Project acronym: Lasers4MaaS

Project title: Laser-as-a-Service Digital Platform with Dynamic Beam Shaping for Acceleration of Smart, Decentralised and Sustainable Factory of the Future

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Deliverable D1.1: Industrial requirements, manufacturing targets and guidelines of Lasers4MaaS

Owner: WMG

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Type		
R	Document, report (excluding the periodic and final reports)	x
DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patents filling, press & media actions, videos, etc	
DATA	Data sets, microdata, etc	
DMP	Data management plan	
ETHICS	Deliverables related to ethics issues	
SECURITY	Deliverable related to security issues	
OTHER	Software, technical diagram, algorithms, models, etc	

Dissemination level		
PU	Public, fully open, e.g. project website	x
SEN	Sensitive, limited under the conditions of the Grant Agreement	
Classified R-UE/EU-R	EU RESTRICTED under the Commission Decision No2015/444	

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HISTORY OF CHANGES

Version	Publication date	Change
1.1	02/02/2025	First draft
2.0	17/02/2025	Second draft with uses cases and serviced added
3.0	21/02/2025	Final version

LIST OF AUTHORS

Name	Organization	Email
Pasquale Franciosa	WMG	p.franciosa@warwick.ac.uk
Volkher Onuseit	USTUTT	volkher.onuseit@ifsw.uni-stuttgart.de
Marco Cinelli	ULEI	m.cinelli@luc.leidenuniv.nl
Franco Donati	ULEI	f.donati@cml.leidenuniv.nl
Constantin Zenz	TUW	constantin.zenz@tuwien.ac.at
Antti Partanen	FUTURICE	antti.partanen@futurice.com
Yao Ren	RACE	yao.ren@ukaea.uk
Domenico Stocchi	ECOR	domenico.stocchi@ecor-international.com

REVIEWED BY

Name	Organization	Email
Pasquale Franciosa	WMG	p.franciosa@warwick.ac.uk

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
AR	Augmented Reality
DBS	Dynamic Beam Shaping
DPP	Digital Product Passport
DT	Digital Twin
ESPR	Ecodesign for Sustainable Products Regulations
H&S	Health and Safety
IIoT	Industrial Internet of Things
IML	Interpretable ML
KPIs	Key Performance Indicators
LBW	Laser Beam Welding
MaaS	Manufacturing-as-a-Service
MIG	Metal Inert Gas welding
ML	Machine Learning
SDG	Sustainability Development Goals
TIG	Tungsten Inert Gas welding
VR	Virtual Reality
XAI	Explainable AI

1. Executive summary

This version of the deliverable D1.1 does disclose the industrial requirements, manufacturing targets and guidelines for the development of the Lasers4MaaS platform. D1.1 will be an official project document which is open for review processes through the entire project duration.

2. Project background

The goal of Lasers4MaaS is to revolutionise laser welding by dynamic beam shaping and digital technologies for servitisation of manufacturing. Lasers4MaaS introduces a six-point strategy to reconfigure, connect, control, predict, improve and ensure compliance in manufacturing. With demonstrations in sectors like automotive, aerospace, food packaging and renewable energy this project aligns closely with Green Deal goals. In Lasers4MaaS, servitisation is defined as production on-demand of customised high-quality products.

In the pursuit of EU Green Deal's goal of carbon neutrality by 2050, the manufacturing sector faces a critical mandate to reduce emissions by at least 55% by 2030[1]. This challenge is compounded by the fast-paced and competitive nature of global markets, which increasingly demand mass customisation. This necessitates a shift towards manufacturing models that offer diversification (*flexibility*) and responsiveness (*reconfigurability*), while also striving to minimise costs and maximise product quality. The shift towards *digital servitisation* - emerged from the paradigm of manufacturing-as-service (MaaS) and propelled by the *digital transformation* of manufacturing industries via cloud manufacturing, Industry 4.0 and smart manufacturing - represents a massive business opportunity. This shift allows manufacturers/end-users to access distributed providers to implement their manufacturing processes. The EC started the Digitising European Industry (DEI) strategy[2] in 2016, aimed at reinforcing the EU's competitiveness in digital technologies. The strategy identified digital platforms[3] for manufacturing as key enablers in addressing competitive pressure and integrating advanced technologies and services. Digital platforms do leverage a network of service providers and find the optimal solutions to fulfil end user requirements concerning quality, time, cost and sustainability; from the technology providers, platforms allow to diversify the offer and accelerating the deployment and adoption of product-service offerings, such as remote monitoring and maintenance, equipment selection and inventory management, digital design and pay-by-use. The *critical challenge* is maximising the functional performance of product-service offerings and embedding novel manufacturing processes for low-mix high-volume, and high-mix low-volume market scenarios, while reducing manufacturing costs, and improving value chain integration through data interoperability, implementation of digital product passport (DPP) protocols and ease access to sustainable and circular facilities. With the ability to make parts on-demand without the need for re-tooling and re-investment, additive manufacturing and CNC machining have been at the forefront of the digital servitisation. However, there is a lack of methodologies to translate across other production processes. In this landscape, the servitisation of welding processes is vital to meet the diverse requirements of both low-mix high-volume and high-mix low-volume market scenarios, mass customisation, fast adaption to changing orders, comply to certification procedures and new regulations.

Among welding technologies, the demand for laser beam welding is rapidly growing catalysed by the need for diverse manufacturing sectors, such as production at scale in automotive e-mobility using recycled and mixed materials, high diversification of components in food packaging machineries and aerospace using special alloys, extensive infrastructure development projects across the EU focusing on renewable and clean energy, and strive for manufacturing flexibility and efficiency in the hydrogen sector (electrolysers and fuel cells). For instance, in the e-mobility sector, the production of battery packs requires extensive welding work, involving up to 20,000 welds per pack. In the food and beverage packaging machines, the welding of pipes is crucial to the safety of the structures, people and the environment; production volumes are in the range of a few hundred with very large product variety (up to 1000x product variants with combination of geometry, alloy grades and thicknesses). This diversity necessitates a high degree of manufacturing flexibility, customisation and diversification. In the hydrogen sector, manufacturing of storage systems, electrolysers and fuel cells calls for innovative advancements in laser welding technologies to address the issue of low manufacturing flexibility and inefficient manufacturing techniques. In the fusion sector, there's a shift from lab-based experiments to technology-driven programmes, requiring the design and production of highly specialised laser welding tools to enable rapid, secure and unmanned remote operations.

[1] *EU Monitor, "EU measures against climate change, 2023*
[2] *EUROPEAN COMMISSION, "The Digitising European Industry initiative in a nutshell"*
[3] *Digital Manufacturing Platforms in Industry 4.0,* https://www.assemblymag.com/articles/97286-digital-manufacturing-platforms-in-industry-40

Lasers4MaaS recognised the importance of digital servitisation of laser welding processes and builds upon the rapidly growing advancement in dynamic laser beam shaping as "all-in-one" welding tool, allowing many new materials and process optimisations to be enabled from the same laser source (Figure 1).

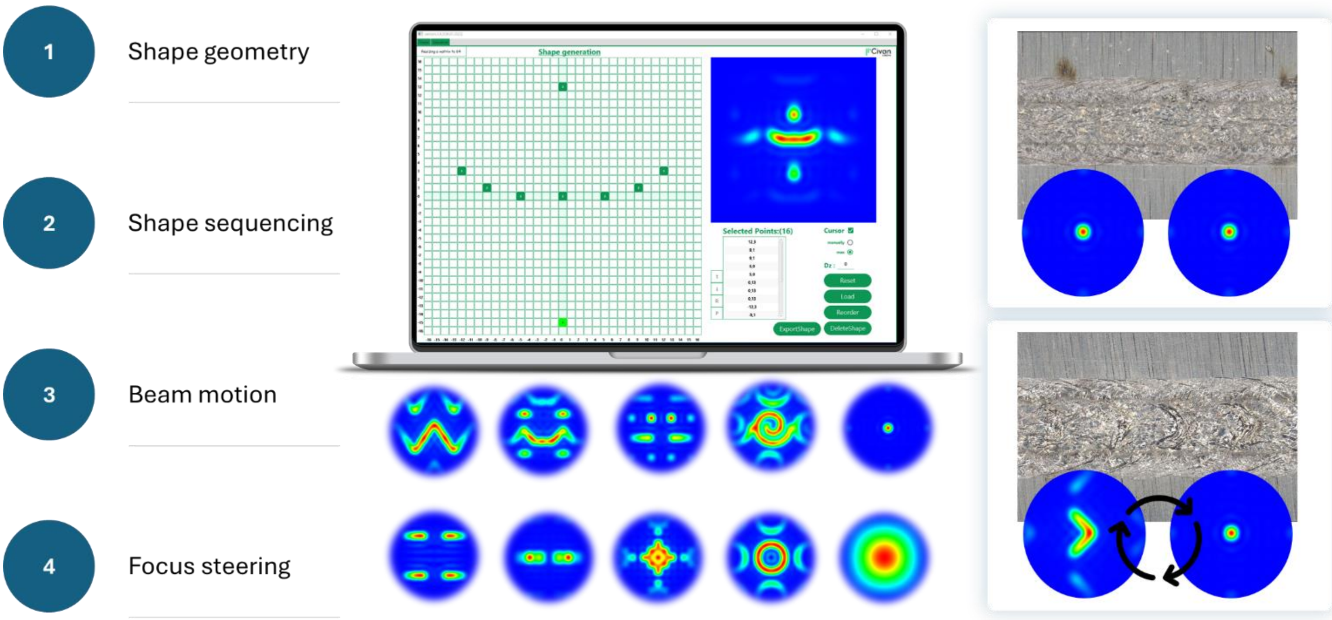


Figure 1: Key features of dynamic beam shaping (credit: CIVAN)

The deployment of dynamic beam shaping within laser welding for manufacturing industries has an immense potential for servitisation: manufacturers will be able to build products on-demand, without the need of re-investment in new equipment, thereby enabling rapid repurposing.

3. The current situation with laser welding systems

In general, laser welding is progressively displacing MIG, TIG, brazing and, arguably, e-beam methods. This is due to the competitive flexibility offers by the laser light itself to process materials, both similar and dissimilar. The current industrial landscape is presented in Figure 2.

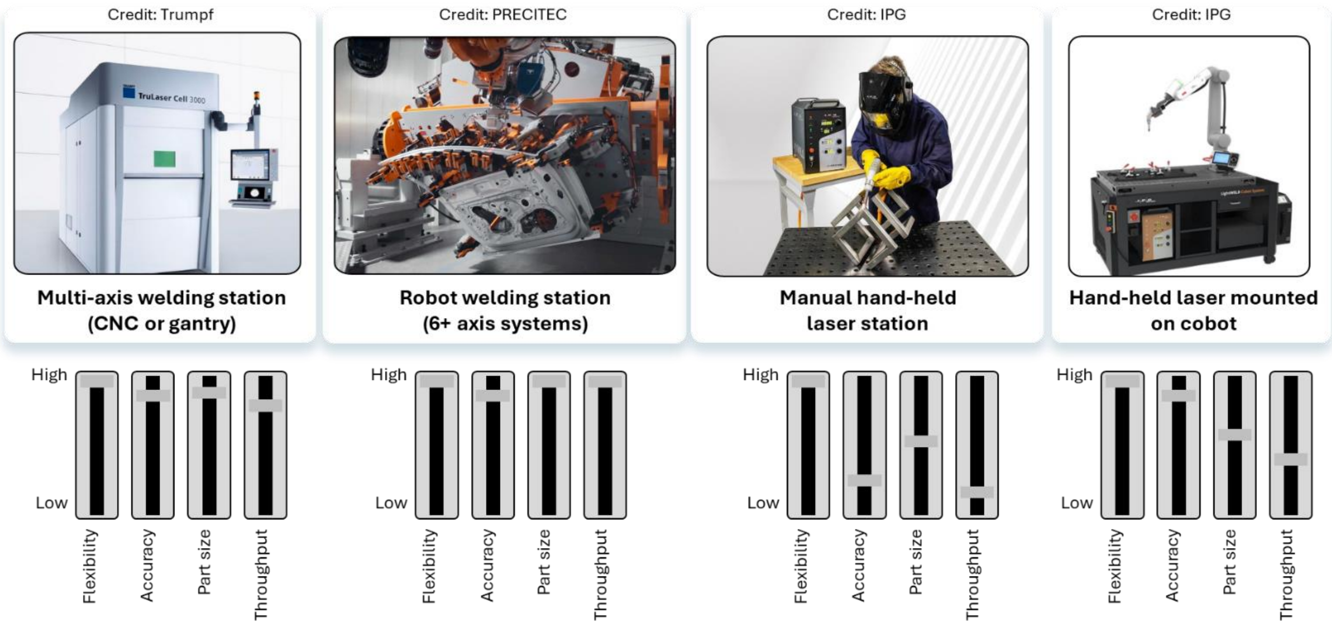


Figure 2: Current industrial landscape of laser welding systems

Although laser welding systems are virtually flexibly, a productivity-driven approach tends to jeopardize its high potential for servitisation.

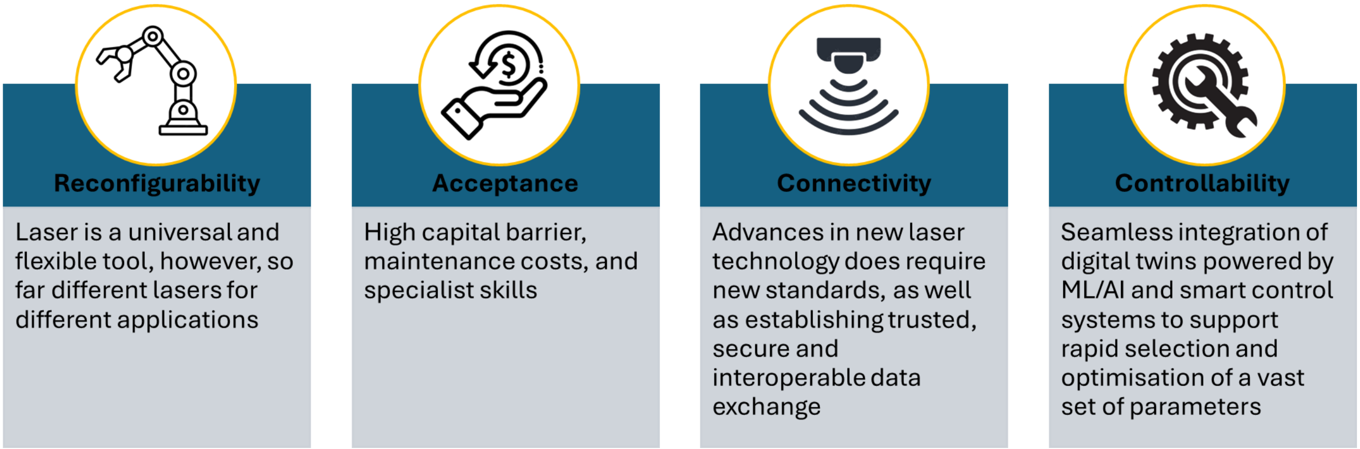


Figure 3: The four challenges set-out in Lasers4MaaS

Four challenges have been identified (see Figure 3): **reconfigurability challenge**, the digital MaaS concept urges manufacturing industries to re-define their production processes for flexibility and reconfigurability. Advanced manufacturing processes are vital in fabricating products with complex structures, enabling the creation of highly customised products across a broad spectrum of markets and significantly contributing to the competitiveness of the EU manufacturing industry. **Connectivity challenge**, it can be argued that lack of interoperability leads to significant economic loss – manufacturers hesitate to fully embrace interoperability, predominantly due to commercial concerns/potential loss of intellectual property and non-unified data formats and protocols. Consequently, establishing trusted, secure and interoperable data exchange is a critical hurdle that needs to be addressed to accelerate the digital servitisation. While the EU is applying various measures to regulate the digital market via the Data Act[4], the establishment of standards and policies is still in an early stage. **Controllability challenge**, seamless integration of DT powered by ML, AI and smart control systems is urgently needed to support rapid selection and optimisation of a vast set of parameters – with state-of-the-art approaches, this process is either too expensive or impractical for some users. Such integration is crucial for assisting manufacturers in significantly enhancing product diversification while reducing defects, waste generation, and ultimately manufacturing costs; collectively, this paves the way to meet UN sustainability development goals, SDG #8, #9, #12, #13. **Acceptance challenge**, high capital barrier, maintenance costs, and specialist skills associated with digital technologies and advanced manufacturing processes lead to challenges in adoption, particularly micro and small to medium-sized enterprises.

4. Lasers4MaaS's goal and strategies

Building upon the growing advancement in dynamic laser beam shaping as "all-in-one" laser welding tool, with immense potential for servitisation, Lasers4MaaS introduces a six-point strategy to reconfigure, connect, control, predict, improve and ensure compliance in manufacturing. With demonstrations in sectors like automotive, aerospace, food packaging and renewable energy this Lasers4MaaS aligns closely with Green Deal goals. Lasers4MaaS will be addressed towards the implementation of the strategic objectives along the WPs and will be tracked through measurable KPIs, presented in Figure 4.

[4]EUROPEAN COMMISSION, "Shaping Europe's digital future/Data Act"

Strategic RI actions		"SMART" objectives	Expected outcome areas with targets and measurable KPIs			
WP3-4	RECONFIGURE	**Objective#1** To integrate advanced robotics and dynamic beam shaping		**Outcome area#1** De-centralised and flexible manufacturing	**50% faster changeovers**	• **Reconfiguration time** • **Lead time** • **OEE (Overall equipment effectiveness)**
WP5-6	CONNECT	**Objective#2** To use fast and secure data exchange beyond the company boundaries		**Outcome area#2** Interoperability, remote monitoring and predictive maintenance	**Interoperability and 30% reduction of maintenance cost**	• **Interoperability index**: no. of exchanges; utilization rate, etc. • **Maintenance/monitoring index**: mean-time-to-repair; etc.
WP7-8	CONTROL	**Objective#3** To combine sensors and digital twins for real-time AI-based decision support	WP15-16	**Outcome area#3** Reduction of defects, waste and improved product lifetime	**20% reduction of defects and waste generation**	• **Process capability index** • **Scrap rate**
WP9-10	PREDICT	**Objective#4** To develop new tools for prediction and simulation		**Outcome area#4** Reduced lead time and improved process efficiency	**3x reduced process development time**	• **Process development time**
WP11-12	IMPROVE	**Objective#5** To solve long-standing laser welding challenges and improve weld quality		**Outcome area#5** Enhanced utilisation of materials, improved production efficiency	**20% weld improvement and 25% increase in productivity**	• **Weld index**: weld depth/uniformity; etc. • **Productivity index**: production volumes/rates, etc.
WP13-14	COMPLY	**Objective#6** To deliver sustainability and design-x-circularity, and shape digital product passport		**Outcome area#6** Sustainability, climate-neutral and resilient industrial value chains	**20% energy/cost saving and reduced emissions**	• **Energy/units produced** • **Energy/processing speed** • **Carbon emission index**: energy, material, fumes, etc.

Figure 4: "SMART" objectives towards the expected outcomes with measurable KPIs

The six overarching objectives, aligned to the project's strategies as follows:

- ***RECONFIGURE. Goal: to integrate advanced robotics solutions and dynamic beam shaping***
  Enhancing reconfigurability will involve: (1) jigless approaches shifting the intelligence from the jig to product's features; (2) employing the innovative dynamic beam shaping for rapid adjustments of processing conditions to tackle welding challenges ensuring swift and efficient production solutions. The 6 principles of reconfigurability (scalability, convertibility, diagnosability, customisation, modularity, integrability) will be considered.
- ***CONNECT. Goal: to implement fast and secure data exchange beyond company boundaries***
  Lasers4MaaS facilitates the use of fast and secure data exchange beyond company boundaries via harmonised protocols with distributed/centralised ledgers for data interoperability and IIoT platforms. This will lead to novel solutions for remote monitoring and predictive maintenance empowered by VR and AR. Lasers4MaaS will build upon open standards to enhance data interoperability.
- ***CONTROL. Goal: to combine sensors and digital twins for real-time AI-based decision support***
  Lasers4MaaS aims to develop a real-time AI-based decision support system to help selecting the optimal processing conditions. A highly relevant strength of the project is the use of XAI and IML to augment the capabilities of the analysis and control, ensuring robust and trustworthy AI applications.
- ***PREDICT. Goal: to develop new tools for prediction and simulation of laser welding process***
  Lasers4MaaS aims to develop new tools for prediction of laser welding processes and enhance the capability to model and predict the response of the material to the laser inputs. Key strength will be the implementation of reduced-order models to drastically reduce computational time and accelerate the simulation of large sets of design scenarios - this will ultimately support the real-time AI-based decision-making and rapid process development.
- ***IMPROVE. Goal: to solve long-standing laser welding challenges and improve weld quality***
  Advancements in understanding laser-material interactions under new dynamic beam shape profiles will be targeted to address challenging material combinations. This action will be complemented by the integration of in-process monitoring IIoT sensors (photodiodes, optical coherent tomography, acoustic emissions, etc.) and advanced in-situ X-ray to close the link between process behaviour and observable weld features.
- ***COMPLY. Goal: to deliver sustainability and design-x-circularity, and shape DPP***
  Lasers4MaaS will address several aspects associated to legal (safety requirements, etc.), social (public awareness, trust, etc.), economic (reduce operational costs, etc.) and environmental impact. The project

promotes circular designs (e.g., designs for recyclability) and closed-loop activities (e.g., repair, recycling). This action will inform the DPP and streamline the life-cycle inventory processes.

The goal of Lasers4MaaS is to revolutionise laser welding by dynamic beam shaping and digital technologies for servitisation of manufacturing (Figure 5).

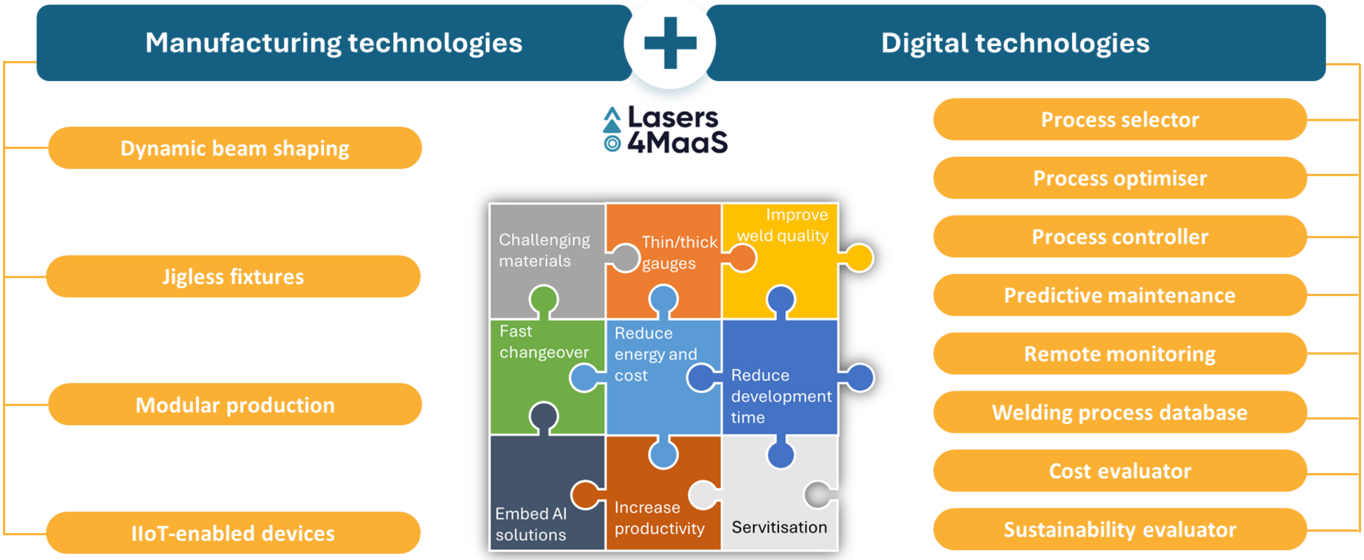


Figure 5: Lasers4MaaS's platform combining manufacturing and digital technologies

5. Industrial use cases and manufacturing requirements

The project will be demonstrated using the multiple selected use cases. Several use cases have been already selected from automotive, food packaging, aerospace, hydrogen, future fusion plants and pharma industry (Figure 6). The main idea is to combine and validate the manufacturing technologies (dynamic beam shaping, jigless fixtures, modular production schemes and IIoT devices) and the services of the digital platform across the key sectors. WMG and ECOR are the selected sites to host the demonstrators. This choice has been motivated by: (a) WMG will develop a demonstration area using surrogate parts to prove in the lab environment the KPIs before moving to the industrial setup in ECOR; (b) the technology area in ECOR will allow to maximise industrial impact and commercial exploitation.

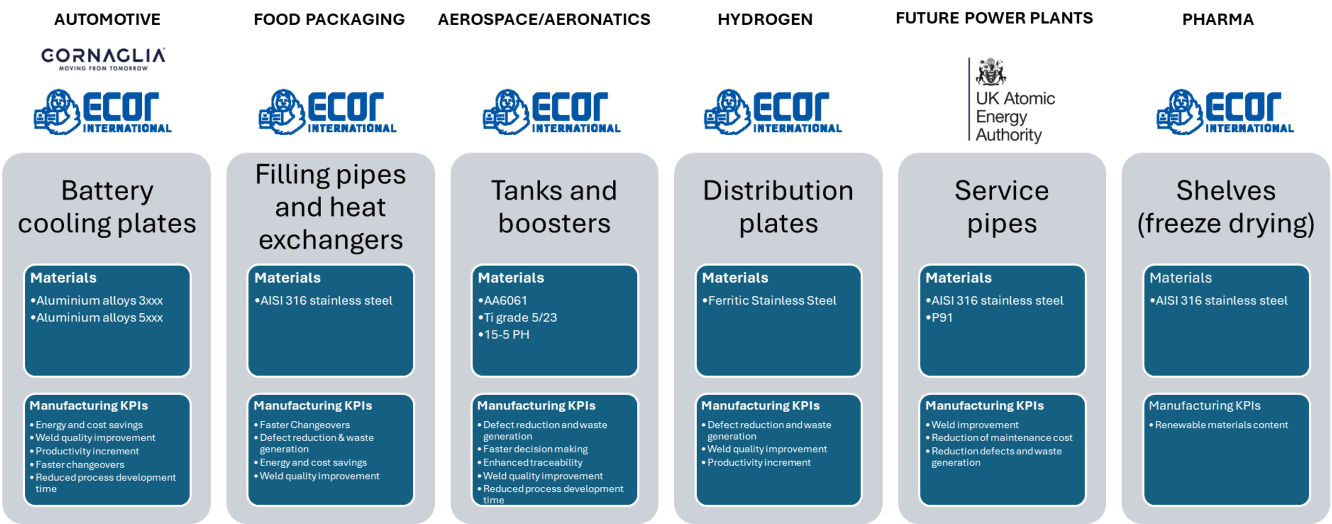


Figure 6: Summary of use cases with materials and manufacturing KPIs

A modular manufacturing scheme, with robot, dynamic beam shaping source, modular/jigless fixture and laser safety booth, will be used across the use cases to prove the re-purposing of production facilities across different supply chains. Details about the demonstration areas the KPIs are reported in D2.2 (preparation of facilities for physical demonstrators) and D2.3 (specifications and manufacturing KPIs of selected use cases).

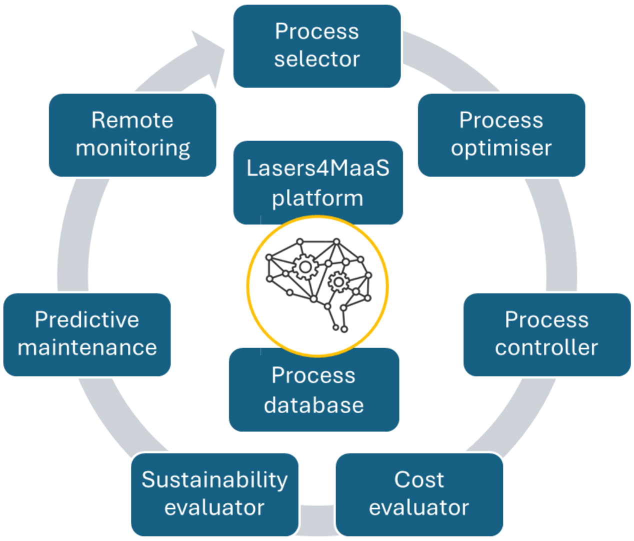
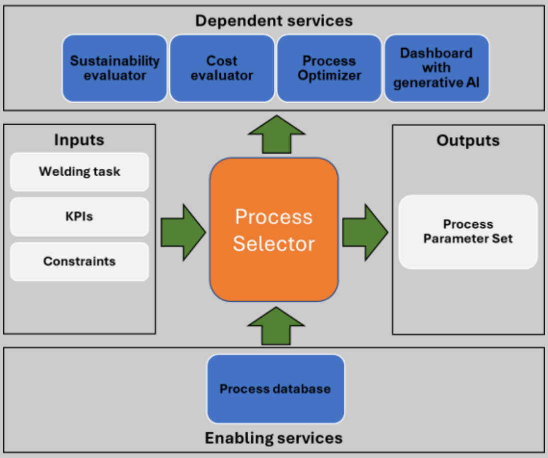


Figure 7: Conceptual representation of the LasersMaaS's platform with integrated services

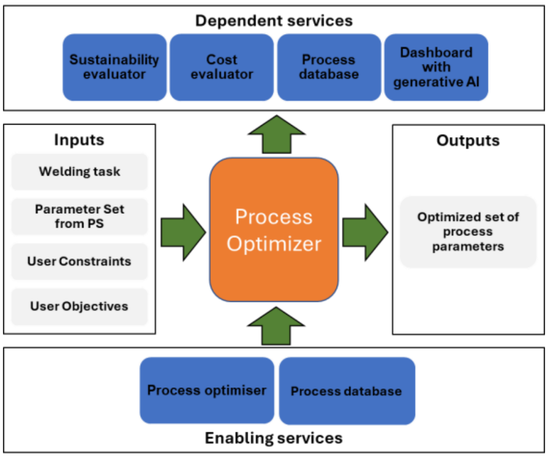
6. Guidelines of Lasers4MaaS's platform and services

The services will be then integrated under the LasersMaaS's platform, as conceptually shown in Figure 7. Table 1 shows the services that will be developed in Lasers4MaaS. It's organised to point-out the main capabilities and the dependencies with other services.

Table 1: Anticipated services that will be developed in Lasers4MaaS

Service	Description and dependencies
Process selector	 **What is it?** For a given user input (Specifications, KPIs), provide set of process parameters (beam shape, feed rate, power, …) within given constraints. Directly estimate a feasible solution based on existing data and fast reduced order models. **What will do?** Use existing information from database, assisted by reduced order models, to find process parameters that will lead to the desired KPIs. This task is solved in "user real-time" (seconds to a few minutes). **User stories:** • User has existing manufacturing solution and needs a parameter set from the process selector to solve a welding task. • User has no own manufacturing possibilities and needs a supplier for the manufacturing given the parameter selection from the process selector. The constraints are given by all manufacturing solutions available in the database. • User wants to choose a possible manufacturing solution as an investment and needs to know what specifications are needed to achieve KPIs (no constraints).

Process optimiser



What is it? The Process Optimizer (PO) is an interactive service designed to refine and enhance the process parameters. Its primary goal is to achieve user-defined objectives under given constraints.

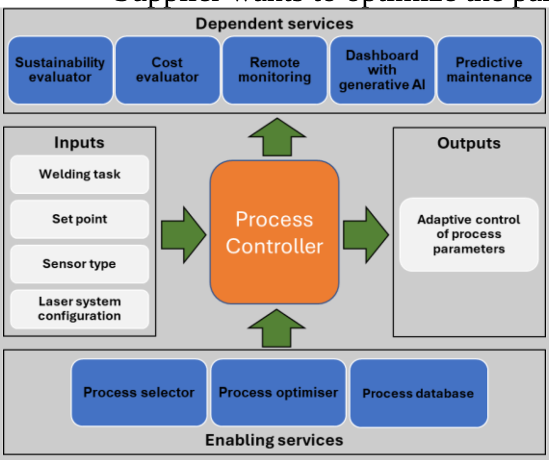
What will do? The PO operates by incorporating iterative feedback to adjust and optimize the parameters to meet the specific requirements of welding tasks. Therefore, the PO will give a set of parameters to be tested to the user or other services and requires the result from the experiment or simulation as a result. Additionally, it will use the data from the database via the process selector and new data provided by user or other services.

Who are the potential users? End-users, researchers, engineers, and quality assurance teams focusing on welding process optimization.

User stories:

- User has an existing laser welding machines and wants to optimize the process parameters at his facility
- Supplier wants to optimize the parameters for a customer.

Process controller



What is it? Adaptive control of process parameters (i.e., beam shape, laser power, feed-rate, type of shielding gas, etc.) for specified/desired values.

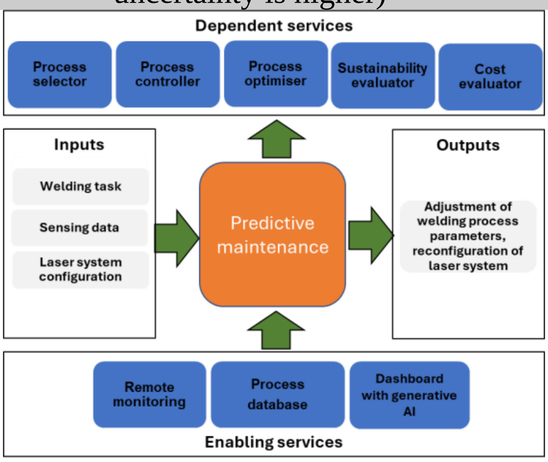
What will do? For a given set of welding tasks, the process controller will allow adjusting the process parameters to compensate the effect of process uncertainty (part-to-part gap, part tolerances, etc.). The service will combine the power of multi-physical modelling, ML/AI and state-of-the-art sensors.

Who are the potential users?
Process and system engineers, machine builders, optics manufactures.

User stories:

- User has an existing laser welding machines and wants to control the process in real-time
- User has no experience with laser welding and needs an intelligent control system to help stabilising the process, especially for the production ramp-up (when process uncertainty is higher)

Predictive maintenance



What is it? Algorithms designed to help determine the condition of in-service laser welding equipment and welding processes, foresee potential issues and estimate when maintenance should be performed, and process should be optimised.

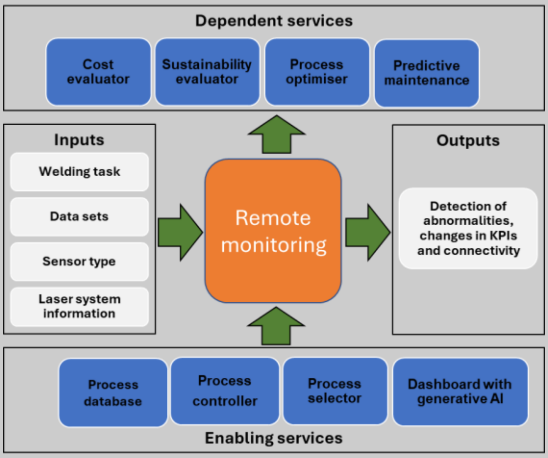
What will do? For a given set of welding tasks, predictive maintenance will allow prediction and autonomous adjustment of process parameters to meet specific quality targets, leveraging the latest developments in ML/AI combined with sensor fusion, to reduce unexpected downtime and extend the lifespan of equipment.

Who are the potential users? Process and system engineers, machine builders, plant maintenance engineers, manufacturing and production engineers

User stories:

- User has an existing laser welding system that is used in manufacturing and wants to gain flexibility and reconfigurability of the system to increase the system efficiency of production.
- Users are from industries with high precision requirements and want to reduce fault conditions

Remote monitoring



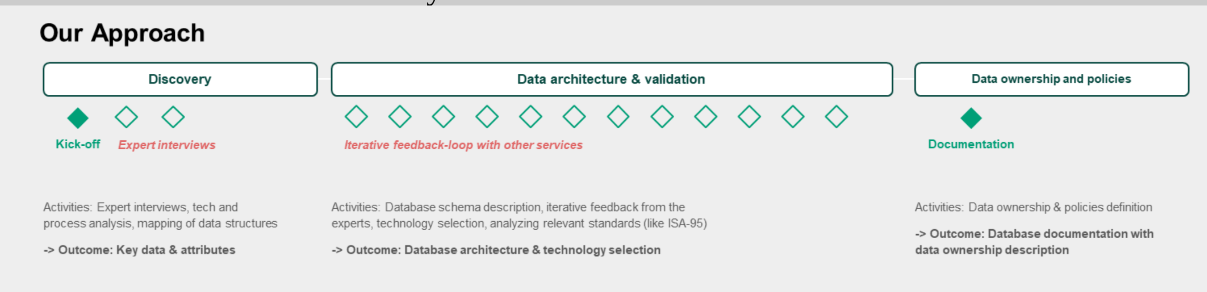
What is it? The process of using connected equipment, integrated in-process IIoT sensors (photodiodes, optical coherent tomography, acoustic emissions, etc.) to gain live insights into machinery, product and process, remotely.

What will do? For a given set of welding tasks, the remote monitoring will access to critical information on welding process variables, welding machine performance, laser-to-material interactions, and environmental conditions, to detect abnormal signs.

Who are the potential users? Plant maintenance engineers, process and system engineers, manufacturing and production engineers.

User stories: user has an existing laser welding system and validated process procedure (for manufacturing, production and/or maintenance) and wants to control and monitor the process using robotics at a remote location (e.g. confined space in a power plant), to reduce mean-time-to-repair/detect, eliminate the need for lengthy and costly manual trial-and-error actions, as well as reduce health and safety risks.

Welding process database



What is it? The needed data structure for operating the laser welding machines in distributed locations and the needed integration with different parties.

What will do? Data architecture of the welding process database is enabling all the other services to communicate with each other and display the data on the dashboard.

Cost and Sustainability evaluator

What is it? The objective of this service is to simplify decision-making involving sustainability, circularity and cost performances for the different configurations of the laser welding systems.

What will do? (1) dynamic and tailored evaluation of the performance, sustainability and cost implications of different configurations of the laser welding system (e.g., different raw materials, different operating conditions, different end of life strategies); (2) decision-making which integrates multiple criteria (i.e., indicators) and preferences of the stakeholders for the different configurations of the laser welding system; (3) a comprehensive overview of the different configurations of the laser welding system via the Digital Product Passport (DPP).

7. Policies in view of the DPP initiative and related enabling technologies

The information system at the base of the Lasers4MaaS services will provide the necessary data to assemble on-demand Digital Product Passports (DPPs) accompanying the welding process. The DPPs will be used to comply with the EU Ecodesign for Sustainable Products Regulations (ESPR). The DPPs generation system is developed with a close eye to the EU Rolling Plan on ICT standardization and EU Manufacturing and Green Deal dataspaces, so to ensure interoperability and reuse of data of Lasers4MaaS production output in other supply chains and future applications.

Background: The EU published its Ecodesign for Sustainable Products Regulation (ESPR) Proposal in March 2022. And a key pillar of the proposal is the creation of a digital product passport, which can be used to champion device and materials sustainability across value chains such as electronics, batteries, and textiles. By 2027 textile, construction and battery for EVs will transition towards DPP. Both public and restricted information to be available using an "access right" approach.

Why: to enable sharing of key product related information that are essential for products sustainability and circularity. For products to be sustainable it is vital to know the ***material used, source of the materials, how best to reuse and repair*** to extend lifetime. The DPP will address this and will track the journey of the product during the lifecycle, and reveal journey, composition, and impact.

What: manufacturers are responsible for generating the DPP. DPP is a product-specific data set, used to structure the disclosure requirements of products. For example, a consumer would scan a QR code embedded into the label of an item and be immediately redirected to the linked Digital Product Passport to view data on the product's sustainability credentials/carbon footprint such as the sourcing, material composition, manufacturing processes, percentages of recycled materials, repair, and disassembly options, as well as repurposing and recycling guidelines.

How: to enable DPP data interoperability is key. This will need to account for:

- **Dataset Identification**: specifying what data will be collected, processed and/or generated
- **Dataset Origin**: specifying if existing data is being re-used (if any), the origin of the data and the expected size of the data (if known).
- **Dataset Format and Type**: describing the structure and type of the data, time and spatial coverage and language and naming conventions, for example:
    - Material source (raw materials)
    - Material composition
    - Process data
        - Process type (welding, etc.)
        - Energy consumption (welding, robot, fixture, cooling unit, etc.)
        - Heat generation
        - Process consumables (gas, wire, etc.)
        - Water usage/cooling water with glycol, ethanol, etc.
        - De-commissioning plan and maintenance plan
        - Waste amount and type and re-use/recycling options
    - CO2 equivalent
    - Disposal options and treatment options
    - H&S items
- **Data Access**: specifying whether data will be shared/made open access.
- **Data Security**: specifying which provisions are in place for data security (including data recovery as well as secure storage and transfer of sensitive data). Furthermore, specifying Personal Data presence and, in that case, privacy management procedures put in practice.

More details have been incorporated in D1.2 (current standards and approaches for interoperability of digital twins for automation workflows) and D1.3 (current standards and approaches for interoperability of data streams).