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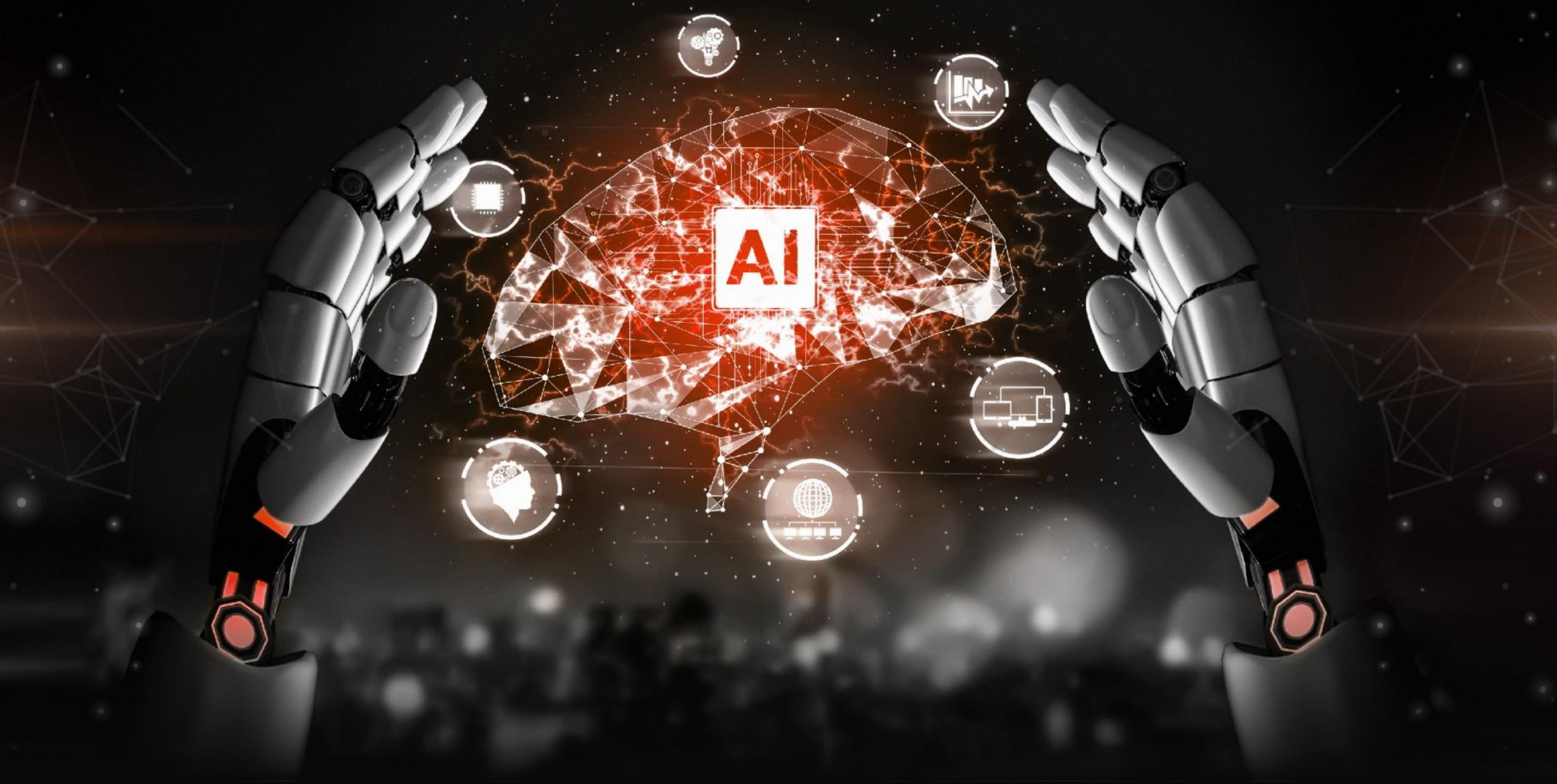
AGIMUS

INNOVATIVE ROBOTICS FOR AGILE PRODUCTION

D1.1 Agile Production Deep Dive Analysis for next generation robotics by design



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Executive Summary

This report was developed within the context of the AGIMUS project, funded by the European Union's Horizon Europe Framework Programme for Research and Innovation 2021-2027, with a view to shed light on (i) agile production as a new trend; (ii) its industrial challenges, barriers, drivers and enablers across key framework conditions which may influence uptake in the shopfloor; (iii) available or forthcoming technological solutions; (iv) associated technical and ethical requirements; (v) key actors and (vi) openly available resources for extending research activities, emphasizing on the use of AI-powered versatile robots.

To investigate the aforementioned aspects, a desk research was conducted, incorporating also a detailed preliminary analysis of the AGIMUS industrial pilot case studies, which was later validated and fine-tuned through 22 semi-structured interviews and a dedicated workshop on ethical dimensions. These interviews involved key technical and ethics experts, actively engaging both the Industrial and Ethics Advisory Board. To expand the collected knowledge, a broader online survey was conducted, which yielded in total 264 responses, out of which 180 were analysed to further shed light in the user driven dimensions of agile production via versatile robotics. As a result of these efforts, AGIMUS' user-centred requirement baseline framework was identified:

<table>
<tr><th colspan="2">Technical requirements</th><th colspan="2">Ethical requirements</th></tr>
<tr><td colspan="2">– Adaptability
– Reliability
– Scalability
– Increased accuracy
– Maintainability
– Interoperability & interconnectivity</td><td colspan="2">– Technical robustness & Safety
– Human agency & oversight
– Privacy & Data governance
– Transparency
– Accountability
– Societal & Environmental well-being
– Diversity, non-discrimination and fairness</td></tr>
<tr><th>Challenges</th><th>Barriers</th><th>Drivers</th><th>Enablers</th></tr>
<tr><td>– Exploitation of big data
– Human-Robot collaboration
– Technology acceptance</td><td>– Unclear scope or value proposition
– Low TRL
– Investment & Maintenance costs</td><td>– Competitiveness
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– Waste reduction
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The gained knowledge will help identify AGIMUS' functional and non-function system requirements and design the overall system architecture.

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Table 1: Terms and Definitions

Abbreviation	Definition	Abbreviation	Definition
ADRA	AI, Data and Robotics Association	ML	Machine Learning
AI	Artificial Intelligence	MPC	Model Predictive Controller
ALTAI	Assessment List for Trustworthy AI	NLP	Natural Language Processing
AR	Augmented Reality	OCP	Optimal Control Problem
CPS	Cyber-Physical Systems	OS	Open Science
DPIA	Data Protection Impact Assessments	PPP	Public-Private Partnerhsip
EAB	Ethics Advisory Board	RL	Reinforcement Learning
EC	Europena Commission	RSI	Repetitive Strain Injury
ECHR	European Convention of Human Rights	SME	Small- and Medium-sized Enterprises
EFFRA	European Factories of the Future Research Association	TAMP	Task-And-Motion Planner
EU	European Union	TRL	Technology Readiness Level
FAIR	Findable, Accessible, Interoperable, Re-usable	VR	Virtual Reality
FoF	Factories of the Future		
FRIA	Fundamental Rights Impact Assessment		
GA	Grant Agreement		
GDPR	General Data Protection Regulation		
HPC	High-Performance Computing		
IAB	Industrial Advisory Board		
ICT	Information and Communication Technology		
IoT	Internet of Things		
IT	Information Technology		

1. Introduction

Despite recent advancements in industrial robotics (IFR, 2020), the final assembly process for certain products still largely relies on manual labour, which can indicatively lead to decreased productivity, higher levels of waste production and increased risk of workers being exposed to hazardous environments. These facts suggest that there are still numerous issues that must be addressed (Sanneman et al., 2020). Current industrial robots:

(i) can often be **prohibitively expensive** for small- and medium-sized enterprises (SMEs), given the high preliminary and maintenance costs;
(ii) usually **perform just a single task**, such as drilling a hole or welding two pieces together;
(iii) require **significant time to set up**, need to be manually programmed in order to perform their task and re-programmed each time the production line changes, which is costly and time-consuming;
(iv) **cannot perform complex tasks** involving object manipulation;
(v) have **limited adaptation capabilities**;
(vi) have **limited perception capabilities**;
(vii) are **designed and trained separately from the site's workforce**;
(viii) **cannot collaborate with people** on the same part at the same time due to safety reasons, as their coexistence may lead to disruption or slow-down of the robot;
(ix) **have limited bandwidth and latency** to access cloud computing.

Furthermore:

(x) current robot **learning capabilities are limited and time-consuming** due to the slow convergence of Reinforcement Learning (RL) algorithms (Arents & Greitans, 2022);
(xi) current generation of industrial robots does **not prioritize energy efficiency** through algorithmic design (EFFRA, 2016).

In addition to the technological obstacles, creating more automated and productive digital ecosystems in manufacturing shop floors through the integration of robotics **requires appropriate design guidelines.** These guidelines should ensure the ethical, safe, secure and trustworthy delivery of the solution, with a positive impact on the deployment process while considering all stakeholders, including the workers.

This report paves the way towards identifying the challenges, barriers, drivers and enablers of AI-powered versatile robots, as well as the associated technical and ethical requirements. By framing AGIMUS' environment and proposing guidelines, the report aims to accelerate the adoption of advanced technologies by small-batch industrial players and expedite their transformation.

To achieve these targets, a variety of research methods was utilised, including desk research, in-depth examination of the industrial pilot case studies, semi-structured interviews with key experts from the consortium, the Industrial Advisory Board (IAB) and beyond, a workshop with the members of the Ethics Advisory Board (EAB) and external ethics experts and an online survey. Through these methods, a comprehensive understanding of the requirements, challenges, barriers, drivers and enablers associated with AI-powered versatile robots was achieved.

Overall, this methodology ensured that the report's findings were grounded in both theoretical research and practical experience, providing valuable insights and guidance for stakeholders in the industry, facilitating informed decision-making and successful adoption of AI-powered robots.

The report’s structure is presented below:

- In **Chapter 2**, we elaborate in detail on the methodological approach we followed.
- **Chapter 3** reveals the outcomes and primary takeaways obtained from the conducted desk research and the case studies analysis, which culminated in the development of the **Initial baseline framework**.
- In **Chapter 4**, we present the results and key insights extracted by the semi-structured interviews.
- **Chapter 5** is dedicated to refining and finalizing the ethical requirements associated to agile production using versatile robotics, resulting in the formation of the **Updated baseline**.
- In **Chapter 6**, we present the results and key insights extracted by the online survey we deployed as well as their translation into concrete implications and suggestions.
- **Chapter 7** comprises the conclusions drawn from the study and outlines the subsequent steps to be taken.

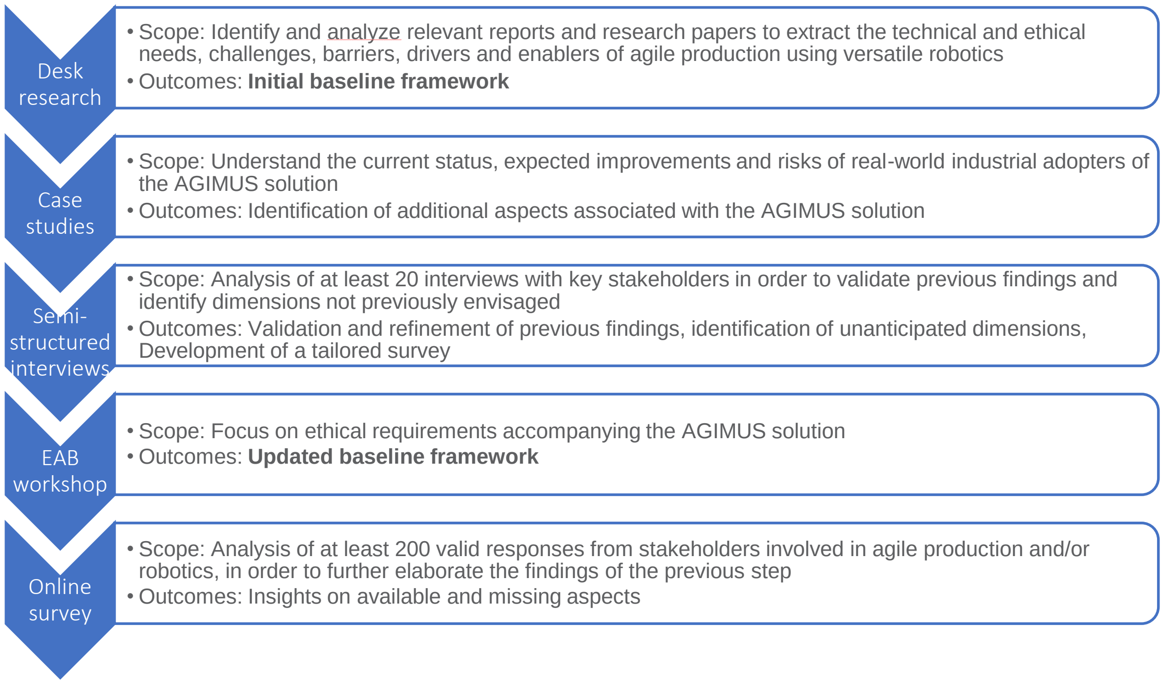
In the **Annex**, the interview guidelines and online survey used for our analysis, as well as openly available technological solutions and other resources for extending research activities are included.

The production of this deliverable is an outcome of the tasks conducted in T1.1 and T1.2.

2. Methodological approach

Our methodological approach is comprised of 5 interconnected steps, schematically depicted in Figure 1.

Figure 1: Methodological approach



2.1 Desk research

As a first step for our analysis, we identified the current state-of-play regarding (i) agile production as a new trend; (ii) its industrial needs, challenges, barriers, drivers, enablers; (iii) available or forthcoming technological solutions; (iv) key actors; (v) openly available resources for extending research activities, based on relevant online literature.

The consortium actively collaborated to refine and enhance our research to include the latest advancements in the application of agile production and robotics, resulting in a more comprehensive and up-to-date version.

This exercise was a key component of our research as it provided AGIMUS' initial baseline framework, including the identified technical and ethical requirements. This framework was crucial in guiding our next steps and allowed us to move forward in a more informed and efficient manner.

2.2 Case studies

An in-depth examination of AGIMUS' industrial pilot case studies was performed next, in order to identify and assess in more detail the (i) current state of the examined case studies; (ii) current industrial conditions of manufacturing process and settings; (iii) non-technical risks related to the adoption of the AGIMUS solution. This permitted us to adjust the initial baseline framework towards actual, well-grounded, real-world paradigms.

2.3 Semi-structured interviews

To validate previous findings, further refine them and effectively identify any unanticipated dimensions, as well as obtain a comprehensive understanding of the overarching picture and precisely determine the crucial elements that must be incorporated into the online survey, 20 semi-structured interviews were organized as a next step. To split the associated effort and increase the interviews' efficiency, the interviews were split between 4 interviewers of different nationality, namely French, Czech, Greek and Spanish, to conduct them in the interviewees' mother tongue.

After internal discussions, 18 questions were identified and an interview guideline document, comprised of a summary of the AGIMUS project, an overview of the scope and objectives of the interview, as well as notes to ensure clear understanding of each question's expected outcome, were shared with the interviewees.

By engaging consortium partners' networks, we identified and interviewed expert stakeholders from the consortium, the Industrial Advisory Board (IAB) and beyond, as well as external ethics experts, involved in agile production and/or robotics. The stakeholders we interviewed included workers, managers and others to gather the most diverse range of perspective possible.

2.4 EAB workshop

With the aim to delve into more detail into ethical dimensions that need to be taken into consideration from the design stage of an AI-powered versatile robotics solution for agile production, a workshop and two semi-structured interviews were organized with AGIMUS' Ethics Advisory Board (EAB) members and experts in ethics for robotics and AI respectively.

During the workshop, the interview and survey observations were discussed using a Miro board[1]. The participants were divided into two groups which were moderated by two facilitators.

The two interviews that followed, helped better shape the workshop's findings, ensured that ethical considerations are properly addressed and solidified the approach that should be used to elicit the ethical requirements. Based on these activities, a better understanding of the necessary elements that would allow a solution that would be ethical-by-design was achieved.

By elaborating on the results from all the aforementioned steps, we were able to identify an arsenal of both technical and ethical requirements that are perceived to be of utmost importance from both literature findings and key stakeholders in the investigated domains. The aforementioned exercises also helped us tailor the questionnaire of the online survey that followed.

[1] Miro is an online whiteboard tool that allows individuals or teams to visualize ideas and collaborate on projects.

2.5 Online survey

As the final step, we deployed an online survey to engage with a greater sample of stakeholders involved in agile production and/or robotics. The insights gathered were profound, allowed the classification of the requirements, challenges, barriers, drivers and enablers of agile production using versatile robotics and provided a better understanding of AGIMUS' environment. This is expected to help more accurately design the envisioned autonomous robotic solution.

The survey was initially set up using MS Forms[2]. To attain the target of 200 responses, we invited members of the AGIMUS consortium to circulate and complete the online survey among their colleagues and networks. Furthermore, the Industrial Advisory Board (IAB), relevant projects such as ADRA-e, euROBIN, CONVINCE, CORESENSE, HARIA, INTELLIMAN, MOZART, PILLAR-ROBOTS, REGO and SESTOSENSO, European industry associations such as European Factories of the Future Research Association (EFFRA) and Industry4Europe, as well as relevant LinkedIn groups, were also invited to contribute to the survey. The online survey was conducted between February 16 and March 26 of 2023, but it received a low number of responses, with only 35 participants.

To improve participation, the survey was updated incorporating the latest findings and a link to the updated survey was shared via the Prolific[3] from March 27 to March 31, 2023. The updated survey was set up using Google Forms[4] instead of MS Forms, as we decided that its interface would better meet our needs.

To identify a suitable sample of individuals involved in agile production and/or robotics, three pilot surveys were conducted on 450 participants prior to conducting the main survey. All pilot surveys included the following questions:

1. *Do you have a good understanding of agile production? (Yes, No)*
2. *Do you have a good understanding of versatile, collaborative robotic solutions for agile production? (Yes, No)*

   Indicative evolution of versatile robotics role in agile production lines:

   - *1st generation of versatile robotics: Workers continue performing their tasks and robotic systems help them be more efficient*

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[2] MS Forms is Microsoft's official survey management tool. MS Forms provides a wide variety of elements, such as open-ended questions, multiple-choice questions and rating scales. The tool is hosted on Microsoft's servers, implementing encryption, access controls and data backups ensuring the proper and secure storage of the beneficiaries' feedback

[3] Prolific is a crowdsourcing platform that provides a space for researchers and scientists to connect with participants for research studies. The platform specializes in recruiting and managing high-quality research participants for academic research, user testing, market research and surveys.

[4] Google Forms is a web-based survey and form creation tool offered by Google. It allows users to easily create custom forms, surveys, quizzes and questionnaires for various purposes such as feedback gathering, event registration, market research and more. Google Forms provides a variety of question types, including multiple-choice, checkbox, drop-down menus and more and allows for customization of themes, logos and backgrounds. The collected data can be automatically organized and analysed through built-in data summaries or exported to a spreadsheet for further analysis. Google Forms is free to use and integrates seamlessly with other Google apps like Google Sheets and Google Drive

   - *2nd generation of versatile robotics: Robotic systems perform the tasks and workers supervise them*
   - *3rd generation of versatile robotics: Robotic systems are autonomous and tasks are performed entirely by them.*
3. *Which generation of versatile robotics is the most common today? (1st, 2nd, 3rd)*
4. *How soon would you assume 3rd generation versatile robotics to be the norm? (It already is, In <10 years, In 10-20 years, In 20-50 years, In >50 years)*

The following criteria were set for pilot survey respondents to be considered eligible for the main survey[5]:

- not have replied "No" to both the first and the second question;
- not have chosen "Third generation" as their answer to the third question;
- not have responded with "It already is" to the fourth question.

A total of 264 main survey responses were collected (229 from Google Forms and 35 from MS Forms), out of which 180 were analysed and included in this report. That is as the MS Forms and Google Forms surveys are not identical, hence the 35 MS Forms responses were excluded to ensure clarity in the analysis, while 49 responses from Google Forms were excluded due to inconsistencies.

At the end of the project, a similar questionnaire will be distributed again to capture a second "snapshot" of AGIMUS' environment and evaluate its evolution over a four-year period. This will enable the extraction of valuable insights on various aspects, such as the perceived trustworthiness, acceptance and overall perception of versatile robotics.

[5] The 1st pilot survey permitted us to identify profiles of respondents who mostly meet the eligibility criteria in order to deploy the following pilot surveys more effectively. (Employment status: Full or Part-time, Industry: Manufacturing or Computers and Electronics Manufacturing, Age: 25-70)

3. Desk research

3.1 Agile production as a new trend

Agile production using versatile robotics is a modern approach to manufacturing that utilizes robotics technology to meet the changing demands of businesses. It requires a flexible system that allows robots to adapt to changes in the production process quickly, without the need for significant downtime or retooling. The goal of agile production is to create a dynamic and efficient production line that can respond to changes in demand and product specifications with ease. To achieve this, it requires the use of advanced robotics technology that is highly adaptable and flexible in its capabilities (Sanneman et al., 2020).

Additionally, agile production places a strong emphasis on ethical considerations, particularly when it comes to privacy, safety and trustworthiness. The fast-paced nature of agile development requires teams to be vigilant in ensuring that the software they produce is not only functional but also meets the highest ethical standards. With increasing importance being placed on social responsibility to local environments, it is imperative to have scientific answers in a manner that is both economically profitable and considers factors such as energy demands, quality of living, natural resources and safety (EFFRA, 2016).

3.2 Key actors

The three arenas in which key actors of agile production using versatile robotics can be classified are industrial, policy and research. The sub-sections below present some indicative actors from each arena.

3.2.1 Industrial arena

I. **Robotics manufacturers**: Companies that design and produce robots for industrial applications, such as ABB, FANUC, KUKA, Yaskawa and PAL Robotics, are key actors in the development and production of (versatile) robotics for agile production. These companies specialize in the design and manufacturing of robots and automation systems that can be adapted to perform a wide range of tasks in various manufacturing environments (Siciliano & Khatib, 2016).

II. **System integrators**: Companies that specialize in integrating robotic systems into existing manufacturing processes and optimizing them for maximum efficiency, such as Bastian Solutions, Honeywell, Intelligrated and Dematic.

III. **End-users**: Companies or organizations that deploy robotic systems in their operations, such as Amazon, BMW and Siemens.

IV. **Researchers**: Academia and industry researchers who work on developing new technologies, improving existing ones and exploring new areas of application for industrial robotics, such as Boston Dynamics, MIT EECS and Carnegie Mellon University.

V. **Regulators**: Governments and regulatory bodies and/or non-profit organizations that set voluntary or compulsory standards and/or regulations for the safe and responsible use of industrial robots, such as the International Organization for Standardization (ISO), the European Committee for Standardization (CEN) and the Occupational Safety and Health Administration (OSHA).

VI. **Service and maintenance providers**: Companies that offer maintenance and repair services for robotic systems, ensuring their proper functioning and minimizing downtime, such as FANUC, KUKA and Yaskawa.

VII. **Early adopters**: Companies that are among the first to adopt new robotic technologies in their operations, such as TESLA, AIRBUS and SAMSUNG.

VIII. **Hardware technology providers**: Companies that provide hardware components that are essential for building and operating robotic systems, such as INTEL, NVIDIA, ABB Robotics, Rockwell Automation, OMRON and RoboSavvy.

IX. **Software technology providers**: they may include companies, foundations, formal or informal communities that provide commercial or free and open software components, such as programming languages, algorithms, and simulation tools, that are essential for operating and optimizing robotic systems, such as MathWorks, Robot Operating System (ROS), Siemens PLM Software, ATOS and RoboSavvy.

3.2.2 Policy & Standardisation arena

Key Actors Involved in Policy:

I. **European Commission** (EC): The EC is responsible for setting policy priorities and funding research and development projects related to robotics and automation.

II. **National Governments**: National governments play an important role in shaping policies related to robotics and automation, including regulations related to safety, data privacy, and cybersecurity.

III. **Trade Associations**: Trade associations such as the Association for Advancing Automation (A3) advocate for policies that support the growth of the robotics industry and provide resources and information to their members.

Some notable policy frameworks or regulations that significantly impact the policy landscape for agile production utilizing versatile robotics include the following:

(i) **EU Charter of Fundamental Rights**: The EU Charter is a set of fundamental rights that apply to all EU Member States. It includes provisions related to human dignity, freedom, equality, solidarity, citizenship, and justice. The Charter is an important framework for ensuring that policies related to robotics and automation align with EU values and respect fundamental human rights.

(ii) **Ethics Guidelines for trustworthiness AI**: In 2020, the European Commission published a set of ethics guidelines for trustworthy AI. These guidelines outline ethical principles for the development and deployment of AI, including respect for human autonomy, prevention of harm, fairness, transparency, and accountability. The guidelines provide a framework for policymakers and stakeholders to ensure that AI is developed and used in a way that is ethical, transparent, and respects human rights.

(iii) **Data Act**: The EU Data Act is a proposed regulation that would govern the use and protection of data within the EU. The act includes provisions related to data privacy, security, and interoperability. The regulation would provide a framework for the responsible and transparent use of data, which is critical for the development and deployment of robotics and automation.

(iv) **AI Act**: The EU AI Act is a proposed regulation that would establish a legal framework for AI in the EU. The act includes provisions related to transparency, accountability, and human oversight of AI systems. The regulation would provide a framework for ensuring that AI is developed and used in a way that aligns with EU values and respects fundamental human rights.

Key public or private Actors Involved in various activities related to Standardization:

I. **International Organization for Standardization** (ISO): ISO develops and publishes international standards for various industries, including robotics and automation.
II. **European Committee for Standardization** (CEN): CEN develops and publishes standards for various industries, including robotics and automation.
III. **German Institute for Standardization** (DIN): DIN develops and publishes standards for various industries, including robotics and automation.
IV. **Technischer Überwachungsverein** (TÜV) Association: TÜVs are independent service companies that provide testing, inspection and certification services for various industries, including robotics and automation. TÜV Association is involved in the development of standards for robotics and automation systems, including safety standards.
V. **European Telecommunications Standards Institute** (ETSI): ETSI is responsible for developing standards for information and communications technologies (ICT) in Europe, including those related to elements of robotics and automation.
VI. **European Committee for Electrotechnical Standardization** (CENELEC): CENELEC is responsible for developing standards for electrical and electronic products and services in Europe, including those related to elements of robotics and automation.
VII. **Institute of Electrical and Electronics Engineers** (IEEE): IEEE develops and publishes standards for various industries, including robotics and automation, on a global scale.

Key Actors Involved in Both Policy and Standardization:

I. **European Robotics Research Network** (EURON): Although this network is no longer active, it played a significant role in promoting collaboration among European researchers in robotics and supporting the development of robotics research and applications in Europe. EURON was involved in developing standards for robotics and automation and worked closely with other organizations such as ISO and CEN to promote standardization in the industry.
II. **National Institute of Standards and Technology** (NIST): NIST is a non-regulatory agency of the United States Department of Commerce that is responsible for developing and promoting measurement, standards, and technology to enhance economic security and quality of life. NIST is involved in the development of standards related to robotics and automation, including safety standards.

Additionally, initiatives such as Industry 4.0 (e.g. "Industrie 4.0" (Industry 4.0 (I40)) of Germany, etc.) and the European Robotics League (ERL), at national or international level, support the development and adoption of advanced manufacturing technologies, including versatile robotics (Michalos et al., 2015).

3.2.3 Research arena

I. **Research institutions**: These institutions are at the forefront of research in agile production using versatile robotics. They conduct studies, develop new theories, and test new technologies and methodologies. Examples of research institutions in this arena include the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA), the National Institute of Standards and Technology (NIST), the Centre National de la Recherche Scientifique (CNRS) and the Institut National de Recherche en Informatique et en Automatique (INRIA).

II. **Universities**: Universities also play a crucial role in the research arena of agile production using versatile robotics. They conduct fundamental research, train students, and collaborate with industry partners to develop practical applications of research findings. Examples of universities in this arena include the Technical University of Munich (TUM), the Massachusetts Institute of Technology (MIT), Stanford University, ETH Zurich, Czech Technical University (CTU), the University of Birmingham and the Fraunhofer Institute.

III. **Industry associations**: These organizations represent the interests of companies in the agile production using versatile robotics arena. They organize events, provide networking opportunities and share industry knowledge and best practices. Examples of industry associations in this arena include the International Federation of Robotics (IFR) and the Association for Advancing Automation (A3).

IV. **Funding agencies**: These agencies provide funding for research projects and support the development of new technologies and methodologies. Examples of funding agencies or instruments in this arena include the European Union's Horizon 2020 programme, the United States National Science Foundation (NSF) and the Japan Society for the Promotion of Science (JSPS).

V. **Conferences and workshops**: These events provide opportunities for researchers to present their work, discuss new ideas, and collaborate with peers. Examples of conferences and workshops in this arena include the International Conference on Robotics and Automation (ICRA), the International Symposium on Robotics (ISR), the International Symposium on Automation and Robotics in Construction (ISARC), the Robotics Science and Systems Conference (RSS conference), and the conferences of the Institute of Electrical and Electronics Engineers Robotics and Automation Society (IEEE RAS).

These organisations are key players in conducting research and development in the field of versatile robotics for agile production, collaborate with industry partners to explore new technologies and applications and to drive innovation in the field (Siciliano & Khatib, 2016).

3.3 Needs, challenges, barriers, drivers and enablers identification

A deep dive into the versatile robotics for agile production paradigm, understanding in more detail the needs, challenges, barriers, drivers and enablers of manufacturing lines that have adopted or require such principles, was attempted.

It is worth noting that some of the identified needs, challenges, barriers, drivers and enablers may be applicable to more than one category. We have categorized them based on the following definitions:

- a need is a fundamental requirement that agile production (using versatile robotics) intends to fulfil;
- a challenge is an obstacle that has to be overcome in order to successfully fulfil the requirements;
- a barrier is a factor that hinders the requirements' fulfilment;
- a driver is a factor that motivates the requirements' fulfilment;
- an enabler is a resource, tool or support structure that facilitates the requirements' fulfilment.

These definitions help avoid repetition, thereby promoting clarity and consistency in our analysis.

Furthermore, we categorized the needs into two types, namely "Technical" and "Ethical", to ensure that all aspects of the project are appropriately examined. Technical needs pertain to the robot's functional abilities, which are critical for achieving project objectives. On the other hand, ethical needs prioritize compliance with ethical standards that respect human values and rights. To identify the ethical needs, we used the EC's Ethics Guidelines for Trustworthy AI as a reference, addressing the ones that we deemed most relevant for industrial applications.

3.3.1 Technical needs

3.3.1.1 Adaptability

Robotic systems must be able to handle a variety of tasks and quickly adapt to changing production requirements (quantity, design, ergonomics, price), changes in demand (volume, type of product) and new product designs (Arents & Greitans, 2022).

3.3.1.2 Reliability

To prevent disruptions in production, robotics systems must be reliable and perform consistently. However, maintaining the reliability of sensors in challenging environments, such as those with high or low pressure, temperature, radioactivity, corrosive atmospheres, or explosive risks, as well as in diverse settings such as ice, snow, rain, mist, fog (Arents & Greitans, 2022), remains a critical concern. Additionally, ensuring the reliability of communication through cloud systems and platforms that enable data-driven, automated analytics and knowledge-based decision support is also a significant issue that needs to be addressed (SRIDA, 2020).

3.3.1.3 Scalability

Robotic systems must be designed to accommodate changes in production volume and size in order to maintain efficiency and flexibility in manufacturing operations. Individual modules and connection elements must be easily scalable by allowing for the replacement of electrical motors and transmissions with those of different power classes and ratios. Additively manufactured parts allow for the creation of different geometries at a low cost, making the system versatile and adaptable to various tasks. By incorporating scalability into the design of robotic systems, manufacturers can maintain productivity and quality while responding quickly to changing market demands (Rossmeissl et al., 2019).

3.3.1.4 Maintainability

To ensure the safe and effective operation of their robots, organisations should implement systems for maintenance and support, which may include regular inspection and maintenance programs, as well as access to technical support and expertise as needed (SRIDA, 2020). Robotics systems should be easy to maintain to minimize downtime.

3.3.1.5 Interoperability & Interconnectivity

A challenge of the implementation of a smart manufacturing system is the integration of new technology equipment with the existing ones. The compatibility of existing devices to the new devices causes various problems in the implementation of smart manufacturing technologies. The old machinery which is being controlled by some communication protocols might be outdated and new devices may have different protocols. Also, the machine-to-machine communication and the interconnectivity of the system requires better communication systems (Phuyal et al., 2020).

According to (Sanneman et al., 2020), some companies value technology systems that are “less likely to disrupt existing infrastructures or require overhaul of old hardware”. It is not uncommon companies to use “legacy systems”, in other words systems of or linked with old and outdated technology (EFFRA, 2016).

Retrofitting existing manufacturing equipment by attaching diverse sensors and IoT nodes, may be a viable solution to avoid replacing all legacy machines. However, extending the usage of cloud systems and IoT beyond the exchange of information between robots to the optimization of production, monitoring and centralised control comprises a significant challenge as well (Kumar et al., 2021; Sanneman et al., 2020; SRIDA, 2020; Wan et al., 2021).

3.3.2 Ethical needs

3.3.2.1 Safety

When implementing Cyber-Physical Systems (CPS) or industrial robotic systems in a workplace, the primary focus should be on the occupational health and safety of personnel working on the site. Particular attention should be given to minimizing the risk of mechanical, electrical, thermal, noise, vibration, radiation, material/substance and other work environment-related hazards (Phuyal et al., 2020).

Work cells, where collaborative robots are used, should conform to safety standards (including speed and force limits for the robots). The decrease of velocity questions the overall utility of a collaborative robot, highlighting the importance of various trade-off considerations from the side of a company (EFFRA, 2016; Phuyal et al., 2020; Sanneman et al., 2020; SRIDA, 2020).

3.3.2.2 Privacy

Privacy is a critical aspect of ethics in agile production, as the software developed often handles sensitive information. Teams must ensure that the information is collected, processed and stored in accordance with relevant privacy regulations and standards and that the security of the data is maintained at all times. This includes implementing measures to prevent unauthorized access, as well as regularly reviewing and updating their privacy practices to ensure that they remain effective (EC, 2019; EFFRA, 2016).

3.3.2.3 Transparency

Organisations should be transparent about the robots' decision-making processes and technology usage, allowing individuals to comprehend the rationale behind decisions made about them and their data collection. To extend the application domains of AI, it is necessary to evolve AI-based systems from black boxes to models that can provide understandable explanations for the decisions they make. This is crucial in domains where machine-human synergy or the accountability of AI are of importance (EC, 2019; SRIDA, 2020).

3.3.2.4 Societal & Environmental well-being

Robotic systems are expected to provide savings in terms of increased efficiency and less wasted material. Additionally, the progress in AI algorithms designed to enhance High-Performance Computing (HPC) contributes to the reduction of a company's environmental impact, i.e. reduction of pollutant emissions, energy consumption and carbon footprint (EC, 2019; SRIDA, 2020).

3.3.2.5 Accountability

Organisations should take responsibility for the actions and decisions made by their robots, should be able to explain their decision-making processes and be accountable for any harm that they may cause. This includes having systems in place to address any incidents or accidents that may occur (EC, 2019; Michalec et al., 2021).

3.3.3 Challenges

3.3.3.1 Exploitation of big data

An intelligent manufacturing system involves interconnected devices that generate significant volumes of data related to device status and process parameters, whilst AI technology requires large volumes of cross sectoral, unbiased, high-quality and trustworthy data (EFFRA, 2016).

Achieving this objective necessitates the establishment of comprehensive data collection infrastructures to gather the requisite sensing data, as well as extensive computational resources for data fusion, mining and knowledge extraction. Availability of annotated data for training and fine-tuning deep learning models is also essential for building robust data assets that enable the derivation of useful information (Sanneman et al., 2020; SRIDA, 2020).

When integrated with AI-based methods, big data analysis can facilitate failure prediction, active preventive maintenance scheduling and decision-making and reduce the cost of operation and maintenance management within a smart manufacturing system (Wan et al., 2021).

3.3.3.2 Human-Robot collaboration

While AI has traditionally focused on full automation, there is growing recognition that designing systems that allow for effective human-AI collaboration is a better approach. The introduction of AI technology can enhance the flexibility of automated production processes and improve efficiency by combining human cognitive and sensorimotor skills with robot precision. Unlike traditional robots, such solutions may not require a safety zone around the robots, or the safety zones may be smaller. However, to achieve successful human-robot interaction, the transformation of the manufacturing operations required, the design of the interaction and control of the robot, as well as task allocation between the operator and robot, must be intuitive (Evjemo et al., 2020; SRIDA, 2020).

To enable more durable interactions between humans and AI, it is important to improve perception of human intent through appropriate sensors and models of human behaviour. This can be achieved through techniques such as natural language understanding, gesture and activity recognition and creating and maintaining shared mental models, which facilitate effective human-AI collaboration (SRIDA, 2020). Failure to accomplish this could limit the effectiveness of automation and hinder the realization of its potential benefits (Arents & Greitans, 2022; Evjemo et al., 2020).

3.3.4 Barriers

3.3.4.1 Unclear scope or value proposition

Unclear or limited knowledge of the capabilities and scope of new technologies can prevent companies from accurately estimating their potential value. This, in turn, may discourage them from investing in such technologies, constituting a significant barrier towards integration within the production process and benefiting from the potential advantages that these technologies can offer (Sanneman et al., 2020).

3.3.4.2 Low Technology Readiness Level

Technological barriers related to sensing, perception and gripping, hinder companies from greater exploitation of robotics technologies (Kumar et al., 2021; Sanneman et al., 2020). Even though versatile robotics for agile manufacturing have become a megatrend these days, according to both the ADRA association and FoF PPP, the majority of available commercial solutions are still not open and at a maturity level that cannot integrate to highly innovative software frameworks (EFFRA, 2016).

Although some progress has been made in addressing the challenge of robotic grasping, particularly for unknown and geometrically complex objects, achieving precise object placement remains a significant obstacle in industrial robotics. Numerous methods have been proposed to address this challenge, but more widespread solutions have yet to be established (Arents & Greitans, 2022). Advancements in deep learning and sensing systems can improve the hardware capabilities of the physical robotic gripping, which still lacks the level of human gripping performance (Sanneman et al., 2020).

Robotic technologies that perform well within a well-controlled laboratory setting, may fail to perform perfectly or completely in an operational environment, where different and complex situations, such as physics simulations, virtual object representations, sensor data recreation, artificial lighting and many other aspects of the real environment, arise (Arents & Greitans, 2022; Sanneman et al., 2020). Research institutions generally focus on results at TRL 1-3, indicating basic feasibility and effectiveness, while industrial enterprises require technologies at TRL 7-8 or higher, which involves prototype demonstration and actual deployment (Wan et al., 2021).

Achieving market readiness for advanced robotics requires a significant investment due to the longer time to market and the high costs associated with each development stage, especially at TRL 7-9. At this stage, there is a need to create advanced and durable prototypes, establish manufacturing processes, develop test and deployment support systems for robots, as well as to provide open-source solutions and data that will allow for faster replication and improvement (SRIDA, 2020).

3.3.4.3 Investment & Maintenance costs

Robotics systems should be affordable for small and medium-sized businesses. The shaping of cloud systems that will be based on the integration of sensor data comprises a strong barrier, given the fact that it requires high investment costs and/or overhaul of company's infrastructure (Sanneman et al., 2020).

3.3.5 Drivers

3.3.5.1 Competitiveness

Agile manufacturing is a widely recognized and established approach to manufacturing that is used to improve the flexibility, responsiveness and overall performance of manufacturing organisations. To maintain a competitive edge, organisations must promote ongoing improvements and innovation in all aspects, including product, process and organisational dimensions.

In an increasingly competitive world, manufacturing organisations have been compelled to improve their speed, quality, agility, flexibility and responsiveness towards their customers' needs, making them more receptive to the adoption of innovative and advanced manufacturing strategies that can generate competitive advantages in the current volatile business environment (Arents & Greitans, 2022; Kumar et al., 2021; Lokhande & Sarode, 2020). If the manufacturing industry fails to adjust to a swiftly evolving business landscape, it may eventually face its downfall (Hormozi, 2001).

Manufacturers are engaged in a competition to deliver innovative, reliable and cost-effective products that can respond rapidly to market changes and meet consumer demands. This competition has culminated in the emergence of smart manufacturing, the digitalization of processes and the implementation of cyber-physical controls in manufacturing plants and business outlets (Phuyal et al., 2020).

3.3.5.2 Customer satisfaction

In the current competitive market, customers expect goods and services that are customized and delivered quickly. To be successful, businesses must have adaptable, intelligent and efficient manufacturing processes. They often use agile manufacturing practices and versatile robotics that can quickly adapt to new product designs. This enables manufacturing companies to offer a wider range of products, increasing their portfolio diversity (Arents & Greitans, 2022; Floridi et al., 2022; Kumar et al., 2021).

3.3.5.3 Return On Investment

In modern times, optimizing production costs requires a comprehensive analysis of the manufacturing chain. Lean manufacturing approaches are typically used to minimize parts costs, and this necessitates highly adaptable manufacturing machines and systems that can accommodate small batches. Quick response, reconfigurable, and high-precision manufacturing processes can offer a cost-efficient solution for such sectors. The cost reduction achieved through precision machining solutions can democratize high-performance mechanisms in sectors where cost is the primary driver. This can lead to an improvement in energy efficiency by better aligning mechanisms and subsystems (EFFRA, 2016).

3.3.6 Enablers

3.3.6.1 5G communications

5G communications have the potential to make manufacturing processes more energy-efficient and cost-effective, which can be beneficial for both businesses and the environment, decreasing the capital and operational costs for a number of reasons (Shurdi et al., 2021):

- Improved network capacity: 5G networks have higher data transfer rates and lower latency than previous generations of mobile networks, which means that data can be transmitted more quickly and with less delay. This can lead to more efficient use of energy and other resources, as processes can be optimized in real-time based on more accurate and up-to-date data.

- Reduced need for physical infrastructure: 5G networks can support a higher number of devices and users per unit of area than previous mobile networks, which means that fewer base stations are needed to provide coverage over a given area. This can reduce the cost and energy consumption associated with building and maintaining physical infrastructure.
- Increased automation and machine learning capabilities: 5G networks can enable more sophisticated automation and machine learning capabilities in manufacturing processes, which can lead to increased efficiency and reduced operational costs. For example, 5G-enabled sensors and robots can be used to monitor and optimize production processes in real-time, without the need for human intervention.

3.3.6.2 Simulation techniques

Simulation techniques, enables companies to:

- Reduce costs associated to designing robotic systems: The use of simulations is highly advantageous in the development of smart industrial robotic systems, as it can enable the generation of vast amounts of data at low costs, expedite the design cycle while reducing costs and provide a secure and completely controlled testing environment (Arents & Greitans, 2022).

- Estimate the value added and the entire life cycle cost of a robotic system: Simulation and modelling methods can be used to achieve high-performance production, by taking into account parameters such as resources and energy consumption during operation, maintenance costs and depreciation of robotic systems (EFFRA, 2016).
- Reduce the time required for integrating appropriate robotic systems: Enhanced digital techniques such as "digital twins", enable the simulation of detailed 3D environments such as manufacturing cells and lines, potentially making also use of Augmented Reality (AR) and Virtual Reality (VR) systems. The development of accessible digital production line models and proper simulation tools will enable effective decision making, optimizing integration time (EFFRA, 2016; Sanneman et al., 2020).
- Study the interaction between humans and robots (SRIDA, 2020): With the incorporation of robots into production lines, it has become imperative to consider the elements associated with human-machine interaction:
    a) establishing societal trust in human-machine interaction and developing the safety and reliability of these systems;
    b) facilitating the use of training data to imitate natural human interaction, such as in the case of brain-computer interfaces and interaction via VR/AR-interfaces;
    c) comprehending and designing data-driven collaborative problem solving, where humans and machines can complement each other's diverse strengths;

3.3.6.3 Ease of use

The development of simple interfaces that allow the straightforward and smooth interaction between robots and humans is key to transform the field of collaborative robots, enabling workers to efficiently reprogram and re-purpose robots to meet changing production needs. SMEs may drive the market if they can utilize robots without specialized skills or relying on integrators, whilst companies who would like to reuse collaborative robots across different manufacturing processes and on various manufacturing lines will be highly advantaged (EFFRA, 2016; Sanneman et al., 2020; SRIDA, 2020).

3.3.6.4 Open-source software

In order to facilitate collaboration among multiple organisations, Enterprise Information Systems (EIS) need to be open-source and reliable. This underscores the need for new information security approaches and related standards (Ng et al., 2016).

3.3.6.5 IT systems

IT is like the nerve system for the manufacturing industry playing a critical role in promoting integration and agility in a company and improving the decision-making ability of the top management, thereby providing a competitive edge to an organisation. IT usages assure better knowledge sharing within and outside an organisation to ensure the availability of the right knowledge at the right place and from the right source (Kumar et al., 2021; Potdar et al., 2017).

3.3.6.6 Standardisation

Standards can serve as a quality management system for users, organisations, research institutions and governments utilizing AI, reducing both the associated complexity and costs. In addition to conventional standards, co-regulatory approaches such as accreditation systems, professional codes of ethics, or standards for fundamental rights compliant design can also be used. Examples of existing standards include ISO standards and the IEEE P7000 standards series, but in the future, a "Trustworthy AI" label could be used to confirm adherence to specific standards related to safety, technical robustness and transparency (EFFRA, 2016).

Nonetheless, IoT development for example is hindered by the lack of standards which is combined with the limitation in data infrastructure (SRIDA, 2020). The existence of tailor-made and home-grown technological systems hampers the integration of old technologies with the new ones, leading to a “mosaic” of different programming languages, interfaces, communication protocols, safety standards, hardware types, etc. (Sanneman et al., 2020).

3.3.6.7 Policy & Regulations

EU and national government regulations and policies are necessary for the successful implementation of agile manufacturing (Hormozi, 2001; Kumar et al., 2021) and expected to be key enablers and levers for adopting solutions such as versatile AI-powered robotic systems.

The law imposes both positive and negative obligations, implying that it should not only restrict certain actions but also enable others. For instance, the EU Charter includes articles on the freedom to conduct a business and the freedom of arts and sciences, alongside articles focused on product safety, liability frameworks, data protection and non-discrimination, which are crucial to ensuring AI's trustworthiness. The uncertainty around policy and regulation of AI, Data, and Robotics creates concerns about compliance for many organisations, as there is a lack of clarity and a common legal framework in areas such as liability, right to explain, data access and trustworthiness. This slows down company growth and the delivery of benefits. To successfully adopt AI, Data and Robotics in new market areas, a legal framework of approval built on regulation and certification processes and standards driven by industry is required (EC, 2019; SRIDA, 2020).

In some application areas, existing regulation can present a barrier to adoption and deployment, particularly where there is close interaction with people or where technologies operate in safety or privacy critical environments. Although the market may move ahead and wait for regulation to react in some areas of AI, Data, and Robotics, a lack of regulation can hold back deployment in many application areas (SRIDA, 2020).

3.4 Case studies

In order to better understand the current status, expected improvements and risks of actual real-world industrial adopters of the AGIMUS solution and uncover further aspects of agile production, more detailed information regarding AGIMUS' industrial pilot case studies were requested from the industrial partners, aligned with activities under T6.1, which are expected to further elaborate on the industrial pilot case studies.

3.4.1 Aircraft & Satellite manufacturing industrial pilot case studies

Aircraft & Satellite manufacturing pilot case studies		
	CS#1.1 Deburring on reactor pylon	CS#1.2 Solar Array Assembly
Short description	A deburring operation (manufacturing process) after final drilling on top of structural aircraft mechanical parts (e.g., pylon wing junction) that involves a long sequence of tasks (aka mission programming for sequences of holes to machine and displacement of the robot basis) and accurate relative positioning from vision (<2mm) and haptic (<1N).	Manufacturing operations (dispensing fluids such as sealant, spray cleaning, or adhesive/glue) on top of solar arrays mechanical parts during satellite assembly phases in the C10000 clean room.
Number of people & their role	2 people performing deburring	Product dependent (i.e., between small size LEO satellite produced by batch, to unique but big size exploration satellite, it can be from 5 to 50 people)
Typical education level	Technical high school education	Highly trained engineers
Equipment used (robotics-related or not)	Pneumatic or electrical drill	Product dependent, i.e., from manual dispenser (for small batch or complex integration to

Aircraft & Satellite manufacturing pilot case studies		
		fully automated with robots for “classical” configuration).
Use-case completion duration [min]	120	Considering full lifecycle, it can be ~2 days including curing time on “normal size”. Dependent on number of cells, and or considered assembly process phasis considered
Needed space [m^2]	20	For classical assembly on small size arrays (in batch) : ~100m2
Materials wasted (material type & quantity [kg])	Titanum and steel : 1kg	N/A
Unplanned downtime [h]	None	N/A
Defect rate	1%	<0,03%
Process variability (how often do you need to customize the product?)	Each part is different from the others.	Dependent on product. Outside of satellite batch for constellation needs (typically LEO sat constellation), variability is very high
Safety [average work accidents/year]	0	0
How long is the current solution used?	50 years	4y for the fully automated, >40y with continuous improvements for the manual process

<u>Opportunities</u>

- Increased productivity
- Improvement of health and safety (myoskeletal, elimination of breathing glue fumes)
- Improved product quality

<u>Challenges</u>

- Quality
- Reliability
- Maintenance

3.4.2 Lift manufacturing industrial pilot case studies

Lift manufacturing pilot case studies		
	CS#2.1 Gluing reinforcement parts in the cabin’s false ceiling	CS#2.2 Floor covering material gluing and assembly
Short description	A process that involves handling the false ceiling and reinforcement parts. Several tasks such as transporting, marking, applying glue, placing and pressuring will be some of the tasks that AGIMUS will learn	In this case study, the workstation of gluing and assembling cabin side parts is involved. The procedure includes moving, applying glue, placing, pressuring and assembling (with screws).

Lift manufacturing pilot case studies		
	and perform during this case study.	
Number of people & their role	2 operators: • Placing, gluing and transport the false ceiling to the next workstation • Transport the false ceiling to the next workstation	2 operators: • Placing, gluing and transport the cabin's floor to the next workstation • Transport the false ceiling to the next workstation
Typical education level	Technical high school education	Technical high school education
Equipment used (robotics-related or not)	-Typical hand tools -Glue -Marker -Cutter -Self-made tools	-Typical hand tools -Glue -Marker -Cutter -Self-made tools
Use-case completion duration [min]	6min	12min
Needed space [m^2]	20m^2	20m^2
Materials wasted (material type & quantity [kg])	0,1kg	<1kg
Unplanned downtime [h]	0,5min (time waiting for the glue to dry)	0,5min (time waiting for the glue to dry)
Defect rate	0 defects	0 defects
Process variability (how often do you need to customize the product?)	Every product is customized	Every product is customized
Safety [average work accidents/year]	0 (employees are exposed to chemical fumes though)	0 (employees are exposed to chemical fumes though)
How long is the current solution used?	15 years	20 years

<u>Opportunities</u>

- Increased productivity
- Improvement of health and safety (myoskeletal, elimination of breathing glue fumes)
- Improved product quality

<u>Challenges</u>

- Operator acceptance
- Fear of possible injuries from the robot system
- Quality issues related to gluing

The 2nd case study (CS#2.2), originally named "Cabin side parts gluing and assembly", has been renamed "Floor covering material gluing and assembly". This change was made because the process for cabin side parts was decided to start being already automated. The requirements for gluing and assembling either the cabin side parts or floor covering material are essentially the same.

3.4.3 Packaging manufacturing industrial pilot case studies

Packaging manufacturing pilot case studies		
	CS#3.1 Gluing cardboard sides together	CS#3.2 Inserting small plastic pieces into the cardboard
Short description	Gluing cardboard sides together by replicating a gluing pattern observed from a human operator. Two separate pieces are glued together and the highly challenging task of folding the flexible cardboard sheets will be investigated.	Fine manipulation of a human operator required for insertion of several small plastic pieces into the cardboard display. Holes in the cardboard are prefabricated and haptic feedback is necessary to perform the insertion. AGIMUS will explore multimodal haptic and perception feedback for controlling the robot during the insertion task.
Number of people & their role	10 operators per shift (3 shifts) 2 managers	10 operators per shift (3 shifts) 2 managers
Typical education level	Operators: Primary school Managers: Vocational high school	Operators: Primary school Managers: Vocational high school
Equipment used (robotics-related or not)	Hand gluing gun Semi-automatic gluing machine Waste removing tool Pallet transporter Tables 3 Cutting Machines Digital Printing Machine	Hand gluing gun Semi-automatic gluing machine Waste removing tool Pallet transporter Tables 3 Cutting Machines Digital Printing Machine
Use-case completion duration [min]	Can vary significantly between products, depending on the specific requirements of the customer	Can vary significantly between products, depending on the specific requirements of the customer
Needed space [m^2]	~40	~40
Materials wasted (quantity & material type)	Average 12% waste per product (paper flute)	Average 12% waste per product (paper flute)
Unplanned downtime [h]	Average 15% downtime per month for the 3 Cutting Machines & the Digital Printing Machine	Average 15% downtime per month for the 3 Cutting Machines & the Digital Printing Machine
Defect rate	Average 3% per product	Average 3% per product
Process variability (how often do you need to customize the product?)	~90% of the products are created in collaboration with the customer and are essentially novel to the company	~90% of the products are created in collaboration with the customer and are essentially novel to the company
Safety [average work accidents/year]	4	4
How long is the current solution used?	4 years	4 years

Packaging manufacturing pilot case studies	
Opportunities • Increased productivity • Reduced stress for operators	Challenges • Safety

3.4.4 Additionally identified needs, challenges, barriers, drivers and enablers

From the case study information, the following needs, drivers and challenges of agile production were identified:

- Needs: Increased accuracy, Reliability, Maintainability, Safety
- Drivers: Waste reduction, Improved health, safety and reduced stress for operators, Cost reduction, Increased productivity and Improved product quality
- Challenges: Technology acceptance

In the following sub-sections, the items that were not covered in the desk research and are not considered to be self-explanatory are analysed:

3.4.4.1 Increased accuracy and product quality

Robotic systems that can perform tasks with high precision and accuracy can improve the efficiency and quality of manufacturing processes. Researchers have explored various methods to achieve higher accuracy in robotic systems, including advanced sensing and control strategies, machine learning algorithms and integration of vision systems (Sun et al., 2023).

3.4.4.2 Technology acceptance

To promote acceptance of new technologies, special consideration must be given to addressing psychosocial factors. This requires analysing user-interaction scenarios and taking into account worker-specific aspects such as ergonomics, skill levels, safety and comfort (Evjemo et al., 2020). Necessary evidence should be provided through best practices, lessons learned and recommendations, towards raising awareness and instigating the necessary discussions that will bring all involved stakeholders to the same table for carefully and successfully designing robotics that will be accepted by most actors (Michalec et al., 2021).

3.5 Initial baseline framework

The identified user requirements, i.e. the "needs", can be categorised into technical and ethical and along with the identified challenges, barriers, drivers and enablers incorporate the initial baseline framework for implementing agile production using versatile robotics. To provide a comprehensive overview of the initial baseline framework, a summary table is presented in Table 2.

Table 2: Initial baseline framework

<table>
<tr><th colspan="2">Technical requirements</th><th colspan="2">Ethical requirements</th></tr>
<tr><td colspan="2">– Adaptability
– Reliability
– Scalability
– Increased accuracy
– Maintainability
– Interoperability & interconnectivity</td><td colspan="2">– Safety
– Privacy
– Transparency
– Accountability
– Societal & Environmental well-being</td></tr>
<tr><th>Challenges</th><th>Barriers</th><th>Drivers</th><th>Enablers</th></tr>
<tr><td>– Exploitation of big data
– Human-Robot collaboration
– Technology acceptance</td><td>– Unclear scope or value proposition
– Low TRL
– Investment & Maintenance costs</td><td>– Competitiveness
– Customer satisfaction
– Return On Investment
– Waste reduction
– Reduced stress
– Cost reduction
– Increased productivity
– Improved product quality</td><td>– 5G communications
– Simulation techniques
– Ease of use
– Open-source software
– IT systems
– Standardisation
– Policy & Regulations</td></tr>
</table>

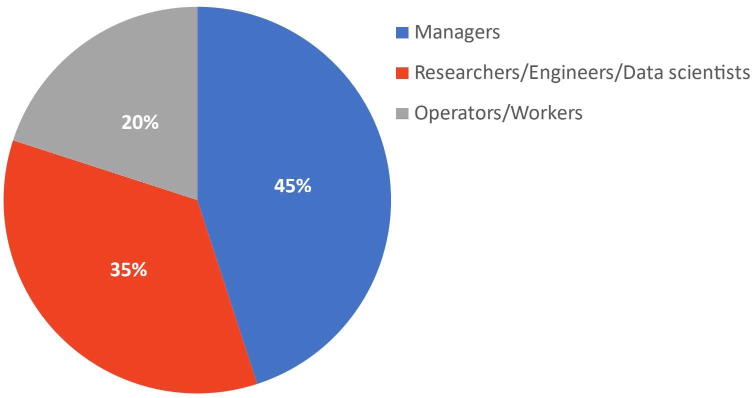
Taking into consideration the identified challenges, barriers, drivers and enablers, the aforementioned requirements will be transformed into specific functional and non-functional technical system requirements that will define AGIMUS's system architecture during the activities of T1.3.

4. Semi-structured interviews

4.1 Interviewee profiles

To validate previous findings and further develop a comprehensive understanding of the requirements, challenges, barriers, drivers and enablers of agile production using versatile robots, we carefully selected a diverse group of 20 interviewees from the consortium, the IAB and beyond. This sample included managers, researchers/engineers/data scientists and operators/workers. Examining all stakeholder groups was particularly necessary for eliciting ethical aspects, where a holistic approach is essential. The percentage of interviewees by designation is presented in Figure 2.

Figure 2: Interviewees' designation



All interviewees within our sample possess experience in agile production and/or robotics. The interviews were conducted in the interviewee's mother tongue, namely 5 in French, 6 in Greek, 6 in Czech and 3 in Spanish.

4.2 Key insights

Our initial baseline framework was validated by the interviewees, as evidenced by the qualitative insights gathered. This agreement between our framework and the opinions of key stakeholders with different backgrounds supports the consistency of our findings. Only a few dimensions were identified during the interviews that were not previously envisaged, and they are included in the following sections.

4.2.1 Requirements / Needs

4.2.1.1 Safety

Safety measures must be a top priority in agile production systems. It's important to provide workers with the necessary safety equipment and certify that they are adequately trained to operate the robotic machinery and safely coexist with it. The AI must be robust and warrant the protection of both the physical and mental health of the workers, but also the safety of the company's property.

As the market's demand for small series and complex orders increases due to the new trend of product personalisation, the companies have to welcome it.

4.2.1.2 Adaptability

The presence of versatile robotics in the production and their responsiveness to various conditions will enable workers to be more flexible and get on with other tasks (e.g., help someone else, work on another post, etc.). Nowadays, companies want to have production lines that are re-configurable.

4.2.1.3 Privacy

Privacy is considered essential for the smooth integration of AI technology into the production line. People from the industry, but also the academic sector, have perceived the installation of cameras or biometric data collectors as a means of monitoring their actions and productivity, raising privacy concerns. For this reason, robotic systems should be designed without retaining any sensitive information and ensure that their data are used only for robotic functions and not any other fraudulent purpose.

4.2.2 Challenges

Personnel training was identified as an additional challenge.

4.2.2.1 Personnel training

To implement agile production lines successfully, it's crucial to consider the necessary personnel training. Additional investment will be required to cover capital and operational costs, as well as hire qualified personnel with knowledge of versatile robotics technology. Employees need to be informed and understand the robots' ethical restrictions through GDPR seminars, communication and educational workshops.

Worker training is especially critical for older employees who may have settled into established work habits. To avoid overwhelming workers with complex manuals, training should be provided in their national language and presented in an easily understandable format.

4.2.2.2 Technology acceptance

Having a prior experience of a "positive change" can help build trust and improve acceptance of the robot in the workplace. Conversely, the lack of such experience may pose a significant risk of resistance to the new technology. Providing a clear explanation of the purpose of the robot can enhance its acceptance among employees, as they would gain a better understanding of its role and perceive it beyond just a machine. Employees would accept an AI technology that makes their lives easier, rather than a technology that is difficult to understand.

4.2.3 Drivers

The prestige of a company was identified as an additional driver.

4.2.3.1 Company's prestige

The deployment of AI-powered robotics and the awareness raising on this can enhance a company's prestige and potentially attract new customers.

4.2.3.2 Increased productivity

Versatile robots can increase production rate and efficiency by performing tasks that are traditionally done by humans, with higher speed, quality and precision. This is particularly beneficial for tedious and repetitive tasks that can cause fatigue and a decline in performance among operators. By taking over these tasks, AI-powered robots also allow operators to focus on more high-value tasks.

4.2.3.3 Customer satisfaction

Agile production can hyper-customize prototypes or even products according to the individual needs of users/customers. This is closer to "production as a service".

4.2.4 Enablers

4.2.4.1 Open-source software

Open-source software enables the sharing of advances and the definition of standards, promoting knowledge, not consumerism. It's a great way to engage young people to get involved in robotics and AI.

4.2.4.2 Standardisation

The robot downloads new policies, or new paths and work sequences, depending on the objects produced. Therefore, the robot must integrate with the system that manages the produced parts, to know for each product what to do. The robot control system must be integrated into the company's software architecture. The main challenge is not controlling the robot, but it's more a matter of software integration and the coexistence of different information management systems: at the low level, industrial sensors are on buses, exchanging data with protocols, which is not at all what is done in the laboratories with Robot Operating System (ROS) or ROS2 systems. The lack of standardisation presents a significant obstacle: while on the robotics side we may standardize with ROS2, on the industrial side each system has its own standard or practice.

4.2.5 Requirements, challenges, barriers, drivers and enablers preliminary classification

The elicited requirements, challenges, barriers, drivers and enablers of agile production using versatile robotics were classified by the percentage of respondents:

- who mentioned them (horizontal axis);
- of each individual stakeholder group who mentioned them (percentages inside each bar).

This classification serves as an indicator of the relative importance of these factors for each group of interviewees. The results of this analysis are presented in Figure 3.

Figure 3: Percentage of respondents per requirement, challenge, barrier, driver and enabler and per stakeholder group

Regarding the requirements, the significance of safety in agile production utilizing adaptable robotics is apparent, but there are differing global priorities among Managers, Researchers/Engineers/Data scientists and Operators/Workers. Managers prioritized safety and adaptability, while Researchers/Engineers/Data scientists prioritized adaptability and societal & environmental well-being. Operators/Workers valued safety, adaptability, reliability and maintainability equally.

The ultimate driver is customer satisfaction, which is important to all stakeholders. However, Managers seem to prioritize cost reduction.

Ease of use strikes out as the most important enabler, according to 100% of Operators/Workers and approximately 50% of other stakeholders. Researchers/Engineers/Data scientists prioritized IT systems, whereas Managers assigned higher value to 5G communications.

Finally, it seems that managers give greater emphasis to the challenges and barriers associated with implementing agile production using versatile robotics. Among them, 78% mentioned personnel training and technology acceptance (most significant challenge overall), as well as unclear scope or value proposition and investment and maintenance costs (most significant barrier overall).

4.3 Lessons learned

4.3.1 How were previous technology changes seen by the employees

Workers generally welcome new technologies that are perceived as personal assistance devices, such as exoskeletons designed to prevent Repetitive Strain Injury (RSI) or improve ergonomics and that make their work easier. On the other hand, technologies that require more knowledge, are too complex to understand, or raise privacy concerns, such as cameras or biometric data collection devices, have been met with resistance. The younger employees are more open to adopting new technologies, while the older employees tend to be more sceptical.

Acceptance of technological changes is influenced by various factors, such as workplace quality, corporate culture, trust in management and effective communication. Introducing new technologies and accelerating their acceptance requires proper training, information and open discussions.

4.3.2 Concerns regarding job loss

AI-powered solutions can reduce laborious and stressful tasks, increase productivity, quality and speed and improve safety in the workplace. However, particularly elder operators who perform laborious, repetitive tasks, are frequently not willing to learn new skills, fear to interact with AI and fear that they will be replaced by robots.

If we view robots solely as economic drivers for growth and profit, it is understandable to assume that there is a high probability that they will be the main option for several industrial shop floor tasks, that are currently being performed manually. However, if we prioritize the well-being of humans and the environment, a well-considered economic model that distributes the value of production equitably can uncover the advantages of AI-powered robotics for humans from a different standpoint. These benefits include increased human resources, collaboration, diversification of responsibilities, delegation of tedious, labour intensive and repetitive tasks, optimization of resources and more.

Even though there is indeed a quite likely case that AI-powered robots will undertake such tasks, new opportunities are expected to also arise from their deployment. Therefore, it is important to implement measures to mitigate the associated negative consequences and leverage new opportunities, by implementing retraining/re-skilling programs and/or employment in new areas. Government policies and regulations should be established to impose such guidelines and facilitate the transition of industrial towards such automation.

4.3.3 Issues with the broad use of cloud applications and 5G for AI applications

While cloud applications and 5G were previously identified as enabler, their widespread use can also give rise to several challenges, such as unstable networks, system failures, misinformation of workers, cyber threats and concerns over data privacy from customers. Despite these potential issues, the need for constant cloud communication may not be necessary during the deployment and training phases and the use of cloud computing can still be beneficial if the downtime costs are low.

5. EAB workshop

Ethics is a complex and multifaceted field concerned with examining and evaluating the moral implications of actions, decisions and behaviours. It involves reflecting on values, principles and moral obligations and applying them to real-world situations. As a matter of fact, ethics is all about deciding what should be considered as right or wrong, good or bad, after weighing all different aspects. Due to this subjectivity, the meaning of ethics can differ considerably across companies or organizations, rendering the classification of ethical requirements redundant.

The objective of this chapter is not to address philosophical questions about ethics, but to guide the realization of AGIMUS' solution, by identifying specific ethical design requirements for next-generation AI-powered robotics for agile production, based on the activities and findings of T1.2.

To this end, the EAB along with two external AI ethics experts, suggested leveraging a Fundamental Rights Impact Assessment (FRIA) and the EC's Ethics Guidelines for Trustworthy AI, reinforcing our decision to base on these guidelines during the desk research. However, it was made clear that all the ethical concerns mentioned may be relevant and therefore need to be potentially considered. As a result, the following ethical requirements were established.

5.1 Ethical requirements

First of all, AGIMUS' solution has to respect and uphold the following fundamental rights of humans, namely, it should:

I. not discriminate against people on the basis of any of the following grounds (non-exhaustively): sex, race, colour, ethnic or social origin, genetic features, language, religion or belief, political or any other opinion, membership of a national minority, property, birth, disability, age or sexual orientation;
II. protect personal data relating to individuals in line with GDPR;
III. respect the freedom of expression and information and/or freedom of assembly and association.

Furthermore, it is imperative to adhere to the four ethical principles and seven key requirements specified in the EC's Ethics Guidelines for Trustworthy AI.

The four ethical principles are:

1. Respect for human autonomy
   AI should respect individuals' freedom and agency and not be used to manipulate, exploit, or restrict individuals' autonomy.
2. Prevention of harm
   AI should not cause harm to individuals or society, and steps should be taken to prevent harm and address harm that has occurred.
3. Fairness
   AI should be developed and used in a way that is fair, impartial and non-discriminatory.
4. Transparency

AI systems should be transparent in their functioning and decision-making processes, allowing individuals to understand and challenge the basis for decisions made about them.

The seven key requirements that AI systems should meet to be considered trustworthy are summarized next:

I. Human agency and oversight
AI systems should enable human beings to make informed decisions and exercise appropriate oversight.

II. Technical robustness and safety
   a. Resilience to attack and security
   b. Fallback plan and general safety
   c. Accuracy
   d. Reliability
   e. Reproducibility

   AI systems should be designed and developed in a way that ensures their technical robustness and safety.

III. Privacy and data governance
   a. Privacy and data protection
   b. Quality and integrity of data
   c. Access to data

   AI systems should respect and protect privacy and personal data and ensure the responsible use of data.

IV. Transparency
   a. Traceability
   b. Explainability
   c. Communication

   The AI systems' operation should be transparent and their decisions and outcomes should be explainable.

V. Diversity, non-discrimination and fairness
AI systems should be developed and implemented in a way that respects diversity, ensures non-discrimination and promotes fairness.

VI. Societal and environmental well-being
   a. Sustainable and environmentally friendly AI
   b. Social impact
   c. Society and Democracy → not applicable in our case

   AI systems should be designed to contribute to the overall well-being of society and the environment.

VII. Accountability
   a. Auditability
   b. Minimisation and reporting of negative impacts
   c. Trade-offs
   d. Redress

   Mechanisms should be put in place to ensure accountability for the development and use of AI systems.

It is worth mentioning, that through this process, standards such as IEEE P7000 Model Process for Addressing Ethical Concerns During System Design, ISO standards and GDPR as well as self-evaluation methodologies such as the EC's Assessment List for Trustworthy Artificial Intelligence (ALTAI) and the National Institute of Standards and Technology (NIST) Artificial Intelligence Risk Management Framework (AI RMF) were also detected.

All the aforementioned guidelines provide a framework for organisations and individuals developing and using AI to ensure that the technology is developed and used in a responsible and ethical manner. To address these guidelines, organisations can develop and implement policies, procedures and processes that align with the ethical principles and key requirements and regularly assess and update their practices to ensure that they remain compliant. Additionally, organisations can engage with stakeholders, including customers, employees, regulators and experts in AI ethics, to ensure that their AI practices are transparent, accountable and aligned with the principles of trustworthy AI.

5.2 Updated baseline framework

The initial baseline framework was revised by incorporating the additional ethical requirements that were identified with the help of the EAB and AI ethics experts. The revised framework is presented in Table 3.

Table 3: Updated baseline framework

<table>
<tr><th colspan="2">Technical requirements</th><th colspan="2">Ethical requirements</th></tr>
<tr><td colspan="2">– Adaptability
– Reliability
– Scalability
– Increased accuracy
– Maintainability
– Interoperability & interconnectivity</td><td colspan="2">– Technical robustness & Safety
– Human agency & oversight
– Privacy & Data governance
– Transparency
– Accountability
– Societal & Environmental well-being
– Diversity, non-discrimination and fairness</td></tr>
<tr><th>Challenges</th><th>Barriers</th><th>Drivers</th><th>Enablers</th></tr>
<tr><td>– Exploitation of big data
– Human-Robot collaboration
– Technology acceptance</td><td>– Unclear scope or value proposition
– Low TRL
– Investment & Maintenance costs</td><td>– Competitiveness
– Customer satisfaction
– Return On Investment
– Waste reduction
– Reduced stress
– Cost reduction
– Increased productivity
– Improved product quality</td><td>– 5G communications
– Simulation techniques
– Ease of use
– Open-source software
– IT systems
– Standardisation
– Policy & Regulations</td></tr>
</table>

The requirement of "Safety" was expanded to include "Technical Robustness & Safety", "Privacy" was expanded to "Privacy & Data Governance", while two additional ethical requirements, namely "Human Agency & Oversight" and "Diversity, Non-Discrimination and Fairness", were added.

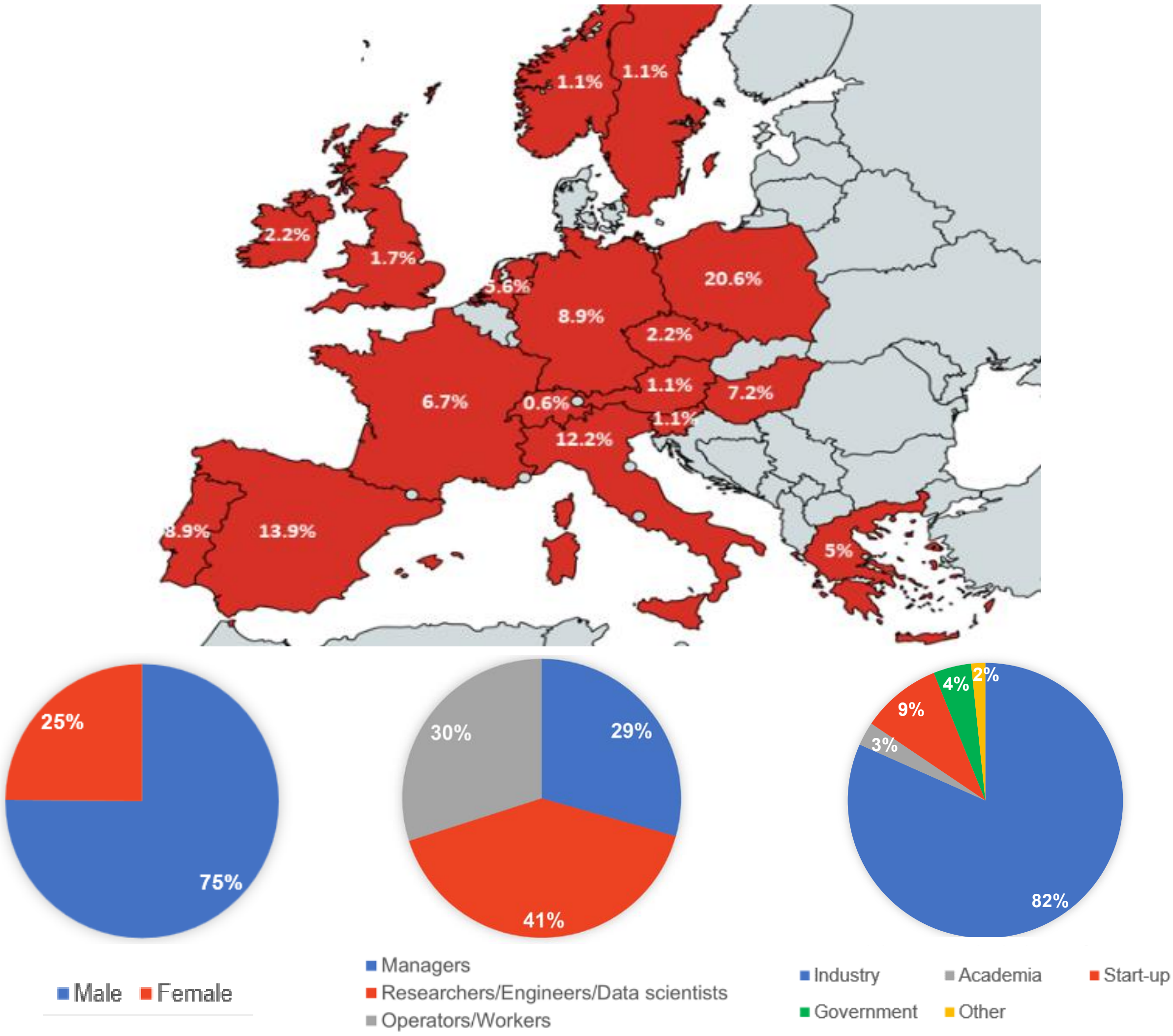
6. Online survey

The results of desk research, semi-structured interviews and the EAB workshop served as the foundation for a tailored survey on the use of versatile robotics in agile production. Uploading the survey online provided the opportunity to stress-test and classify the identified dimensions with a significantly larger sample size.

6.1 Sample and respondents

Of the 264 responses we received, 180 valid answers from individuals involved with agile production and/or versatile robotics in Europe were chosen, as explained in section 2.5. Figure 4 provides an overview of our sample profile along with its characteristics.

Figure 4: Demographics of respondents by Country, Gender, Organisation Type and Designation



The study examined a sample that was relatively evenly distributed among Managers, Researchers/Engineers/Data scientists and Operators/Workers. About 82% of the sample worked in the industry. Although most respondents had a expressed a positive understanding of versatile robotics, a non-negligible minority (11.7%) disagreed or strongly disagreed with that. Due to the applied eligibility criteria presented in section 2.5, none of the selected respondents disagreed or strongly disagreed when asked about their good comprehension of agile production.

6.2 Key insights

6.2.1 Requirements, challenges, barriers, drivers and enablers classification

The elicited technical requirements, challenges, barriers, drivers and enablers of agile production using versatile robotics, were classified according to the Weighted Mean Value (WMV) of importance derived by:

- all stakeholders (horizontal axis)
- each individual stakeholder group (WMVs inside each bar)

To calculate the WMVs, responses ranging from “Not important” to “Extremely important” were assigned scores from 1 to 5 respectively. Then for all stakeholders:

$$WMV_{aspect} = \frac{\sum_{i=1}^{5} N_{i_{aspect}} * i}{N}$$

where:

- $N_{i_{aspect}}$ the population of all stakeholders who gave “i” as score to the examined aspect
- N the total stakeholder population (i.e. 180 in our case)

and for each stakeholder group “x”:

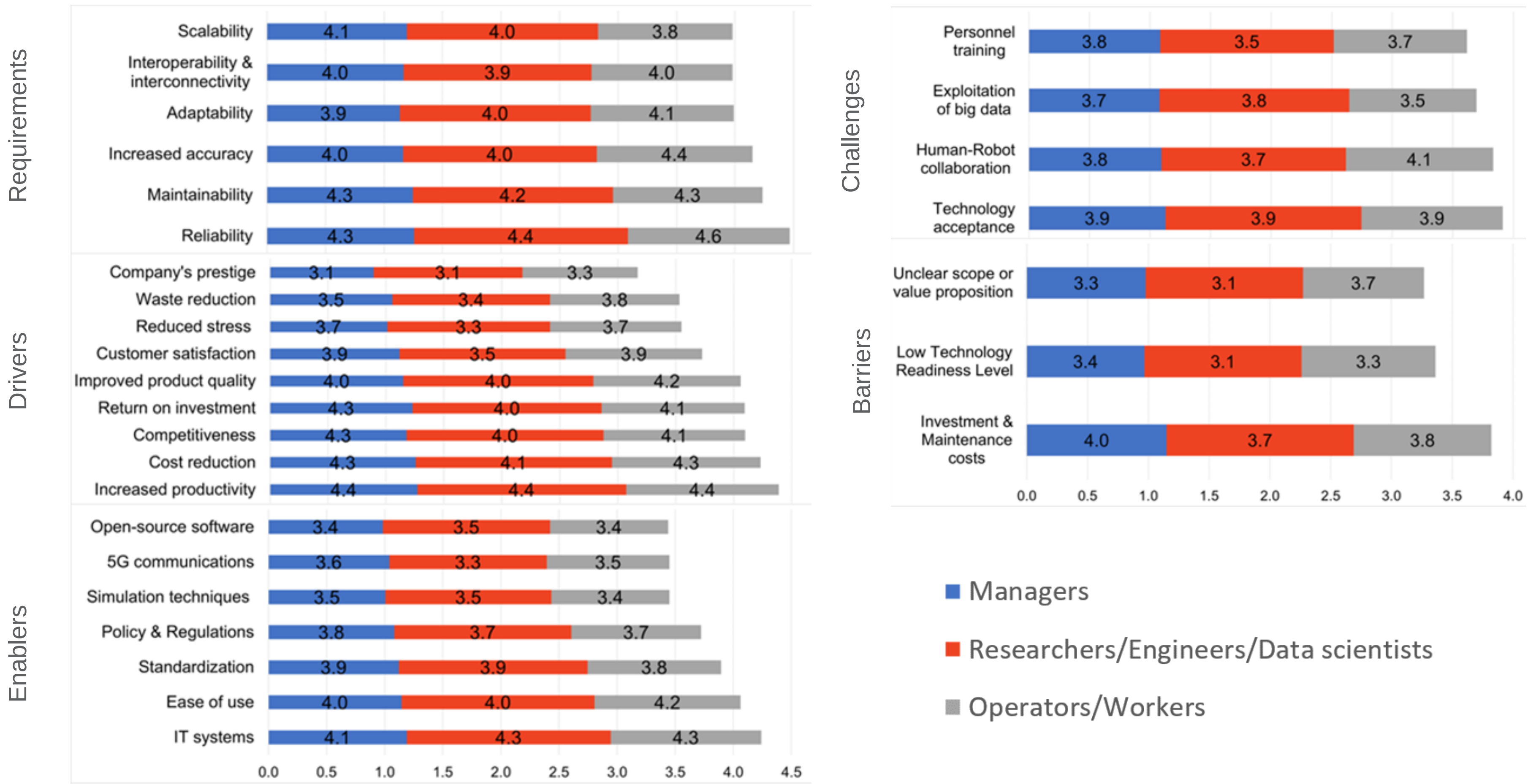
$$WMV_{aspect_x} = \frac{\sum_{i=1}^{5} N_{x_{i_{aspect}}} * i}{N_x}$$

where:

- $N_{x_{i_{aspect}}}$ the population of the stakeholder group “x” who gave “i” as score to the examined aspect
- N_x the total population of the stakeholder group “x”

Figure 5 provides a summary of these results. This classification method was not applied to ethical requirements, as ethics is about deciding how to deal with conflicting interests. In such cases, solutions need to be deliberated and justified while upholding the values of the decision maker, such as a company, and minimizing any potential negative impacts. Due to the substantial variability in how different entities value ethical requirements, attempting to categorize them would be futile, as discussed in the first paragraph of Chapter 5.

Figure 5: WMV of importance per technical requirement, challenge, driver, barrier, enabler and per stakeholder group



*Scores:

1: Not important
2: Slightly important
3: Moderately important
4: Very important
5. Extremely important

The survey results seem notably more uniform than the interview results discussed in section 4.2. This is because the interviewees did not have access to a complete list of the requirements, challenges, drivers, barriers and enablers during the interviews, resulting in them only mentioning the most crucial items. Nevertheless, the interview and survey outcomes align effectively in terms of the most essential aspects within these categories:

- **Adaptability** and **Reliability** emerged as the most frequently mentioned **technical requirements** in the interviews and were rated above "Very important" in the online survey.
- **Ease of use** and **IT systems** were the most frequently mentioned **enablers** in the interviews and were all rated above "Very important" in the online survey.
- **Technology acceptance** and **Human-Robot collaboration** were the most frequently mentioned **challenges** in the interviews and were also the highest rated in the online survey. They were rated a bit below “Very important”.
- **Investment & Maintenance costs** and **Unclear scope or value proposition** emerged as the most frequently mentioned **barriers** in the interviews, with all identified barriers rated from “Moderately” to “Very important” in the online survey.
- In the interviews, the 2nd and 3rd most frequently mentioned **drivers** were **Increased productivity** and **Cost reduction**, both rated above "very important" in the online survey.
  The only mentionable deviation is the customer satisfaction aspect, which was the most frequently answered driver in the interviews but did not make it to the top 5 in the survey, still being rated close to “Very important”.

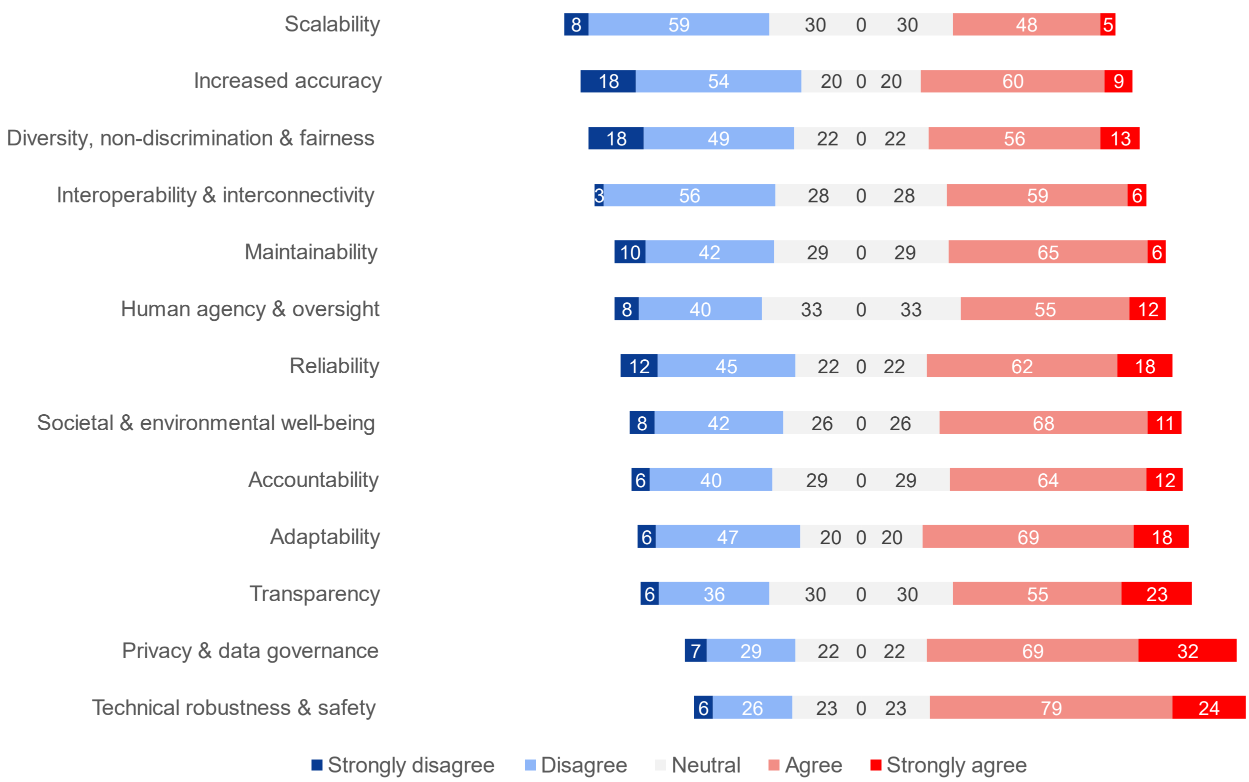
For all stakeholder groups, all the identified aspects were rated as moderately important or higher.

In addition, the survey uncovered some intriguing findings, that will be addressed next.

6.2.2 How difficult will it be to achieve the identified requirements

The participants in our survey were questioned about their thoughts on whether it would be difficult to achieve the requirements listed on the left side of Figure 6. The right side of this figure displays the number of respondents who provided responses ranging from "Strongly Disagree" to "Strongly Agree”.

Figure 6: Difficulty in meeting requirements for versatile robotics in agile production



Justifications from those who selected "Strongly Agree" were requested and the most significant of them are presented in the following sub-sections.

6.2.2.1 Technical robustness & Safety

Ensuring safety and security is crucial for the efficient and secure evolution of intelligent systems. The safety and health of human operators must not be compromised and robots should be able to work alongside them without safety barriers.

In addition to safety, protecting robotic systems from malicious attacks is essential, as hackers are advancing at the same pace as protection measures. Despite efforts to improve security, data is never managed securely and accidents still occur, highlighting the need for robust cybersecurity measures.

Intelligent systems' reproducibility is also challenging to attain because it necessitates precise knowledge of the inference process.

6.2.2.2 Privacy & Data governance

The increasing use of robotic systems, AI technology and data farming programs/machines in data collection and processing can pose serious challenges for data privacy and protection. The potential for mistakes leading to data leaks, private information being sold to third parties and unpredictable actions by robots can exacerbate these issues. Additionally, with big corporations providing AI technology as a service, smaller companies may be at the mercy of the provider.

6.2.2.3 Transparency

Ensuring transparency in the use of versatile robots in agile production is essential to building trust with stakeholders, which can be challenging to achieve when dealing with complex systems and processes. Explanation of AI is one of the least transparent and solved topics now and it comes together with all questions about the reliability, assigning responsibility to AI and trusting it to make fair choices. Additionally, companies may choose to keep their manufacturing processes secret to maintain a competitive advantage, leading them not to be transparent.

6.2.2.4 Adaptability

The adaptability of a system depends on its architecture. If it is trained for only one task, it will only perform that task in the specific environment it was trained for. However, if the system learns over time, there is a risk of learning unwanted behaviours.

Adapting the mindset to agile robotic production will be a challenge, and it will require a trial-and-error approach. A robot that is trained to perform a specific task in a particular environment and under specific circumstances may not be able to generalize its task if the environment changes significantly enough. For example, an autonomous robot trained to recognize images of a factory's interior may not be able to perform the same task with natural noise present in other environments.

6.2.2.5 Social & Environmental well-being

The development of robotics and AI within the current economic model, based on growth and strong reliance on automation, may exacerbate existing social inequalities and tensions, including the reduction of job opportunities. While some argue that automation can enhance societal and environmental well-being, it can be difficult to convince people to fully embrace it. Additionally, the speed at which machines operate can be overwhelming for human workers, potentially creating disparities between humans and robots in completing certain tasks.

6.2.2.6 Reliability

The lack of reliability is the primary reason why human resources remain the main operators, as the industry needs to invest in innovation to enable robots to take over. Robots are mechanical machines that have many moving parts, requiring lubrication, and developing reliable software to control their hardware can be challenging. Additionally, the success and reliability of the system in robotization is not only dependent on the constant and dependable functioning of the robot, but also on the way that humans interact with those robots, as well as the configurations of software and hardware.

6.2.2.7 Human agency & oversight

The implementation of advanced robotics technology in industries will require more expert and highly qualified labour, who must be properly trained to operate and maintain the complex systems. However, the success of implementation heavily relies on the human factor, as the lack of well-trained staff and adequate policies can hinder the adoption of new technology.

One of the main challenges in the adoption of robotics technology is the lack of trust that most people have in robots. People can easily get distracted and may not readily accept the idea of working with robots. Moreover, not everyone is fully prepared to commit to a fully robotic industry, as not everyone can understand the intricacies of how it works.

6.2.2.8 Maintainability

The high cost of robotic systems and the rapid evolution of technology can make it difficult to keep up with necessary updates and repairs. As more machines are employed, the need for maintenance increases. Additionally, malfunctions in robotics systems are not uncommon.

6.2.2.9 Interoperability & interconnectivity

Establishing interoperability between robotic systems necessitates a common standard, which must undergo multiple iterations of change and optimization to fit all systems. However, creating a standard can be challenging since various robot suppliers use their own operating systems, which can make interconnectivity problematic.

6.2.2.10 Diversity, non-discrimination & fairness

To achieve diversity and equity in robotics technology, it is essential to consider the needs and abilities of a diverse range of users, including factors such as gender, ethnicity, age, disability, and cultural background. However, this can be challenging because much of the data available for training robotic systems is biased and limited to certain social groups or regions. It is crucial to prevent the perpetuation of harmful human biases in AI by ensuring that datasets are diverse and inclusive. By doing so, we can create robotics technology that benefits everyone and promotes equality.

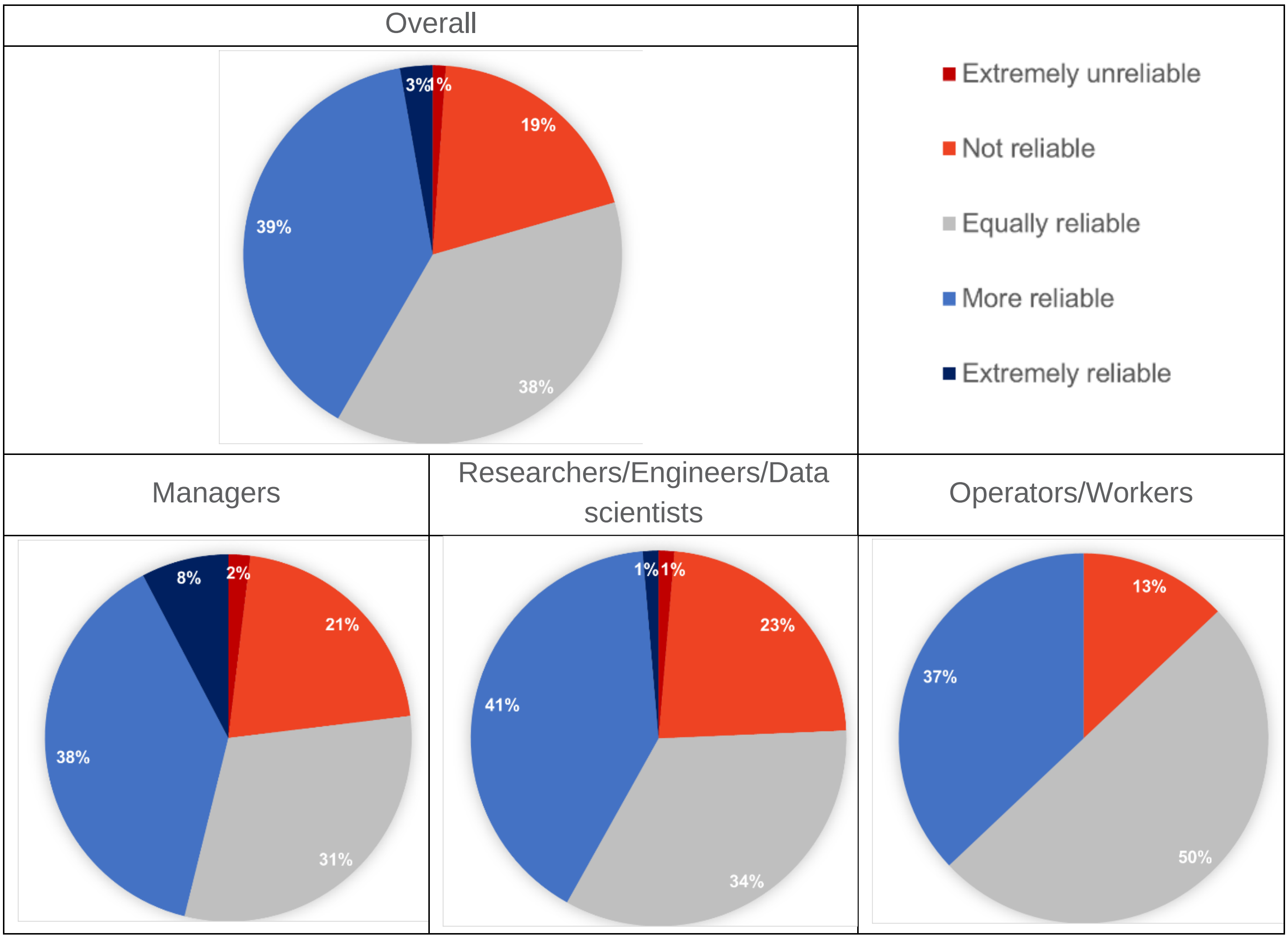
6.2.2.11 Scalability

If a robot is trained to execute a specific task under certain circumstances in a particular environment, it might not be able to extend its ability to other environments if there are substantial changes in the environment. For instance, an autonomous robot that is taught to identify images inside a factory might fail to complete the same job when there is natural interference in other areas, jeopardising its scalability.

6.2.3 How reliable are AI-powered compared to classical engineering-based solutions

To gain further insight into reliability, the survey participants were requested to compare the reliability of AI-powered solutions with classical engineering solutions. The summary of their responses is presented in Figure 7.

Figure 7: Understanding stakeholders' opinion on the reliability of AI-powered vs engineering-based solutions



One notable point is that 46% of managers place more trust in AI-powered solutions than engineering-based ones, as compared to 42% of Researchers/Engineers/Data scientists, 37% of Operators/Workers who share the same opinion and to ~42% if we take into account all stakeholder groups.

Moreover, 23-24% of Managers and Researchers/Engineers/Data scientists expressed doubts about the reliability of AI-powered solutions in comparison to engineering-based solutions. In contrast, only 13% of Operators/Workers share the same level of scepticism.

According to the respondents, the reliability of AI-powered solutions compared to classical engineering-based solutions depends on the specific application. AI-powered solutions have the potential to be very reliable, when it comes to analysis of large amounts of data and predictivity based on patterns that humans may not be able to detect. However, AI is not yet capable of understanding engineering problems that require creativity and understanding of design consequences. A properly designed AI-powered system can be more error-resistant than a human-based system, but the reliability of AI-powered solutions is heavily dependent on the potential for bias and the quality of the data used to train them.

6.2.4 Impact of the advent of versatile robotics

Our survey participants were requested to indicate whether they agreed that the introduction of versatile robotics would have a beneficial impact on areas that significantly influence their professional lives. The items that were considered are listed on the left side and the number of respondents who provided responses ranging from "Strongly Disagree" to "Strongly Agree" are displayed inside the horizontal bars in Figure 8.

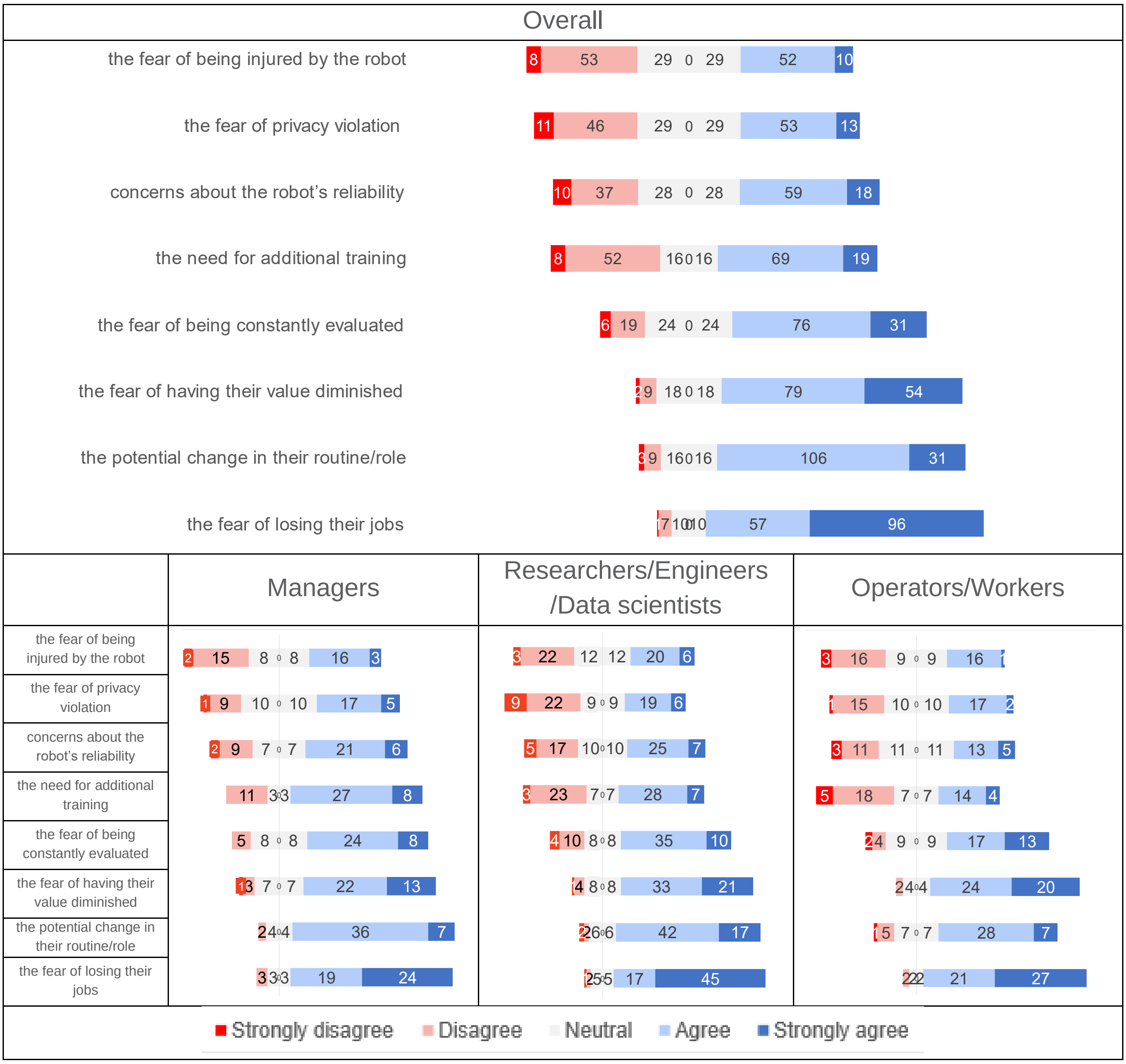
Figure 8: Examining the positive effects of implementing versatile robotics

Overall, the results suggest that versatile robotics have the potential to enhance various aspects, such as health and safety, work-life balance, job satisfaction and the creation of higher-income jobs. Nevertheless, the survey respondents from all stakeholder groups confirmed the apprehensions expressed during the interviews regarding potential job losses resulting from the adoption of these technologies.

6.2.5 Operators'/Workers' potential opposition to versatile robotics

Our survey participants were then asked about the reasons they believed Operators/Workers would oppose to the introduction of and cooperation with versatile robotics. The possible reasons are listed on the left side and the number of respondents who provided responses ranging from "Strongly Disagree" to "Strongly Agree" are displayed inside the horizontal bars presented in Figure 9.

Figure 9: Understanding Operators'/Workers' resistance to versatile robotics



According to the survey results, the primary reason for Operators/Workers to resist the implementation of versatile robotics is the fear of job loss. Other notable concerns mentioned include potential changes to their routine or role, apprehension about their value being reduced and the fear of constant evaluation.

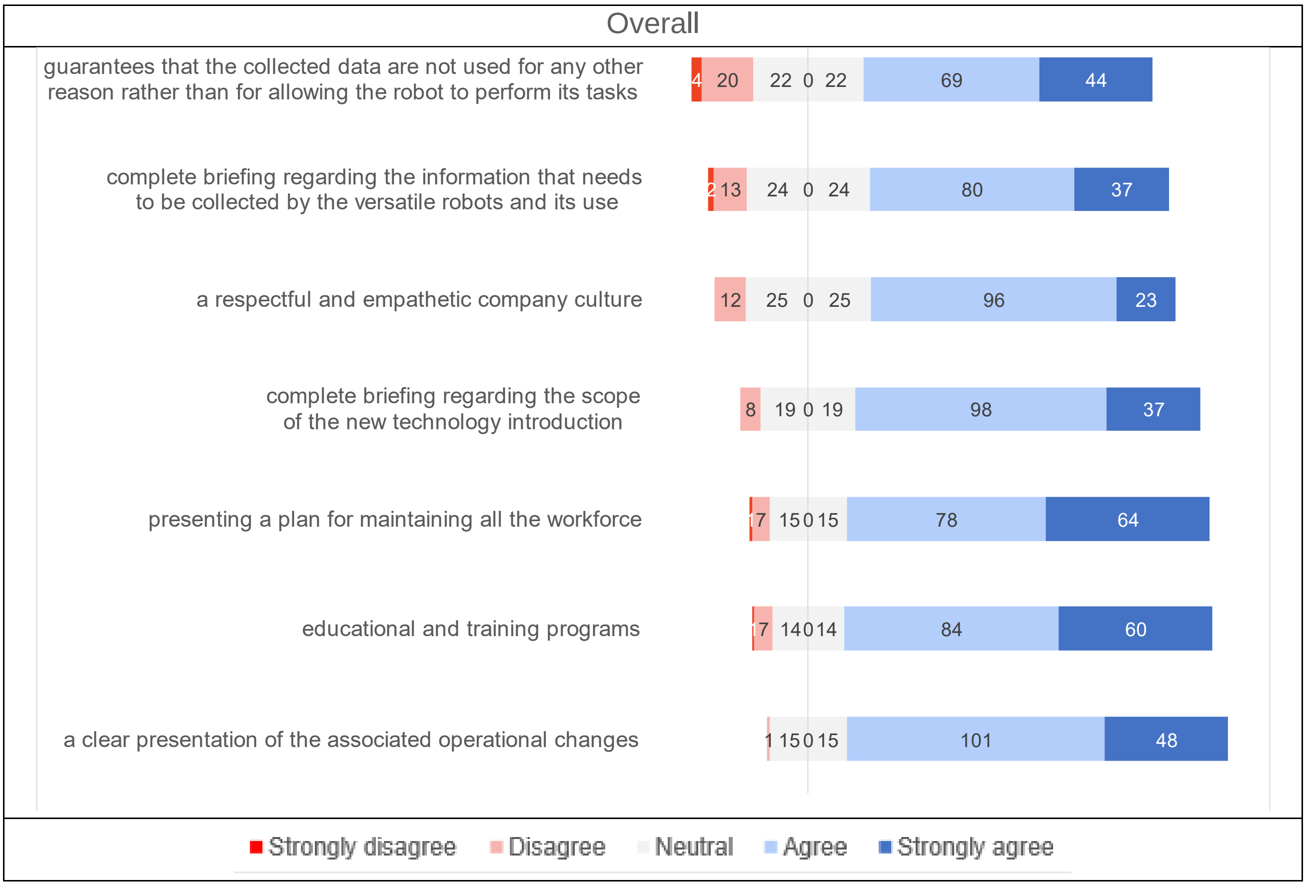
The responses of the Operators/Workers themselves indicate that their fear of having their value diminished due to the advent of versatile robots is considerably more significant than any unwillingness regarding changes to their routine/role. Nevertheless, the unwillingness regarding changes to their routine/role still ranked third.

Additionally, the majority of operators/workers disagreed that the need for additional training is a drawback for them.

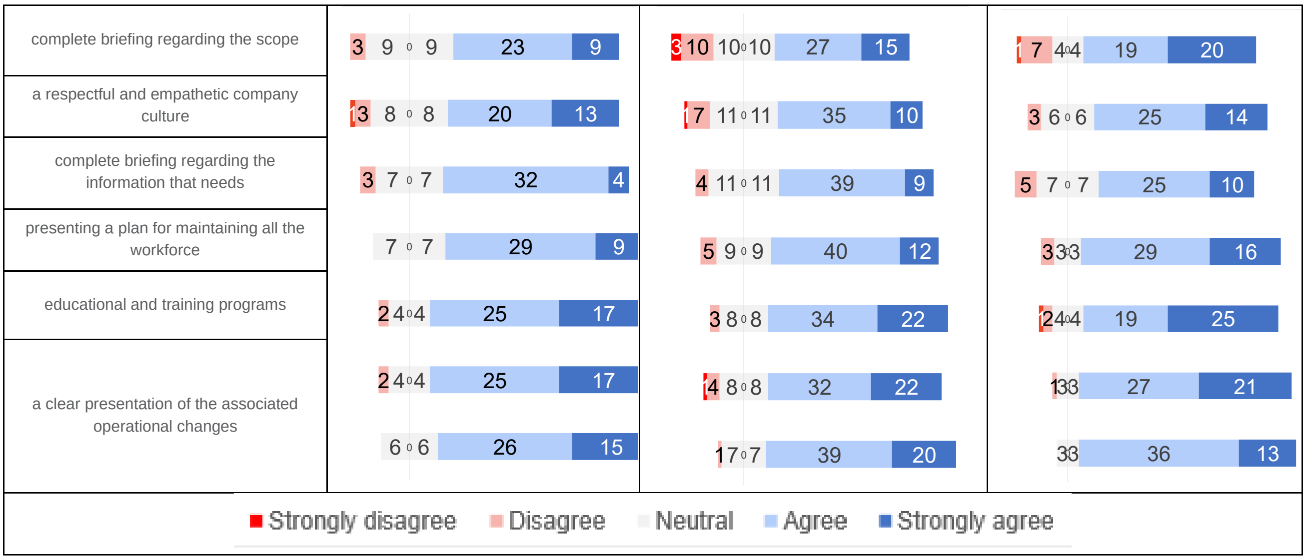
6.2.6 How can acceptance of versatile robotics be achieved

Finally, the survey participants were queried about the extent to which they concurred with the methods presented on the left side of Figure 10 for attaining acceptance and trust of versatile robotics. Inside the horizontal bars below, the number of respondents who provided answers ranging from "Strongly Disagree" to "Strongly Agree" is presented.

Figure 10: Understanding Operators'/Workers' resistance to versatile robotics



	Managers	Researchers/Engineers /Data scientists	Operators/Workers
guarantees that the collected data are not used for any other reason rather than for allowing the robot to perform its tasks			



All the proposed methods received positive evaluations by all stakeholder groups, with the highest number of "Strongly Agree" responses being obtained for "presenting a plan for maintaining the entire workforce".

7. Conclusions & Next steps

This report provides a comprehensive overview of the agile production landscape, covering the associated technical and ethical requirements, challenges, barriers, drivers and enablers, with a special emphasis on the use of versatile robotics. Employing a user-centre methodology the analysis covered an extensive desk research that was validated and fine-tuned by 22 semi-structured interviews with key technical and ethics experts, actively engaging with both the IAB and EAB. Following a wider online survey expanded the gathered knowledge collecting 264 responses, out of which 180 have been analyzed. Key insights for the aforementioned elements were included in sections 3.3, 4.2, 4.3 and 6.2 to provide context and enhance understanding. The summary of all the aforementioned aspects constitutes the baseline user-driven framework for guiding the implementation of the AGIMUS solutions:

<table>
<tr><th colspan="2">Technical requirements</th><th colspan="2">Ethical requirements</th></tr>
<tr><td colspan="2">– Adaptability
– Reliability
– Scalability
– Increased accuracy
– Maintainability
– Interoperability & interconnectivity</td><td colspan="2">– Technical robustness & Safety
– Human agency & oversight
– Privacy & Data governance
– Transparency
– Accountability
– Societal & Environmental well-being
– Diversity, non-discrimination and fairness</td></tr>
<tr><th>Challenges</th><th>Barriers</th><th>Drivers</th><th>Enablers</th></tr>
<tr><td>– Exploitation of big data
– Human-Robot collaboration
– Technology acceptance</td><td>– Unclear scope or value proposition
– Low TRL
– Investment & Maintenance costs</td><td>– Competitiveness
– Customer satisfaction
– Return On Investment
– Waste reduction
– Reduced stress
– Cost reduction
– Increased productivity
– Improved product quality</td><td>– 5G communications
– Simulation techniques
– Ease of use
– Open-source software
– IT systems
– Standardisation
– Policy & Regulations</td></tr>
</table>

While this framework offers guidance for the AGIMUS solution, it is important to note that it may evolve over time and require periodic updates to address emerging issues and changing circumstances.

7.1 Next steps

The knowledge gained from this report will primarily fuel the activities of T1.3, which aims to identify AGIMUS' system requirements. The dimensions identified and validated in terms of needs, challenges, barriers, drivers and enablers will serve as the building blocks for the AGIMUS framework to develop a solution, or set of solutions, that will address these topics, translating them into functional and non-function system requirements, while designing the overall system architecture. Moreover, the groundwork for the 1st training workshop/winter school in December 2023 will be laid. The consortium has decided to incorporate the preliminary findings from T1.3 activities into this workshop and to organize the school in a timely manner to engage as many academic stakeholders as possible.

In addition, the case study exploration that began in the context of T1.1 will continue through T6.1, where further emphasis will be placed on the design and preparation of the industrial pilots and their case studies.

Regarding T7.1, key insights of this report will feed the creation of dissemination and communication material, such as infographics and scientific publications. This material will help raise awareness of the topic and promote knowledge transfer. Under T7.4, discussions with projects and initiatives that were already identified mainly during the interview and online survey activities, will be followed-up, in order to establish fruitful synergies. Meanwhile, T7.3 will rely on market insights to inform business modelling and planning activities.

Ultimately, openly available resources included in the Annex, can be utilized for expanding research activities.

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Annex

Interview guidelines

Questions

No	Interview's topics/questions	Notes for interviewers *(to activate/trigger the dialogue, or give some hints, explanations, or examples)*
1	**What is the definition you would give on agile production?**	Guide the interviewee if his/her definition is ambiguous. Indicative definition: *"Agile production is a term applied to an organisation that has created the processes, tools, and training to enable it to respond quickly to customer needs and market changes while still controlling costs and quality. It is seen as the next step after lean manufacturing in the evolution of production methodology."*
2	**How do you envision versatile robotics could address the agile production line needs?**	Indicative definition: "*Versatile robotics are robotic systems able to quickly adjust and adapt to many different functions, activities or changes,*

No	Interview's topics/questions	Notes for interviewers *(to activate/trigger the dialogue, or give some hints, explanations, or examples)*
		causing minimum interruption to the production process."
3	**Are you aware of any versatile robotics solutions for agile production?** **Are you aware of any available or forthcoming technological solutions for agile production?**	Goal: to find out about the competition e.g., advanced perception algorithms, Task-And-Motion Planner, Cloud systems and Internet of Things
4	**Which are the 5 most important needs of agile production lines in your opinion? Why? Does the use of versatile robotics create more/different needs? Why?**	-
5	**What kind of technologies were you using instead of robotics? When did you first use robotic systems? What kind of robotics did you use?**	-
6	**Which were/are the most important drivers of implementing agile production in general and versatile robotics in particular? Why?**	e.g., Industry, customers' requirements, infrastructure, government policies, company interests, other
7	**How were technology changes in your production process seen by the employees? What allowed them to take place? What did perhaps decelerate/accelerate their progress or reduce/increase their acceptance?**	-
8	**Do you have in mind any measurable changes depicting the impact of introducing agile production methods in general and the use of versatile robotics in particular?**	with respect to productivity, efficiency, quality, profit, other

No	Interview's topics/questions	Notes for interviewers *(to activate/trigger the dialogue, or give some hints, explanations, or examples)*
9	**Which are the 5 most important challenges that agile production lines face in your opinion? Why?** **Does the use of versatile robotics create more/different challenges? Why?**	e.g., culture, access to properly skilled human capital, technology, regulations, policy support e.g., excessive deployment time, maintenance, costs, any other particularity
10	**To which extend are AI-powered solutions beneficial for the employees? Which employee category do you expect to oppose to the deployment of AI-powered solutions?**	e.g., impact on the work life quality, specialized training and abilities may be needed in order to integrate robots in the production line and work with them, patiently teaching a robot how to carry out repetitive tasks may be required
11	**What would you consider as sufficient guarantee regarding the responsibility and accountability of an AI-powered solution, before integrating it into the production line?**	e.g., performance metrics; safety guarantee about the behavior of the robot; explicability of the robot behavior (for example displayed on an external screen or leading to interpretable movements); safety measures in case of failure; time-to-reset metrics
12	**How reliable do you consider AI-powered compared to classical engineering-based solutions? How reliable would you like an AI-powered solution to be in order to consider integrating it or replacing your current solution?**	The interviewee should provide a quantitative metric (e.g., the success rate regarding a specific task) if possible
13	**Have you considered the environmental & energy cost of deploying AI-powered solutions to your company/organisation? If you are already using AI-powered solutions, have you considered using more efficient algorithms to reduce the environmental impact?**	e.g., energy consumption, type of energy used by the data centres, hidden costs of cloud-based solutions

No	Interview's topics/questions	Notes for interviewers *(to activate/trigger the dialogue, or give some hints, explanations, or examples)*
14	**There are concerns that AI-powered solutions, such as versatile autonomous robots, will replace workers. What is your point of view and which do you consider to be an ethical approach to this deployment?**	-
15	**AGIMUS' framework results are expected to be the foundation of an open-source, international, robotics software consortium. What kind of benefits would your company/organisation expect to participate in it?**	-
16	**What issues do you expect to arise with the broad use of cloud applications and 5G for online & offline training of an AI-powered solution?**	-
17	**From the 7 key requirements defined by the EU ethics guidelines for trustworthy AI, which do you consider to be the most important? Please elaborate how this could be applied in the case of versatile robotics for agile production.**	EU ethics guidelines for trustworthy AI key requirements: 1. Human agency and oversight 2. Technical robustness and safety 3. Privacy and data governance 4. Transparency 5. Diversity, non-discrimination and fairness 6. Societal and environmental wellbeing 7. Accountability
18	**Would you consider any additional aspect of agile production & implementation of versatile autonomous robotics that we did not manage to address?**	Goal: to check the completeness of the questionnaire & make adjustments; to receive feedback on aspects not covered

Online survey

Agile production & robotics knowledge

Topic (not visible in the online survey)	Question as implemented in the survey	Answer options
	To what extent do you agree with the following statements: I have a good understanding of ...	Scale from 1 to 5: [1=Strongly disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly agree]
Agile production	… agile production.	
Versatile robotics	… versatile & collaborative robotic solutions for agile production.	
	If you answered “Strongly disagree” or “Disagree” to the questions above, you are kindly requested to abort completing this survey. Thank you for your understanding.	
	Indicative evolution of versatile robotics role in agile production lines: • 1st generation of versatile robotics: Workers/Operators continue performing their tasks and robotic systems help them be more efficient • 2nd generation of versatile robotics: Robotic systems perform the tasks and workers/operators supervise them • 3rd generation of versatile robotics: Robotic systems are autonomous and trivial tasks are performed entirely by them Which generation of versatile robotics is the most common today?	Radio buttons (only one option allowed): • 1st • 2nd • 3rd
	How soon would you assume 3rd generation versatile robotics to be the norm?	Radio buttons (only one option allowed): • It already is • In <10 years • In 10-20 years • In 20-50 years • In >50 years

Industrial challenges, barriers, drivers and enablers grading

Topic (not visible in the online survey)	Question as implemented in the survey	Answer options
	Please grade the **challenges** associated with agile production using versatile robotics:	Grade from 1 to 5: [1=Not important; 2=Slightly important; 3=Moderately important; 4=Very important; 5=Extremely important]
Industrial challenges	Exploitation of big data	
	Personnel training	
	Human-Robot collaboration	
	Technology acceptance	
	Please grade the **barriers** associated with agile production using versatile robotics:	Grade from 1 to 5: [1=Not important; 2=Slightly important; 3=Moderately important; 4=Very important; 5=Extremely important]
Industrial barriers	Low Technology Readiness Level	
	Unclear scope or value proposition	
	Investment & Maintenance costs	
	Please grade the **drivers** associated with agile production using versatile robotics:	Grade from 1 to 5: [1=Not important; 2=Slightly important; 3=Moderately important; 4=Very important; 5=Extremely important]
Industrial drivers	Company’s prestige	
	Waste reduction	
	Return on investment	
	Reduced stress (for the workers/operators)	
	Product quality	
	Cost reduction	
	Customer satisfaction	
	Competitiveness	
	Increased productivity	
Industrial enablers	Please grade the **enablers** associated with agile production using versatile robotics:	Grade from 1 to 5: [1=Not important; 2=Slightly important; 3=Moderately important; 4=Very important; 5=Extremely important]
	5G communications	
	Simulation techniques	
	Policy & Regulations	
	Open-source software	
	Standardization	
	IT systems	
	Ease of use	

Technical requirements grading

Topic (not visible in the online survey)	Question as implemented in the survey	Answer options
	Please grade the **technical requirements** associated with agile production using versatile robotics:	Grade from 1 to 5: [1=Not important; 2=Slightly important; 3=Moderately important; 4=Very important; 5=Extremely important]
Technical requirements	Interoperability & Interconnectivity	
	Scalability	
	Maintainability	
	Reliability	
	Adaptability	
	Increased accuracy	

How straightforward is it to comply with the requirements below?

Topic (not visible in the online survey)	Question as implemented in the survey	Answer options
	To what extent do you agree with the following statements regarding technical & ethical requirements of agile production using versatile robotics: Using versatile robotics in agile production, it will be hard to achieve/comply with:	Scale from 1 to 5: [1=Strongly disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly agree]
Technical requirements	Interoperability & Interconnectivity	
	Scalability	
	Competitiveness	
	Maintainability	
	Reliability	
	Adaptability	
Ethical requirements	Human agency and oversight	
	Technical robustness and safety (Resilience to attack and security, Fallback plan and general safety, Accuracy, Reliability and Reproducibility)	
	Privacy and data governance (Privacy and data protection, Quality and integrity of data, Access to data)	
	Transparency (Traceability, Explainability, Communication)	
	Diversity, non-discrimination and fairness (Avoidance of unfair bias, Accessibility and universal design, Stakeholder participation)	
	Societal and environmental well-being (Sustainable and environmentally friendly AI, Social impact, Society and Democracy)	
	Accountability	

Topic (not visible in the online survey)	Question as implemented in the survey	Answer options
	(Auditability, Minimisation and reporting of negative impacts, Trade-offs, Redress)	
	Could you please elaborate on “Agree” & “Strongly agree” answers?	Free text

Insights regarding agile production using versatile robotics

Topic (not visible in the online survey)	Question as implemented in the survey	Answer options
Insights	How reliable do you consider AI-powered compared to classical engineering-based solutions?	Scale from 1 to 5: [1=Extremely unreliable; 2=Not reliable; 3=Equally reliable; 4=More reliable; 5=Extremely reliable]
	Would you please elaborate on your answer?	Free text
	To what extent do you agree with the following statements: The advent of versatile robotics do/will positively impact ...	Scale from 1 to 5: [1=Strongly disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly agree]
	… the total job count.	
	… the creation of higher income jobs.	
	… health and safety of workers/operators.	
	… the work-life balance of workers/operators.	
	… job satisfaction. (Workers/Operators will have time to focus on more complex, more creative and less laborious tasks.)	
	To what extent do you agree with the following statements: Workers/Operators will oppose to the introduction of & cooperation with versatile robotics due to ...	Scale from 1 to 5: [1=Strongly disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly agree]
	… the need for additional training.	
	… the potential change in their routine/role.	
	… the fear of being injured by the robot.	
	… the fear of privacy violation.	
	… the fear of being constantly evaluated.	
	… the fear of losing their jobs.	
	… the fear of having their value diminished.	
	… concerns about the robot’s reliability.	
	To what extent do you agree with the following statements: Acceptance and trust with respect to the introduction of & cooperation with versatile robotics could be achieved via ...	Scale from 1 to 5: [1=Strongly disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly agree]
	… a respectful and empathetic company culture.	
	… a clear presentation of the associated operational changes, e.g. needed training, role changes.	

Topic (not visible in the online survey)	Question as implemented in the survey	Answer options
	… complete briefing regarding the scope of the new technology introduction.	
	… complete briefing regarding the information that needs to be collected by the versatile robots and its use.	
	… guarantees that the collected data are not used for any other reason rather than for allowing the robot to perform its tasks.	
	… presenting a plan for maintaining all the workforce.	
	… educational and training programs.	

Background information

Topic (not visible in the online survey)	Question as implemented in the survey	Answer options
Gender	Please specify your gender	Male / Female / Non-binary / Other
Educational background	Please indicate your educational background	Radio buttons (only one option allowed): • Business administration • Science, technology, engineering, mathematics • Social sciences and humanities • Vocational and/or practical training
Organisation type	Please specify your organisation type	Radio buttons (only one option allowed): • Academia • Start-up • Industry • Government Other (please specify: free text)
Organisation size	Please specify your organisation size	Radio buttons (only one option allowed): • <10 employees • 10-50 employees • 50-250 employees • >250 employees
Positioning in the organisation	Please indicate your positioning in the organisation you are working	Radio buttons (only one option allowed): • Top-level manager • Middle-level manager • Engineer • Researcher • Data scientist • Technician • Operator • Worker Other (please specify: free text)
Country	Which country are you based in?	Free text

Available or forthcoming technological solutions

The following sections discuss various technological solutions related to agile production that are currently available or soon to be released.

AI-powered versatile robots

Versatile robotics has emerged as a significant technological solution for agile production in modern manufacturing environments. These robots are capable of performing multiple tasks, adapting to changing conditions and learning new skills quickly, making them an ideal fit for flexible manufacturing processes. To enhance their capabilities, artificial intelligence (AI) technologies such as advanced perception algorithms and sophisticated Task-And-Motion-Planners (TAMPs) can be utilized. These AI technologies enable robots to handle objects and situations that were unseen during initial training, reducing the need for manual intervention.

However, the increased complexity and computational requirements of these AI methods (Schwartz et al., 2020; Strubell et al., 2019) can impact the overall energy footprint of these robots (Schwartz et al., 2020). Recent research has shown the benefits of advanced actuation systems that can store mechanical energy, increasing the robot's autonomy (Carabin et al., 2017) and optimal control techniques that can minimize the instantaneous power required by the actuators during motion planning (Carabin et al., 2017; Kudruss et al., 2015). By employing these techniques, robots can become more energy-efficient while maintaining their high level of versatility and adaptability.

The ambition of the AGIMUS project is to significantly reduce the overall energy consumption for both online, onboard computation as well as for intensive offboard training and planning. This will be achieved by:

(i) reducing the computational cost by optimizing our predictive models;
(ii) including model-based learning to control policy learning and therefore reducing the number of training iterations;
(iii) planning energy-efficient motions, thus reducing the energy consumption of robots while;
(iv) producing optimized software requiring less computational resources for solving the underlying planning problems;
(v) developing general object perception models that can handle new unseen objects at test time without costly re-training thereby obtaining major energy savings.

The energy footprint of the 5G adoption will also be investigated to assess the effect on the energy footprint e.g., through the advanced sleeping modes (Shurdi et al., 2021).

Cloud systems

In order to operate efficiently, robots require the transfer of massive amounts of data with off-board systems, sensors, the workforce and the cloud, particularly in industrial settings. However, existing wireless protocols cannot adequately support this data exchange, be it due to latency, bandwidth or reliability issues (Rahimi et al., 2017).

The ambition of the AGIMUS project is to investigate the benefits of the reliable high-bandwidth, low-latency 5G connection (Attaran, 2021; Qiao et al., 2021) linking the robot with the off-board sensors (such as additional cameras), systems (such as other parts of the manufacturing line) and powerful AI-equipped computing servers together with large-scale data memory available on the cloud. In particular, the new generation of adaptive controllers developed in the AGIMUS project run on edge at >1kHz but use cloud computation capabilities for visual processing and high-frequency predictive policy computation. The requirements on bandwidth are driven by the new perception algorithms developed in the project that require (multiple) high-resolution (1920x1080 at 30fps) video streams as input. The project will investigate the benefits of the 5G technology compared to existing wireless solutions such as a WiFi network through infrastructure available at the testing zones.

IoT sensors

The integration of disparate technological systems can present significant challenges for industries, often requiring the development of customized communication solutions to ensure seamless integration of hardware, regardless of age (Sanneman et al., 2020). To realize the ideal future factory, where humans can interact with collaborative robots without safety barriers and robotic systems exhibit trustworthy operation and performance, the use of the Internet of Things (IoT) is paramount (SRIDA, 2020).

The IoT is a network of physical devices and objects embedded with sensors and software that enable them to connect and exchange data. By utilizing IoT technologies, robotics and manufacturing products can be optimized towards the holistic transformation of production lines, increasing the efficiency of production processes (Sanneman et al., 2020). Sensors, such as skin sensors, light or laser curtains, proximity and capacitive sensors, can be used to monitor equipment performance and ensure smooth production processes.

However, it is crucial to note that despite the numerous benefits of IoT sensors, there are critical issues related to privacy, data ownership, autonomy, security, cross-national transfer of information, and safety that need to be adequately addressed (EFFRA, 2016).

Edge computing

Edge computing involves processing data closer to the source, rather than sending it to a centralized location. This can help to reduce latency, improve response times and enable real-time decision-making in manufacturing processes.

Non-AGIMUS related technological solutions

Brief descriptions of additional technological solutions that are not directly related to AGIMUS are included below for the sake of completeness.

Digital twin technology

A digital twin is a virtual replica of a physical product, process, or system. Manufacturers can use digital twin technology to simulate production processes and test different scenarios, helping to identify and resolve issues before they occur (SRIDA, 2020).

Augmented reality

Augmented reality (AR) can be used to provide workers with real-time information about production processes, including instructions, safety guidelines, and other relevant data.

Blockchain

Blockchain technology can be used to track the movement of goods and materials within a supply chain, ensuring transparency and accountability.

3D printing

3D printing is a process that allows manufacturers to produce parts and products on demand, which is particularly useful for small production runs or customized products. 3D printers can be used to create prototypes, tools and even finished products, reducing lead times and costs, avoiding expensive trial and error runs.

Openly available resources for extending research activities

In the frame of the AGIMUS project, open-source software and datasets will be uploaded to open libraries and repositories, offering transparent knowledge transfer and promoting research activities and European excellence throughout the digital supply chain.

Datasets

AGIMUS will generate a variety of open datasets, including motion datasets, image datasets for object localization and video datasets for the video demonstration extractor. To facilitate this, AGIMUS will develop a motion dataset module that can memorize trajectories generated by the motion planner

(T2.3, T3.4) or trajectory optimizer (T2.2) and generate a set of diverse trajectories that automatically adapt to a given scenario at inference time.

Repositories

AGIMUS' data that are produced and considered open for re-use, will be deposited in a trusted repository in line with the FAIR principles and following the rule "as open as possible, as closed as necessary". Table 4 summarizes the repositories already used by AGIMUS' partners, as well as potential options for future exploration.

Table 4: Repositories

	Repositories		
	Title	**Description**	**Already in use by AGIMUS**
1	Zenodo	Open-access repository that allows researchers to share and preserve research outputs, including datasets, software, preprints, and other scholarly works. The repository is managed by CERN, the European Organisation for Nuclear Research, and is free to use for anyone. Zenodo provides a permanent digital identifier for each upload, ensuring long-term accessibility and discoverability of the research outputs. Zenodo also integrates with ORCID, enabling researchers to connect their Zenodo account with their ORCID profile for a more streamlined workflow.	✓
2	Open Research Europe	Open-access publishing platform for research articles from Horizon 2020 projects funded by the European Union. The platform provides free and immediate access to research outputs, including articles, data and software. Open Research Europe operates on a transparent peer-review process and aims to increase the visibility and impact of European-funded research.	✓
3	arXiv	Preprint repository that hosts papers in various fields of science and mathematics, including physics, computer science, and biology. arXiv allows researchers to share their work before it undergoes formal peer review, which enables fast dissemination of research findings and fosters collaboration. arXiv is widely used by researchers worldwide and is considered a valuable resource for scientific communication and discovery.	✓
4	HAL	Open archive of scientific articles developed by the Centre pour la Communication Scientifique Directe (CCSD). It provides free access to articles, theses, and research papers from various disciplines. HAL is a collaborative platform that allows researchers to upload their publications and share them with the scientific community. It also provides tools for citation analysis, enabling users to track the impact of their research.	✓
5	GitHub/GitLab	Web-based platforms for version control and collaborative software development. They allow developers to host and review code, track changes and collaborate on projects with other contributors.	✓
6	Dryad	Non-profit digital repository that hosts data underlying scientific publications. Dryad allows researchers to share and store their research data in a sustainable way and provides tools for data curation and preservation. Dryad's primary goal is to facilitate open access to scientific data and promote reproducibility and transparency in research.	✗

	Repositories		
	Title	Description	Already in use by AGIMUS
7	Figshare	Repository where researchers can store, manage and share their research outputs, such as data, figures, posters and software. Figshare enables researchers to make their work more accessible, visible and citable and to comply with data sharing requirements from funding agencies and journals.	✘

Open-source software libraries

AGIMUS will develop new methods for learning contact models directly from sensor data (such as force signals and images) with the objective of reducing the simulation-to-reality gap, hence improving simulation accuracy. Building on the successes of previous software packages, this simulator is expected to become the next generation of robot simulation and the “go-to” software library for the community, capable of producing more realistic motion while being efficient and accurate.

Table 5 provides a summary of the open-source software platforms already used by AGIMUS’ partners, ensuring the reproducibility of the project's research results, as well as potential options for future exploration.

Table 5: Open-source software libraries for robotics

	Open-source software libraries for robotics		
	Title	Description	Already in use by AGIMUS
1	Humanoid Path Planner (HPP)	Open-source software library designed to help developers plan and execute complex motions for humanoid robots. It provides a range of tools and algorithms for motion planning, collision checking, and trajectory optimization. Written in C++, HPP can be used with other open-source robotics software libraries such as ROS and Orocos, and its modular design enables customization to specific needs.	✓
2	CosyPose	Open-source software library that provides a range of tools for 6D object pose estimation, using deep neural networks. It supports various types of cameras and sensors and can be trained on large-scale datasets. Cosypose is written in Python and can be integrated with other open-source computer vision libraries. RoboPose, FocalPose and MegaPose are included under CosyPose’s umbrella.	✓
3	Pinocchio	Open-source software library for efficient and accurate computation of the dynamics of rigid bodies. It provides tools for forward and inverse kinematics, forward and inverse dynamics, and collision detection. Written in C++, Pinocchio is designed to be modular and can be used with other open-source robotics software libraries such as ROS and OpenRAVE.	✓
4	Crocoddyl	Open-source software library for fast and efficient optimal control for robotics. It provides tools for trajectory optimization, model-based reinforcement learning, and differential dynamic programming. Written in C++, Crocoddyl is designed to	✓

	Open-source software libraries for robotics		
	Title	Description	Already in use by AGIMUS
		be easily integrated with other open-source robotics software libraries such as ROS and Pinocchio.	
5	Stack of tasks	Open-source software library that provides tools for hierarchical control of robot motions. It enables the specification of multiple tasks, each with its own priority, and generates optimized joint trajectories to accomplish them. Written in C++, it can be used with other open-source robotics software libraries such as ROS and Pinocchio. The Stack of Tasks is designed to be modular and customizable to specific robot platforms and control requirements.	✓
6	ProxSuite	Open-source software library for proximity-based technologies, such as RFID and NFC. It offers a wide range of tools and features for developing and integrating proximity-based applications into various platforms. With its user-friendly interface and extensive documentation, ProxSuite enables developers to easily create innovative solutions that leverage the power of proximity-based technologies.	✓
7	ACADOS	Open-source software package that provides numerical optimization tools for dynamic control and estimation problems. It includes solvers for linear and nonlinear optimization, differential and algebraic equations, and model predictive control. Written in C, ACADOS is designed to be high-performance and can be integrated with other open-source robotics software libraries such as ROS and Simulink. ACADOS is used widely in academia and industry for control and estimation of complex systems, including robotics and autonomous vehicles.	✗

Educational material

Educational material built upon research findings will be transformed into Open Educational Resources (OER) and uploaded to OER platforms. Table 6 summarizes the educational platforms already used by AGIMUS' partners, as well as potential options for future exploration.

Table 6: Training and educational material

		Description	Already in use by AGIMUS
1	OERCommons	Digital library of open educational resources (OER) that aims to provide free and accessible educational materials for learners and educators worldwide. The repository offers a vast collection of OER materials, including textbooks, videos, lesson plans and assessments. The platform is user-friendly and allows users to search, browse, and customize OER materials according to their needs.	✓
2	Inria's Academy	Training program offered by the French National Institute for Research in Digital Science and Technology (INRIA). It provides high-quality training courses in computer science and related fields for students, researchers, and professionals. The academy offers a diverse range of courses, including short-term workshops, online courses and PhD programs, aimed at promoting research and innovation in the digital sciences.	✓
3	Inria's learning lab	Digital platform that offers resources and tools for teaching and learning computer science and digital technology. The platform provides access to a wide range of educational resources, including online courses, tutorials, and interactive tools, to support learners and educators in the field of computer science. The Learning Lab also offers customized solutions for educational institutions and organisations, including the development of tailored educational programs and the design of educational content.	✓
4	Inria's MOOCs	Massive Open Online Courses (MOOCs) in computer science and digital technology, free and accessible to anyone interested in learning about topics such as programming, machine learning, data science and cybersecurity. The courses are designed and taught by INRIA researchers and educators and are offered through platforms such as FUN-MOOC and Coursera. The MOOCs provide a flexible and engaging way to learn about cutting-edge research and technology in the field of computer science, and offer learners the opportunity to interact with a global community of fellow learners and experts in the field.	✓
5	Pinocchio's tutorials	Tutorials for Pinocchio	✓
6	Crocoddyl's tutorials	Tutorials for Crocoddyl	✓
7	Object recognition and computer vision course material	Automated object recognition -- and more generally scene analysis -- from photographs and videos is the grand challenge of computer vision. This course presents the image, object and scene models, as well as the methods and algorithms, used today to address this challenge.	✓