore, no internationally agreed skills framework. A consequence of this vagueness is that we lack sound comparable data on skill needs internationally, the advancement of I4.0, and digitalisation.

4.1.4 Validation

A group of 45 experts formed by VET representatives (15), industry representatives (18), and policymakers (12) from 7 countries gave their insights by analysing a summary of 16 statements and their corresponding challenges provided by the LCAMP consortium. We summarised their thoughts and comments in the document included in this report.

Main Results of the evaluation by experts:

Although most of the experts agree with the given statements, they differ in estimating how long it will take for certain trends will become reality.

The experts believe that the impact of environmental and social challenges on Advanced Manufacturing should incentivise companies to consider their mission and its impact. Many challenges predicted by the LCAMP Consortium are already affecting some areas of the industry. There is a widening gap in how companies engage with and assess the importance of digitalisation, green production and sustainability. Educational projects closing this gap are needed.

Notions of sovereignty and protection from geopolitical risks can endanger individual companies as well as the European economy in the broadest sense (problems with the supply of materials, components and energy, etc.). They should be taken into account.

Ultimately, the experts agree that we should anticipate challenges to our business models and rethink them. Tomorrow's industry will either be circular/sustainable, or it won't survive. We need to move away from the pattern of exploiting resources to produce waste.

Companies require soft skills from their people: good communication, pro-social behaviour, self-driven improvement, self-training ability, and project management. Agile project management will become a necessity for projects dealing with uncertainty, a common aspect of digital projects.

Many of the key topics are already included in European educational programmes. At the moment, the knowledge and competencies are included in different subjects and need more structured and integrated approaches.

The main challenge remains how to include these topics in new curricula, at different educational levels, with a specific scope of competencies at each level. In most cases, the need for new competencies is already recognised, although not formally.

The effort to create meaningful material and scenarios for learning should not be underestimated. If learners are not engaged well, the most magnificent learning environment might only confuse them. Secondly, learners must be mentored well. Learners are individuals, and gain more from an individualised learning experience, rather than predefined paths. They need to be able to leave the beaten path for a moment, and to be motivated to do so mentors must encourage and challenge them. This requires a lot of competencies on the side of the mentors as well.

AI might soon play a major role in personalising the learning experience and offering support for the learning process, reducing some parts of the workload without replacing the mentor.

4.1.5 Next steps for WP3 Observatory

1. To continue to evaluate and validate the methodology and to optimize it for the Observatory.
2. To evaluate the Expert Group's contributions.
3. To include the remaining pillars inside the 2nd reporting period: 2) The impact of technology on industry, (3) Existing qualifications and educational offers, and (4) Employability, including the most in-demand jobs and skills, in collaboration with other LCAMP working groups.
4. To integrate the findings of this report into the LCAMP products, services, and the platform.

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8 ANNEXES

8.1 TECHNOLOGY TRENDS' FIELDS

Field 1. TECHNOLOGY TRENDS in ADVANCED MANUFACTURING	**Partner**
Topic 1.1 Mega trends in Advanced Manufacturing	
Topic 1.1.1 Mega trends in Advanced Manufacturing (Technologies)	Mecanic Vallée H Danton
Topic 1.1.2 Mega trends in Manufacturing and Insights for VET	TKNiKA JC Molinero
Topic 1.2 Classification, mapping of EU projects on industry 4.0 and classification of their outputs in relation with LCAMP thematic	AFIL E Ipek
Topic 1.3 Standards and TRENDS in industry about digitalization, (green & digital)	
Topic 1.3.1 Learning Analytics	KIC V Milosevic
Topic 1.3.2 Machining: Turning, Milling, High Speed Machining, Grinding)	
Topic 1.3.3 Metalforming (Stamping, Forging, Bending, etc.)	CMQE A Le Bras
Topic 1.3.4 Welding, Casting, Powder metallurgy	
Topic 1.3.5 Multiaxis machining processes, machines and tools	
Topic 1.4 Digitization of manufacturing processes Most used Technologies and applications	INVEMA L Solaberrieta
Topic 1.4.1 Sensoring of manufacturing processes	
Topic 1.4.2 Data collection, analysis of data	
Topic 1.4.3 Multitask and hybrid machines, flexible systems	
Topic 1.4.4 Automation of processes	
Topic 1.4.5 Additive manufacturing	
Topic 1.5 Robotics	
Topic 1.5.1 Industrial robotics	DHBW KD Rupp
Topic 1.5.2 Collaborative robotics	

Field 1. TECHNOLOGY TRENDS in ADVANCED MANUFACTURING	**Partner**
Topic 1.5. Service Robots	
Topic 1.5. Entertainment Robots	
Topic 1.5. Qualification for Robot Engineers	
Topic 1.5.3 Mobile robotics	TKNiKA L Burgoa
Topic 1.5.4 Mobile robots based on ROS technology	KPDoNE A Firat
Topic 1.6 Additive Manufacturing	
Topics 1.6.1 Generative design	
Topics 1.6.2 Topology optimization	Camosun M Handman, G Minto, R Burman, R Gale
Topics 1.6.3 3D metallic printing	CMQE, TKNiKA A Le Bras
Topics 1.6.4 Hybrid machines	
Topics 1.6.5 3D scanning	TKNiKA
Topics 1.6.5 Laser sintering	KIC V Milosevic
Topic 1.7 Digital Factory	
Topics 1.7.1 Flexible and intelligent machines and systems	
Topics 1.7.2 Digital workplaces, ergonomics	Simumatik M Ayani
Topics 1.7.3 Energy Efficiency / Carbon Footprint	Mecanic Vallée H Danton
Topics 1.7.4 Predictive Maintenance	Mecanic Vallée N Venet
Topics 1.7.5 Life Cycle/ Eco-desi gn/Carbon Footprint	Gebkim IOZ + Mecanic Vallée
Topics 1.7.6 Simulation of manufacturing processes	Simumatik / TKNiKA M Ayani
Topics 1.7.7 VR/AR/MR	Simumatik / TKNiKA I de Lamo Blas
Topics 1.7.8 Cyber security	Mecanic Vallée / TKNiKA

Field 1. TECHNOLOGY TRENDS in ADVANCED MANUFACTURING	**Partner**
	H Danton, JC Molinero
Topics 1.7.9 Digital twin	Simumatik / TKNiKA A Otaño

Field 2. IMPACT OF TECHNOLOGIES IN INDUSTRY (how technologies are impacting people/workers)	**Partner**
Topic 2.1 Impact of digital transition in Advanced Manufacturing. Most common job transitions	
T2.1.1 Automatization of processes	
T2.1.2 Digital workplaces (interactions with digital devices to carry out common tasks)	Linked with 1.7.2
T2.1.3 Assisted jobs (Safety-ergonomics related)	Mecanic Vallée N Venet
T2.1.4 Human robot integration	Linked with 1.5 robotics
Topic 2.2 Most demanded skills in advanced manufacturing, especially for workers in VET levels.	
Topic 2.3 Comparative analysis of Different skills frame works for advanced manufacturing	
Topic 2.4 Trends on training systems (in companies). LMX platforms, using VR/AR/MR	
Topic 2.5 Trends towards Industry 5.0 (human centric, resilience, sustainability)	
Topic 2.6 Cybersecurity Skills	Mecanic Vallée Linked with 1.7.3
Topic 2.7 Impact of remote working/teleworking applications in the organization	

8.2 STATEMENTS TABLE

				45		19		14		12		7		9		5		8		8		1		7	
				Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	Topic	Statement	Challenges	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
1	Mega trends in Advanced Manufacturing	Industry 5.0 paradigm is emerging in Europe towards a more human-centric, resilient and sustainable industry. Transformations are not technology-driven but simultaneously technology and human-centric.	Definition of I5.0 aspects, including the i5.0 skills: - Human-centric skills, resilience skills and sustainability skills - What does it mean to move from I4.o to I5.0? - How should we update skills frameworks to i5.0? - How should we update training programmes to i5.0?	2,2	45	2,5	19	2,1	14	2,1	12	2,6	7	2,3	9	2,6	5	1,6	8	2,5	8	2,0	1	2,0	7
2	Trends in Advanced Manufacturing and Insights for VET	The Advanced Manufacturing sector is facing a green transition, including energy efficiency, energy neutrality and ecological emphasis. Green skills and circular economy concepts must be included in all the training programmes. Therefore, Green skills need to be defined.	- Definition of Green skills - Inclusion of Green skills in current training programmes - Energy efficiency, energy saving, reuse - Circular economy skills	2,6	44	2,5	19	2,8	13	2,6	12	2,7	7	2,9	9	2,8	5	2,1	7	2,8	8	3,0	1	2,3	7

				45		19		14		12		7		9		5		8		8		1		7	
				Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	Topic	Statement	Challenges	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
3	Trends in Advanced Manufacturing and Insights for VET	A culture for lifelong learning is not developed enough among students and workers. VET centres and companies must place mechanisms towards strengthening Lifelong Learning pathways.	- Define the skills for lifelong learning - Identify effective methods for upskilling - Enhance motivation for lifelong learning among learners - Foster the use of Collaborative learning Factories (CLF) to Enhance lifelong learning activities	2,2	45	2,4	19	2,2	14	2,0	12	2,7	7	2,1	9	2,4	5	2,5	8	2,0	8	1,0	1	2,0	7
4	Review of EU projects	The EU's investment in research and innovation programmes, emphasizes the need for digital skills of students and workers as well as the adoption of new technologies to adapt to the changes brought by Industry 4.0	- Propose/adopt a skill Framework for digital manufacturing - Update advanced manufacturing curriculums with digital skills - Enhance digital literacy of the workforce	2,7	43	2,6	18	2,6	14	2,7	11	3,0	6	2,4	8	2,8	5	2,9	8	2,9	8	1,0	1	2,3	7

				45		19		14		12		7		9		5		8		8		1		7	
				Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	Topic	Statement	Challenges	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
5	Learning analytics	Learning analytics is the opportunity to identify potential gaps in an organization's skill set and to develop training programmes to address those gaps. Additionally, analytics provide valuable data to help companies assess the effectiveness of their training programs and make necessary adjustments. It is rarely used in Vocational Education and Training (VET) centres.	- Raise the understanding of the benefits of learning analytics in companies and education to improve the skills provision - Capacity building for VET centres in learning analytics - Improve interoperability between Learning analytic systems	2,1	40	2,0	18	1,8	12	2,5	10	1,3	3	2,1	9	2,2	5	2,3	7	1,9	8	1,0	1	2,4	7
6	Sensoring of manufacturing processes	A global deployment of 5G technology, eliminates the need for distributed edge computing, enabling lower costs for data mining and management on servers in the cloud. 5G enables better communication and supports the maturity levels in digital transitions of companies.	- Integrate 5G industrial application in an educational environment to learn/research the technology - Create training/programmes on 5G	2,1	39	2,1	16	1,8	13	2,4	10	2,2	6	1,9	7	1,0	3	2,4	7	2,6	8	2,0	1	1,7	7

				45		19		14		12		7		9		5		8		8		1		7	
				Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	Topic	Statement	Challenges	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
7	Data collection, analysis of data	The application of Artificial Intelligence (AI) techniques in manufacturing has made it possible to formalise complex multivariate knowledge of machine and process conditions. These tools enhance the work of the operator, which also increases his value as a technician. The massive generation of data through Internet of Things (IoT) is giving AI a huge boost in the industrial sector.	- Define the competences/skills of AI-supported technicians - Define the job transitions driven by the integration of AI into manufacturing - Foster the use of Collaborative Learning Factories (CLF) to enhance AI applications	2,4	41	2,3	18	2,8	12	2,3	11	2,5	6	2,6	8	2,0	4	1,9	7	2,8	8	3,0	1	2,4	7
8	Metal forming	The resource efficiency in terms of material saving and reduction of wastes make metal forming processes an attractive alternative to produce complex parts. Furthermore, the improvement of quality and efficiency due to digitalization increases its opportunities.	- Define job transitions in metal forming processes due to the digitalization - Define the new competences/skills for technicians in metal forming	2,5	35	2,6	14	2,4	12	2,7	9	2,8	6	2,8	6	3,5	2	2,4	7	2,4	7	1,0	1	2,2	6
9	Cybersecuri ty	Cybersecurity is strategic for SMEs as a result of the in-depth digital connectivity of all the value chains.	- Integration of cybersecurity skills in all the training programmes	2,7	42	2,8	18	2,6	13	2,5	11	2,9	7	2,9	8	2,8	4	3,0	7	2,9	8	0,0	1	2,0	7

				45		19		14		12		7		9		5		8		8		1		7	
				Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	**Topic**	**Statement**	**Challenges**	**Average**	**Nb Experts**	**Average**	**Nb Experts**	**Average**	**Nb Experts**	**Average**	**Nb Experts**	**Average**	**Nb Experts**	**Average**	**Nb Experts**	**Average**	**Nb Experts**	**Average**	**Nb Experts**	**Average**	**Nb Experts**	**Average**	**Nb Experts**	**Average**	**Nb Experts**
10	Assisted jobs (robotics)	Collaborative robots (cobots) and autonomous mobile robots (AMR) have already changed the way humans and machines work together, but the use of Cyber Physical Systems (CPS) will take this to a new level. Increased interaction between the worker and the technological environment enhance safety by reducing risk and preventing accidents.	- Develop skills on Cobots and AMR - Pilot practical implementation of cobots and AMRs in Vocational Education and Training (VET) labs - Foster the use of Collaborative Learning Factories (CLF) to enhance the use of Cobots and AMRs	2,3	41	2,5	18	2,2	14	1,9	9	2,6	7	2,0	6	2,4	5	2,1	7	2,2	8	2,0	1	2,3	7
11	Selective laser sintering / 3D metal printing	Metal additive manufacturing, concretely Selective Laser Sintering (SLS) is a growing and developing technology that requires specific skills and knowledge to design parts and operate equipment. The shift to automated manufacturing processes such as SLS requires retraining of existing staff in order to remain employable.	- Define specific skills and knowledge for Vocational Education and Training (VET) - Create curricula for (Metal) Additive manufacturing competences - Link to existing initiatives in metal additive manufacturing	2,5	35	2,7	15	2,7	10	2,0	10	2,7	6	2,8	5	2,3	3	2,4	7	2,4	7	1,0	1	2,7	6

				45		19		14		12		7		9		5		8		8		1		7	
				Global		Industry		Trainer		Official		France		Germany		Italia		Slovenia		Spain		Sweden		Turkey	
No	Topic	Statement	Challenges	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts	Average	Nb Experts
12	Reverse engineering	3D scanning is a core element in reverse engineering and requires specific equipment and software, through different solutions, and more affordable options to Vocational Education and Training (VET) Centers which are incorporating these training programmes into their courses. This will require more collaboration between trainers and industry in order to maintain currency in training processes and equipment.	- Find financial resources to use 3D scanning systems in education	2,6	39	2,6	16	2,8	13	2,5	10	2,7	6	2,8	8	2,7	3	2,9	8	2,9	7	2,0	1	2,0	6
13	Ergonomics	By incorporating ergonomic principles and digital technologies into vocational education, students learn to thrive in a rapidly changing manufacturing landscape. This includes training in ergonomics, human factors and digital technologies, as well as hands-on experience with digital workstations and equipment.	- Set up digital workstations in VET labs - Define the skills and competences and their assessment methods for the field	2,9	43	3,2	17	2,6	14	2,7	12	2,9	7	3,2	9	3,0	5	2,8	8	2,7	7	2,0	1	2,7	6

No	Topic	Statement	Challenges	Global (45) Average	Global (45) Nb Experts	Industry (19) Average	Industry (19) Nb Experts	Trainer (14) Average	Trainer (14) Nb Experts	Official (12) Average	Official (12) Nb Experts	France (7) Average	France (7) Nb Experts	Germany (9) Average	Germany (9) Nb Experts	Italia (5) Average	Italia (5) Nb Experts	Slovenia (8) Average	Slovenia (8) Nb Experts	Spain (8) Average	Spain (8) Nb Experts	Sweden (1) Average	Sweden (1) Nb Experts	Turkey (7) Average	Turkey (7) Nb Experts
14	Predictive Maintenance	The creation phase of predictive models, which is fully automated in many cases encourages companies to engage in predictive maintenance.	- Training programs on AI-driven predictive maintenance - Integrate AI-driven predictive maintenance systems in Vocational Education and Training (VET) labs	2,6	43	2,7	18	2,5	14	2,5	11	2,7	7	2,8	8	2,2	5	2,6	7	2,6	8	3,0	1	2,4	7
15	Virtual Reality/Artificial Reality/Mixed Reality	Collaborative immersive virtual environments are a safe and useful tool for training on complex or risky processes and establishing useful digital twins in advanced manufacturing. In addition, new solutions simplify the process of creating teaching materials, giving teachers and trainers a leading role.	- Integrate Virtual Reality/Artificial Reality/Mixed Reality in Vocational Education and Training (VET) labs for advanced manufacturing processes	2,3	43	2,4	19	2,3	14	2,2	10	2,9	7	1,6	8	2,8	5	2,3	7	2,4	8	2,0	1	2,1	7
16	Digital Twin	Digital twin (DT) technology is an emerging valuable tool for Vocational Educational Training (VET) as it is used to create digital replicas of physical assets and processes that are monitored and analysed in real time.	- Promote methods to implement DT in VET labs - Scale up the implementation of Digital twins in VET labs - Find financial resources to us DT solutions in VET	2,5	43	2,5	19	2,6	13	2,5	11	2,3	6	2,6	9	2,8	5	2,4	7	2,9	8	3,0	1	2,0	7

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Co-funded by the
Erasmus+ Programme
of the European Union