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MANUELA
Additive Manufacturing
using Metal Pilot Line

Deliverable D1.4

Analytic Toolbox Specifications

WP 1

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Terms and definitions

Acronym	**Description**
AM	Additive Manufacturing
CAE	Computer Aided Design
EBM	Electron Beam Machine
ELM	Engineering Lifecycle Management
LBPF	Laser Powder Bed Fusion
HPC	High Performance Computing
TRL	Technology Readiness Level
REST	Representational State Transfer

Executive Summary

MANUELA aims at deploying a TRL 7 metal additive manufacturing pilot line, overcoming identified metal additive manufacturing process limitations, namely:

• Limited manufacturing speed,

• Limited capability of right-first-time production,

• Limited number of qualified materials,

• Lack of controlled quality monitoring at a line level,

• Lack of automated data analytics at line level for part, process and material parameters with tested functionality,

• Lack of an easy-to-use, comprehensive, user-interface with access to all pilot-line facets for both expert and non-expert users.

In order to derive pilot line specifications (materials, process, process parameters, line monitoring, post process, associated simulation software) we identified six use cases.

- UC_01: Avionics use case (QIOPTIQ), design and pilot manufacturing of Helmet mounted displays (HMDs) components intended for Aerospace applications
- UC_02: Space use case (RUAG), design and pilot manufacturing of novel slip rings allowing energy and signal transfers for rotating actuators
- UC_03: Medical use case (CBE), design and pilot manufacturing of custom made cranial implants created by the usage of titanium alloy
- UC_04: Power use case (ENEL), design and pilot manufacturing of power plant machinery components subjected to high thermo-mechanical stresses
- UC_05: Automotive use case (OEB), design and pilot manufacturing of rocker for motorsport competition
- UC_06: Energy use case (SIEMENS), design and pilot manufacturing of gas turbine heat shields

This document is a Key Deliverable capturing specifications of Analytical Toolbox. This represents the major basement of the MANUELA's project.

Indeed the latter Toolbox, leveraging a Digital Thread along the design to manufacturing process will enable end users to address above limitations, by sustaining a right decision the first time thanks to an Analytical Learning Process associated to Digital Twins relative to previous use cases.

1 Introduction

This deliverable (D 1.4) addresses task 1.4 of the MANUELA project, namely specifications of the analytical toolbox empowering the optimization of design to manufacture of the six use cases of the project.

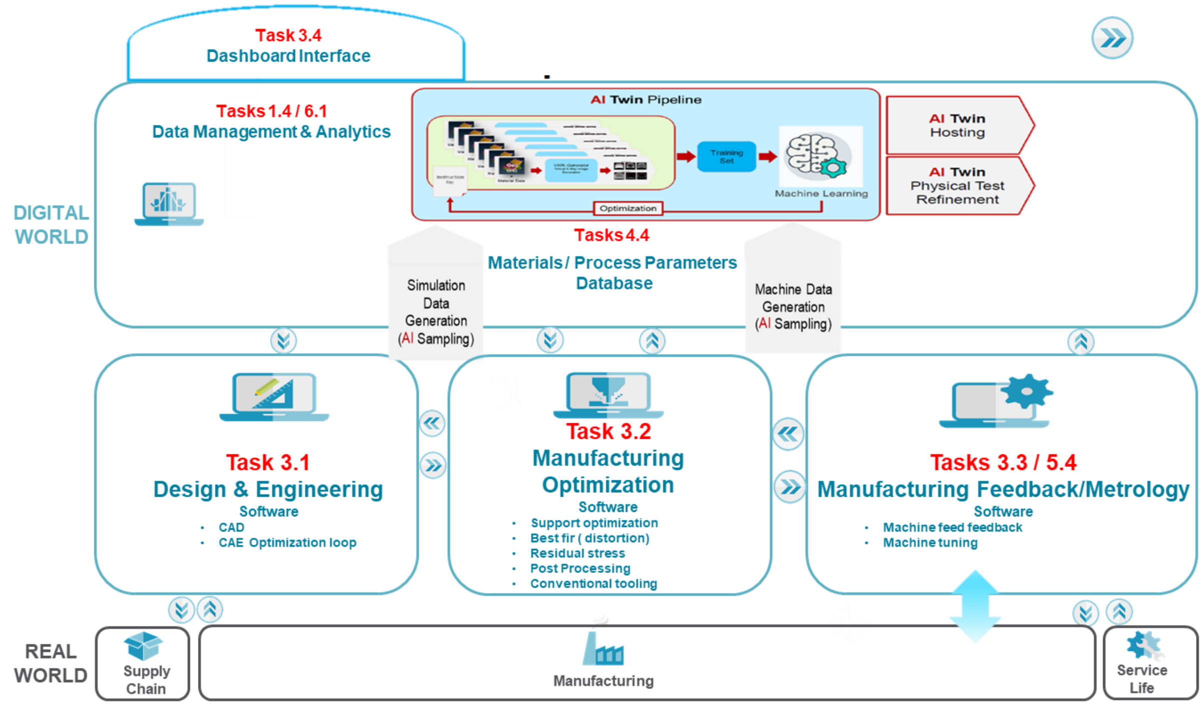

Figure 1-1: MANUELA's Digital Thread

As illustrated by Figure 1-1 Digital input/output might have different source/target. Namely, part of the data sets are generated along a physical process execution while remaining ones are fully part of virtual representation.

As such, D 1.4 needs to comply with requirements of the end users, expressed and compiled in Deliverable 1.1, while management of data manipulated and traced have to align with specifications of physical process itself, included in Deliverable 1.2 relatively to Pilot line and Deliverable 1.3 as far as post Additive Manufacturing is concerned.

D1.4 will therefore summarize Physical process data (extracted from dedicated deliverables) to map them with toolbox specifications, prior to deep dive on purely digital world.

Support of the latter one is relying on sets of requirements associated to the various aspects to cover, namely

- Big data, Data mining and Machine learning
- Multi-scale and Multi-physics simulation tools
- Real-time and continuous data feedback

As a reminder use cases cover:

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- UC_01: Avionics use case (QIOPTIQ), design and pilot manufacturing of Helmet mounted displays (HMDs) components intended for Aerospace applications
- UC_02: Space use case (RUAG), design and pilot manufacturing of novel slip rings allowing energy and signal transfers for rotating actuators
- UC_03: Medical use case (CBE), design and pilot manufacturing of custom made cranial implants created by the usage of titanium alloy
- UC_04: Power use case (ENEL), design and pilot manufacturing of power plant machinery components subjected to high thermo-mechanical stresses
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2 Physical Processes (Manufacturing & Control)

As shown Figure 2-1, MANUELA's pilot line relies on two main AM process, namely LPBF and EBM.

The LPBF and EBM machines that MANUELA targets to integrate to the pilot line will include additional or improved sub-systems developed by the AM machine providers, to be specified based on the use case requirements.

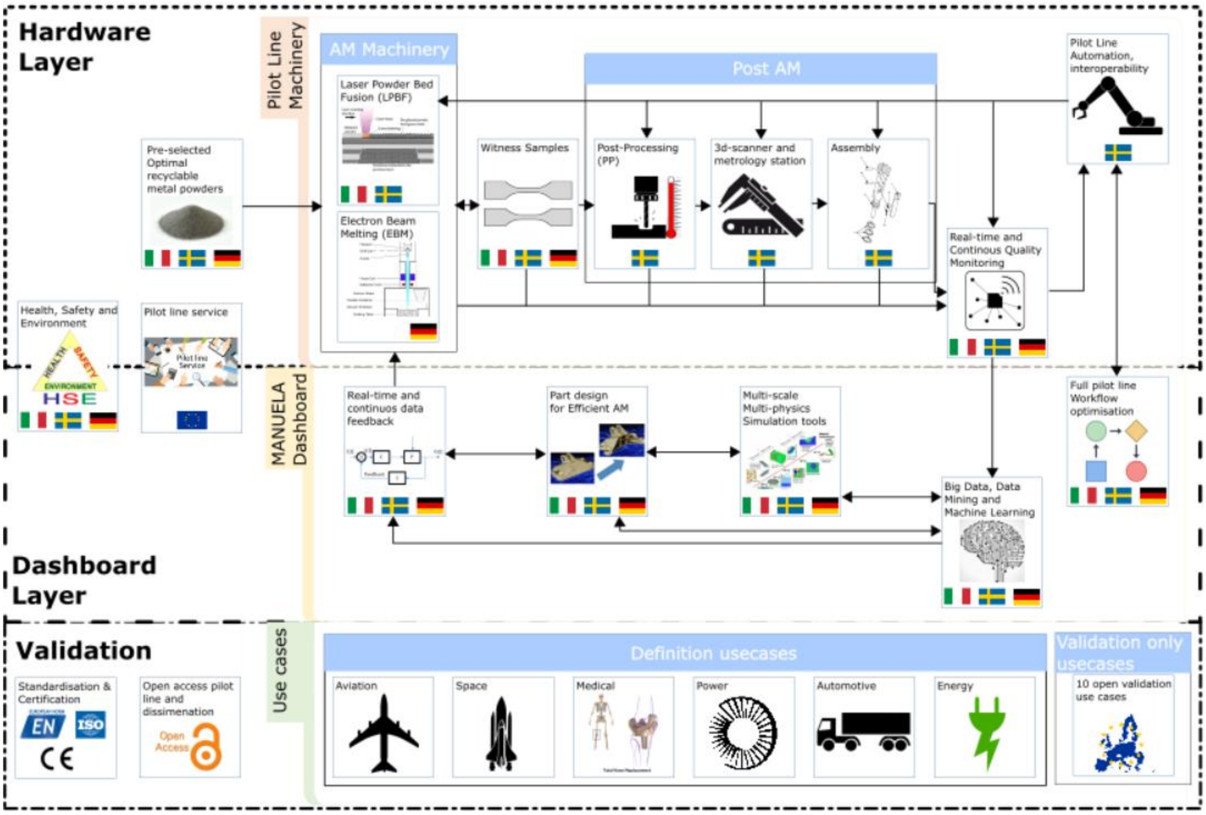

Figure 2-1: Pilot line overview

We will collect many source of information along construction of the Data Pound serving the Big Data mining activity as well as Machine Learning algorithms. Both Input and output will appear in the implementation of Real-time and continuous feedback, which will start, from Material selection, whose characteristics are traced from the initial sample measurements until the usage of derived engineering allowable in specific manufacturing process execution to be controlled by metrology.

2.1 EBM Machine

The EBM machine available in partners' premises, as well as its operational functionalities correspond to the following specifications, while the details of accessible process parameters appear in Table 2-1.

- **Machine name:** ATHENE (retrofitted Arcam S12 EBM-machine)
- **Max. power**: 6 kW (twice as high as that of commercial Arcam EBM-machines)
- **Build envelope**: 120 x 120 x 200 mm³
- **Beam diameter**: ~ 400 µm
- **Layer thickness:** 50 - 100 µm
- **Process monitoring**: ELectron-Optical observation (ELO) system by means of the detection of the backscattered electrons
- **Materials**: Ti-6Al-4V, pure copper and copper alloys powder with a particle size ranging from 45 to 105 µm

Parameter / measurement / …	Input	Output	Before process	During process	datatype
Component design	x		x		CAD file
Supports	x		x		CAD file
Build chamber pressure		x		x	Numerical value
Heating parameters	x			x	Parameter file
Build volume temperature		x		x	Numerical value
Rake travel	x			x	Parameter file
Powder amount per layer		x		x	Numerical value
Preheating parameters	x			x	Parameter file
Scanning strategy	x		x		Parameter file
Melting parameters	x		x		Parameter file
ELO parameters	x		x		Parameter file
Image of the melted layer (ELO)		x		x	Image file
Cathode information		x		x	Parameter file
Layer thickness	x		x		Numerical value
Build height		x		x	Numerical value

Table 2-1: EBM machine, FAU

2.2 LPBF Machine

The LBPF machines available in partners' premises, correspond to specification displayed respectively in Table 2-2 and Table 2-3.

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Technical data EOS M 290	
Building volume	250 mm x 250 mm x 325 mm (9.85 x 9.85 x 12.8 in)
Laser type	Yb fibre laser; 400 W
Precision optics	F-theta lens; high-speed scanner
Scanning speed	up to 7.0 m/s (23 ft./sec)
Focus diameter	100 µm (0.004 in)
Power supply	32 A / 400 V
Power consumption	max. 8,5 kW / average 2,4 kW / with platform heating up to 3,2 kW
Inert gas supply	7,000 hPa; 20 m³/h (102 psi; 706 ft³/h)
Dimensions (W x D x H)	
System	2,500 mm x 1,300 mm x 2,190 mm (98.4 x 51.2 x 86.2 in)
Recommended installation space	min. 4,800 mm x 3,600 mm x 2,900 mm (189 x 142 x 114
Weight	in)approx. 1,250 kg (2,756 lb)
Software	
EOSTATE Everywhere, EOSPRINT incl. EOS ParameterEditor	
Materials*	
EOS Aluminium AlSi10Mg, EOS CobaltChrome MP1, EOS MaragingSteel MS1, EOS NickelAlloy HX, EOS NickelAlloy IN625, EOS NickelAlloy IN718, EOS StainlessSteel CX, EOS StainlessSteel PH1, EOS StainlessSteel 17-4PH, EOS StainlessSteel 316L, EOS Titanium Ti64, EOS Titanium Ti64ELI, EOS Titanium TiCP Grade 2	
Optional accessories	
EOSTATE Monitoring Suite (EOSTATE Laser, EOSTATE PowderBed, EOSTATE MeltPool, EOSTATE Exposure OT), Comfort Powder Module, IPCM-M extra, IPCM-M pro**, wet separator, blasting cabinet	

Table 2-2: LBPF machine, Chalmers university

Specfications	Value
Building volume	400 mm x 400 mm x 350 mm
Laser type	Yb-fiber laser; 1 kW
Scan speed	Up to 7 m/s
Focus diameter	90 µm
Inert atmosphere	Nitrogen

Table 2-3: LBPF machine, Polito

2.3 Metrology

Consortium’s measurement capabilities cover: melt-pool monitoring, powder bed monitoring, thermal imaging, electron optical observation. The metrology station includes:

- CMM / 3D scan,
- X-ray tomography
- Residual stress measurement.

CMM data output is 3D point cloud as per the two following references:

http://www.absolutegeometries.com/3D_Scanning_file_output.html

https://en.wikipedia.org/wiki/X-ray_microtomography

The scanner tools a addressing the function listed below:

3D-scanner and metrology station	GOM Atos, Z-snapper 4M, Real-time quality or metrology control for the digitization of the post processing needs and requirements

Details on technology are accessible respectively via links hereafter:

Gom ATOS: https://www.gom.com/3d-software/gom-inspect.html#downloadForm

Z-snapper 4m: http://www.eosti.com/pdf_files/zsnapper4m.pdf

As for the tomography consortium can benefit form:

X-ray tomography	Custom build CT equipment with 190 kV X-ray tube, 4k detector and a maximum resolution of 1 micrometre.

Custom-developed X-ray computed tomography system consisting of a 190 kV micro focus X-ray tube, a 4k digital detector, and a novel metrology system for highest-accuracy measurements. Parts sized 20 mm (light metals) to 100 mm (plastics) can be measured with a resolution of the order of 1/4000 of the part dimensions (maximally 1 µm).

(E.g. machining parameters, on the machine process monitoring, localized temperature profiles, acoustic information, metrology station, digital images).

3 Data Model supporting the Physical World

The datasets associated to Materials/Process pair has to sustain 'materials' generic pure information (name, size,…), domain properties (mechanical, thermal,…), usage condition (temperature, size,…) and potentially a documented source of the information so that a quality rating could be associated to the decision process(acceptance, surface quality, verification…) induced by the AI mechanism.

In order to make such information searchable we propose to create categories in the "attributes" (placeholder for a particular piece of data), that will be assembled in a structured way that we will call a schema.

The materials schema is composed of four major categories:

- material classification
- properties
- source for each property
- parameters for each property

To represent these four major categories the materials schema is composed of the following object types:

- "MatMaterial" - contains the material's classification
- "MatSource" - contains a property's source attributes
- "MatParameterSet" - contains the property's parameter attributes
- "MatRevisableProperty" - contains a single property value

The “MatMaterial” contains the attributes that identify or classify the material in the collection of materials. There can be any number of these attributes and their types are one of the “MaterialCenter” data types.

The “MatSource” contains attributes to identify the source of a single property. There can be any number of source attributes and their types can be of any of the MaterialCenter data types. Each property has a reference to a “MatSource” for independently specifying the source for each property.

The “MatParameterSet” contains attributes to identify the parameters of a single property. There can be any number of parameter attributes and their types can be of any of the MaterialCenter data types. Each property has a reference to a “MatParameterSet” for independently specifying the parameters for each property.

The “MatProperty” has a type from the MaterialCenter data types to hold the various material types of data. Each property has its own set of source attributes and parameter attributes that reflect the source of the property and the parameters that define the origin of the property. Properties are independent of any grouping such as a property set and are related to the material that they belong to. Views can be constructed on the properties, though, to provide a property set view of the data. Each property can belong to one or more property sets too.

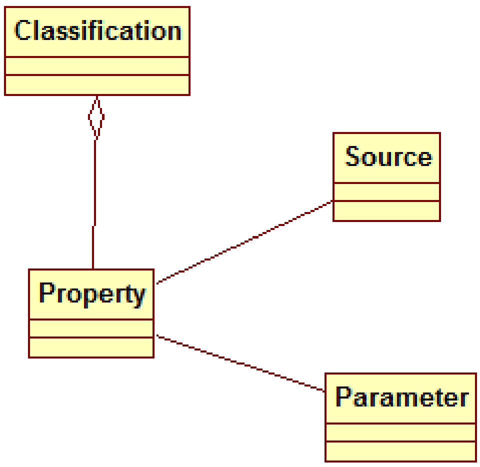

Figure 3-1: Data Model Architecture

A “MatProperty” contains the value for a property but the property definition of what the property models is a “MatPropertyDef”. For instance, the “MatPropertyDef” contains the definition of a Modulus. Modulus is defined as a measure with a quantity type of Modulus. The “MatProperty” definitions are independent of the schemas and created globally to the entire MaterialCenter database. This is because properties are the same for any schema and it also allows the properties to be queried together across schemas. The “MatPropertyDef's” are created when the system is initialized but new ones can be added or the existing ones can be modified if there are no references to the properties (i.e., there are no “MatProperties” that have values for a “MatPropertyDef”).

Characterizing materials requires a high degree of detail and complexity. MANUELA have the requirement to store curves, movies, images, documents, single point values with units, dates of testing, in order to fully classify, a physical test or a design record. In order to store and characterize complex material records. Therefore, we anticipate supporting the following data types:

- *Measure*: Real number (can contain a min, max, nominal value, and ranges). The attribute is associated to a quantity type with units.
- *Curve*: X, Y Curve points, or equation
- *String*: String of characters
- *Document*: File of any type in its native format (including geometric part models)
- *Image*: Image file
- *Movie*: Movie file
- *Date*: Date value
- *Matrix*: N x M matrix double values. Each value have the same units
- *Boolean*: contains True or False
- *Long*: Integer number without units
- *Many Reference*: Multiple reference to other objects in the database
    - used to link associated test specimens, CAE data and test standards
- *One Reference*: A single reference to another object in the database

We take also provision to make sure schema can be expanding on demand should unpredicted attribute might appear and become crucial for the management and optimization of the process

4 Digital Process (Multi-Scale Simulation, Analytics)

4.1 Multi Scale simulation Process

Simulation process is expected to sustain design for AM, as well as optimization of the simulation process itself.

4.1.1 Manufacturability along Part Design Optimization

Digital thread in the context of MANUELA starts with an existing proposed design optimized in respect of engineering objectives in the context of “conventional” manufacturing. Designing for AM requires a new way of thinking for designers, to take full advantage of the AM benefits. Present-day design tools insufficiently if usually very mature in respect of topological optimization, rarely (not to say never) account for manufacturability analysis and optimization of support design for overhanging parts.

Primary specification for topological optimization lays in “Manufacturability parameters” like overhanging angle.

The second aspect of the topological enhancement going beyond the work on the user interface connected to new capability of the solver for accounting the manufacturing variable is to couple the finite element mesh resulting from analysis with a smoothing algorithm. Indeed optimization tends to produce kind of a “Lego” model, where the optimized part expected for next step of the workflow (AM Process) has to appear as an “enhanced” geometry.

The third one resides in the capability interact between machine and simulation to exchange parameters (toolpath optimization…). The initial attempts representing the State of the Art ar based on specialized connector (Software/Machine), which is not fully satisfactory for portability across heterogeneous machine pool. Specifications for enhancement here are relative to API for rapid agnostic implementation.

4.1.2 AM process optimization

From a high-level perspective, consortium as decided to simulate AM process at macro scale to enable reasonable calculation time. Behavioral model is relative to mechanical representation of the process and a full thermomechanical idealization of the process along the entire cycle is missing to enable some technological choices.

So far, state of the art solution in this domain is a powerful and scalable software solution for the simulation of metal-based additive manufacturing processes relying on Inherent Strain Approach. This already deliver guidelines helping to:

- Reduce and compensate Deformation of the manufactured part and of the base plate
- Minimize residual stress
- Optimize the build-up orientation
- Optimize the support structure
- Condition the part after heat treatment, base plate & support structure removal

Some work on prediction of the microstructure and indication of criteria-based part failure in preliminary phase is required to progress on overall workflow optimization

The second axis to enhance AM process simulation means is the introduction of thermomechanical impact (layer by layer to preserve efficiency of a macro level representation), so that thermal effect will no longer be limited the post-processing phase. As a major outcome, the behavioral representation of the manufacturing process will relying on much higher fidelity.

4.1.3 Post AM process optimization

Part of the post AM for EBM & LBPF is already satisfactorily included in the AM process simulation package as described above. Project is under evaluation of other needs that would be required to go beyond. It seems it would be mainly associated to conventional manufacturing add-on or specific surface treatment. No conclusion is available at that stage to propose specifications.

4.2 Big data, Data mining and Machine learning

In addition to data sets introduced in previous sections, the dashboard must be designed to manage all types of data emerging from the AM pilot lines and relevant to knowledge extraction algorithms (e.g. beyond process parameters, information like images, CAD files). What is requested for management of analytical inputs is also valid for data created by machine learning techniques.

Then dashboard must also allow external applications to be called and executed along a prescribed workflow. This intends to facilitate the integration of various data mining and machine learning tools (to be developed in T6.1), which will be implemented under different environments (e.g. Python, C+) and called upon by the dashboard.

The expectation is that these external machine-learning applications will mainly take the form of:

- Data pre-processing techniques (e.g. data filtering, image processing)
- Model building techniques (e.g. part quality prediction, AM process deviation prediction)
- Model prediction feedback (e.g. to inform an on-going manufacturing process)

Using these machine learning tools, workflows should then be relatively easily designed through the dashboard to meet the demands of each use case, in terms of in-line and off-line feedback and optimisation. These will be designed in future work-packages.

But to clarify, in a workflow, the data collected in the pilot lines can be made available automatically to these external machine-learning applications through the dashboard, also enabling protection of confidential data (e.g. protected machine parameter ranges). While the data and information created by these machine learning tools (e.g. filtered data, predictive models, model prediction results) can be transferred back, through the dashboard, to a centralised data base or directly to on-going processes (e.g. manufacturing processes, simulation processes).

Finally, although the information management approach will be completed in more details in task 5.4, a first review of the expected types of data to be manipulated by the machine learning techniques was conducted. The aim was to gain an initial understanding of:

- The data types to be analysed (e.g. images, numerical values)
- The accessibility of the data (e.g. can it be automated? how frequently is it collected?)
- The potential for standardisation and for the development of big data analytics (e.g. can data be shared and analysed through cloud computing)
- The flexibility of the controllable factors (e.g. can they be modified automatically through the dashboard or only by an operator).

The main results produced by partners providing manufacturing and metrology technologies are shown in Annex 1. This will be used as starting point to design initial machine learning workflows. The results also suggest that the dashboard specifications mentioned in previous section is adequate to handle the range of expected data types.

5 Data Model supporting the Digital World

Starting from the MANUELA Dashboard concept as per Figure 1-1 above the expressed needs is represented by a collaborative platform capturing information from heterogeneous workflows in a unified environment (from Design to Manufacturing Control via Manufacturing Process idealization). As introduction to data management the below definitions will allow understanding basic Specified solution principles about data management that will be named ELM (Engineering Lifecycle Management) platform

Objects: ELM stores data as objects that are a group of metadata and files. The list of available metadata for an object depends on its type.

Data model: The out-of-the-box object type definition is expendable in the User Interface (UI) to create or enrich types with new attributes. All types derive from a master type containing all necessary information to build the pedigree of an object (Who, what, when, how).

Project/Container: any object belongs to a container that defines user permissions. Containers can be nested to provide an organization comparable to folder structure.

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Object links and workflows: the first level of linkage is the container. If an object is part of a workflow, strong or weak links between objects are automatically set.

Lifecycle: depending on the level of maturity of an object, lifecycle events such as promotion or deletion are handled through a set of rules and propagated through the object links. The rules can be configured for each object type.

5.1 ELM Data Model

5.1.1 Data Management

Here are the main elements of ELM data model, along with examples to understand their usage:

- *Project - Organization by product line and/or discipline.*
- *Item - A product, part or subsystem.*
- *Variant - A distinct design for an item. For Example: different shape, material, or manufacturing process.*
- *Model – Idealizations of a given variant. For example CAD model, Analysis models, structural, fatigue, CFD, dynamic, etc.*
- *Input Deck – A run ready analysis model file. Typically, a formatted text file is specific to a particular solver such as Nastran, Adams, and so on.*
- *Result - Result of a model run (output file).*
- *Key Result - Special representation of result. For example value, image, movie, etc.*
- *Targets - Analysis criteria that applies to a desired Scenario. For instance Stress < 200 MPa.*
- *Study Dashboard - Summary of results derived from Targets to Key Result Quantities.*

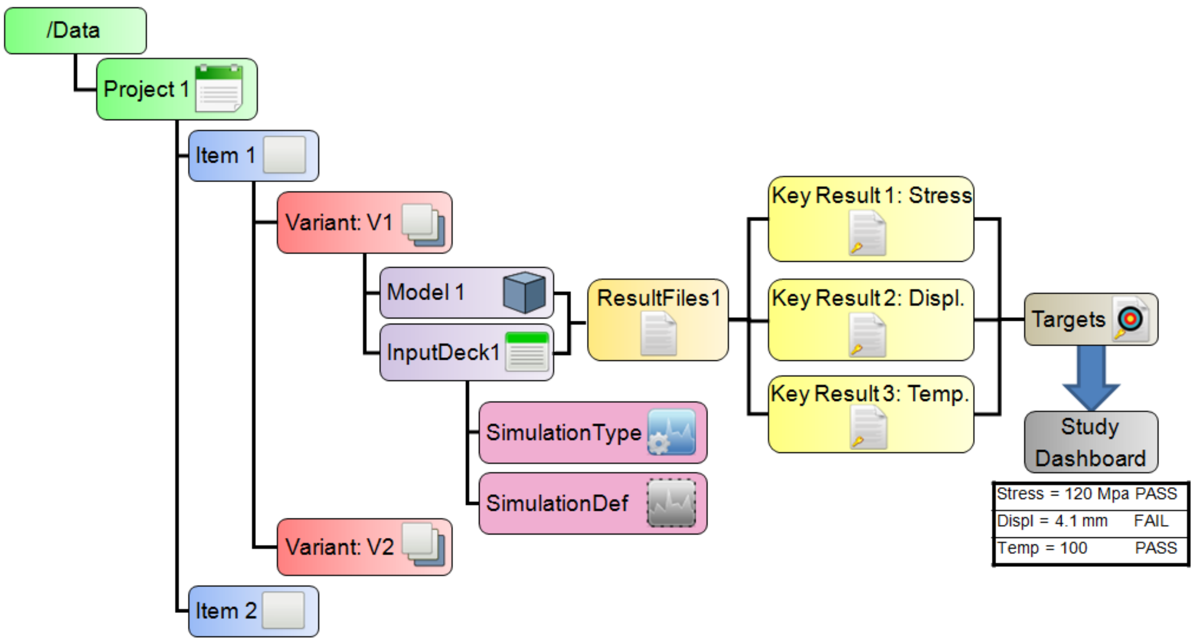

Figure 5-1: Data Model Components

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5.1.2 Versioning

ELM has to handle data changes by creating new versions of that data, corresponding to learning sets, validation sets as per the illustration bellow of Variant Simulation assemblies of models & Scenarii, and finally data to process.

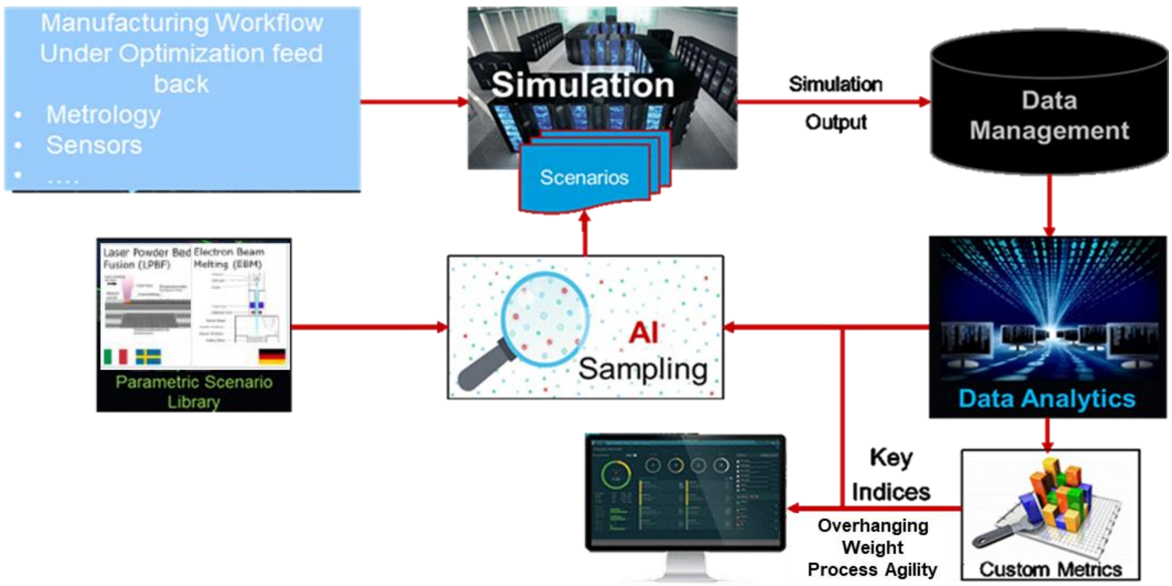

Figure 5-2: Digital Learning sets variants generation

Variants and revisions are therefore introduced at that stage.

- *Variants in case of alternatives or major versions*
- *Revisions for the subsequent iterations on the same data*

As explained in the traceability section, all hardware engineering data are linked to the data, which has been used to generate it. This allows identifying very quickly which objects are impacted by a change. Default behavior of ELM is, that always the latest revision is used, so all downstream processes will automatically use the most recent data available.

We have the ability to propagate specific comments along the dependency chain so that when data get outdated; all dependent data are marked as well, thus transporting the change information. Users can also watch specific data and will be notified automatically when a new version of that data is published in the system.

Based on impact graph, dedicated change request can be generated for engineers to review and eventually update their data. Powerful comparison tools are available so that engineers can take the right decision.

5.1.3 Type of Data

ELM has to be flexible enough to provide native object types for the main entities that are used in the CAE world: Model, Input Deck, Result, Key Result, Report, etc… Each type has a set of common attributes (name, description, files, creation time...) as well as specific meta-data designed to support type-specific needs (sub models, format, curve data…).

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Object type will also determine which actions can be launched from objects of that type: solver can be launched from an Input Deck; simulation report can be attached to a Result, etc... (in a perspective of automation of a workflow)

Each main type of object can be adapted to sub-types to provide capabilities that are more specific. For example, a Mesh Model will have embedded meshing information whereas a Nastran Result will hold Nastran-specific information.

Documents will be handled in the same way, which allow covering specifications word document as well as standalone reports generated out of the system.

5.1.4 Data Access

If the whole set of information, has to be stored for the purpose of data analytics execution, materials and machine owners for instance as all project partners are also looking for IPR protections, while export compliance in an international activity has also to be guaranteed.

As such, it is mandatory to establish rules managing access rights.

The proposed specification in that respect will leverage the following components:

- **Permissions:**

Each data belongs to a specific project (and only one) and access permission to that data is set at project level. Users get privileges on project data depending on:

  - *His profile (internal, external, administrator…) assignment*
  - *His group (Design, Manufacture, managers, Company…) assignment*
  - His named assignment

It is anticipated to manage such a structure though Administration function for the whole ELM.

- **Maturity:**

All objects also have a release level (0 to 3) which determines the read/write/execute privileges that users will have on it. Typically, the privileges are reduced as the release level grows. The figure bellow will be elaborated in Lifecycle section for more details

	Project Role ->	Project - Visitor				Project - Consumer				Project-Member				Project-Collaborator				Project-Manager				Project-Administrator			
	Release Level ->	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
Object Privileges	read	o	o	o	x	o	x	x	x	o	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	write									o	o	o		x	x	x	x	x	x	x		x	o	o	
	delete									o				o				x	x	o		o			
	release (promote)									o	o			o	o			x	x	x		o	o		
	demote										o				o				x	x	x		x	x	x
	chown (change owner)									o	o			o	o			x	x	x		x	x	x	x
	createTempRevision									o	x	x		x	x	x		x	x	x		x	x	x	
	activateRevision									o	x	x		x	x	x		x	x	x		x	x	x	x
	moveObjectFromProject																	x	x	x	x	x	x	x	x
	createObjectInProject									x	x			x	x			x	x	x	x	x	x	x	x

Figure 5-3: Role based security

- **Sharing:**

To avoid administration overhead, unitary objects can also be shared to other projects, which provides access right the users of that project. This is typically used when a

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department has to deliver data to another department across extended enterprise as show in following figure.

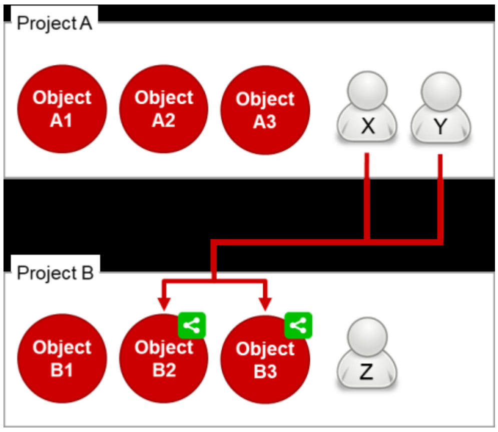

Figure 5-4: Secured collaboration

- **Confidentiality:**

Security labels are flags that can be assigned to objects in order to protect them. They work like locks: only a user that possesses the keys for all the locks on an object is allowed to access the object. This is especially targeting export compliance classified information.

5.1.5 Lifecycle

Every object in ELM will have a release level that is similar to a maturity level of the data. User access to a data is granted depending on its maturity. Proposed release levels are:

- *Level 0 - Draft: early stage data, only visible by the owner*
- *Level 1 - Public: available for defined user groups*
- *Level 2 - Published: available for defined user groups and not modifiable*
- *Level 3 - Archived: the object is in the system to keep tracking on information*

At creation, the data are by default set to Private and can be promoted to the next release level in few clicks. Propagation rules are used to set related data to same release level. For example, when a report is Published (level 2) it is important to ensure that all its ancestors (from CAD to simulation outputs) are also published.

5.1.6 Traceability

Every action launched on an object and their outcomes are automatically traced in the system, which provides the complete pedigree for all data.
Another aspect of the traceability is the ability to track the sequence of events that is part of the data history.

5.2 Collaboration Management

5.2.1 Workflows

ELM will provide a ‘Work Request’ capability that allows an organization to define a human workflow and relate it to different documents, inputs and actions. When a work order is

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requested, an instance of a Work Request is created along with its sub tasks and assigned to users.
A work request is based on referenced inputs that the requestor provides when he instantiates the request. Those inputs can be any kind of object such as parts, instruction documents, requirements…
Work requests and sub tasks can be chain to ensure consistency of the whole process. It allows the end user to launch the work requests and their activities in the appropriate order. He is guided in his activities, but not restricted to a rigid process. Sub task have status information that are set automatically depending on the activity execution success or failure.

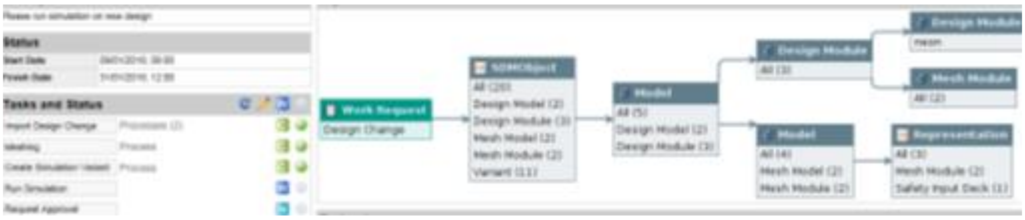

Figure 5-5: Workflow Management and Traceability

It it very easy to prepare work requests for CAE activities (meshing, simulation…) as well as for administration tasks such as preparing documents or a project structure.

5.2.2 Workflows Overviews

ELM will provide a task overview per project as an out-of-the-box component. It shows an overview of all work requests and sub tasks organized per phase. Color-coding and status allow users to get important information at a glance.

Project Work Request Task Status

	00 Concept	01 Preliminary	02 Detailed
Data			
Knuckle			
SteeringKnuckle Simulation	Work In Progress	Not Started	
Publish Knuckle Docs	Approved	Not Started	
Publish Loads	Not Started	Not Started	
Publish CATIA Model	Work In Progress	Not Started	
Publish FEM	Not Started	Not Started	
Publish Input Deck	Not Started	Not Started	
Publish Result file	Not Started	Not Started	
Publish Stress key results	Not Started	Not Started	
Publish Report	Not Started	Not Started	
RotorHub			
RotorHub simulation	Work In Progress	Work In Progress	Not Started
Publish Rotor Docs	Approved	Approved	Not Started
Publish Loads	Approved	Complete	Not Started
Publish CATIA Model	Approved	Work In Progress	Not Started
Publish FEM	Complete	Not Started	Not Started
Publish Input Deck	Complete	Not Started	Not Started
Publish Result file	Complete	Not Started	Not Started
Publish Stress key results	Work In Progress	Not Started	Not Started
Publish Report	Not Started	Not Started	Not Started

Figure 5-6: Workflow Monitoring

5.2.3 Validation and approval

ELM will handle quality checks on hardware engineering data. This usually comes from validation tools (such as mesh quality analysis) that are integrated within validation work request which gets assigned to quality engineers as part of the validation workflow. Quality indicators can also be set manually if needed.

We also handle lists of approver users who are allowed to validate data depending on their skills and responsibility, associated to leaning process of the AI.

5.3 Application Integration

There is no "one size fits all" integration specified approach in the pilot line, though ELM offers different ways of interacting with external application mainly based on the maturity and automation level of the associated process.

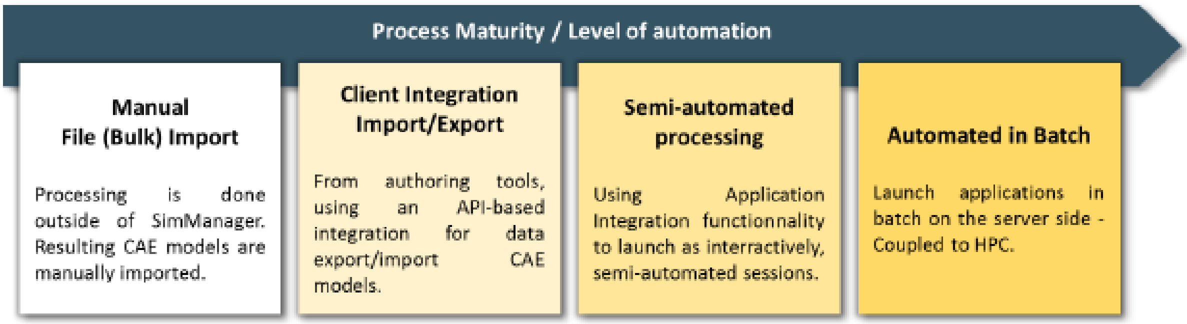

Figure 5-7: Scalability along applications' integration

The Figure 5-7 illustrates the various levels of integration and automations. Any AI algorithm along the Machine Learning process will fold in one of these cases (see paragraphs 4.3.3)

5.3.1 The right tool to the right people

Applications are objects and as such have their own lifecycle and access control. More than this, access can be controlled on the application context (version, environment, level of automation…) and parameters (Command line parameter options).
This allows the user to be able to launch the tool they want, in the way they should launch it – Improving quality and efficiency.
This also help administrators to keep control on the toolset available to end users.

5.3.2 ELM Plugins

Plugins necessary between CAE world and physical domain (metrology and/or machine feedback /interaction) will be built in engineering tools to publish and retrieve ELM data using REST API provided by ELM.
REST API allows Data query and retrieval via RESTful URLs (REpresentational State Transfer). A client application can retrieve data from the SimManager database and vault with very simple means. Additionally, actions can be launched.
The access to the data is Web based using the HTTP protocol. The client application can run everywhere, mainly on users' desktops. The interface creates standard XML output being easy to parse. There is no dependency on any kind of programming language and no dependency on any kind of additional software.

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The data being requested is secured with the same mechanism as the Web UI. I.e. a user has be logged in before he can access any data and he can only retrieve data he is allowed to see.

We support two output formats for REST queries: XML and JSON. In case of a request for the file from the vault, the file is returned as is. Such capability will empower Analytics evaluation of stored data through exchange with Microsoft Excel for instance or csv formats, as illustrated in Figure 5-8

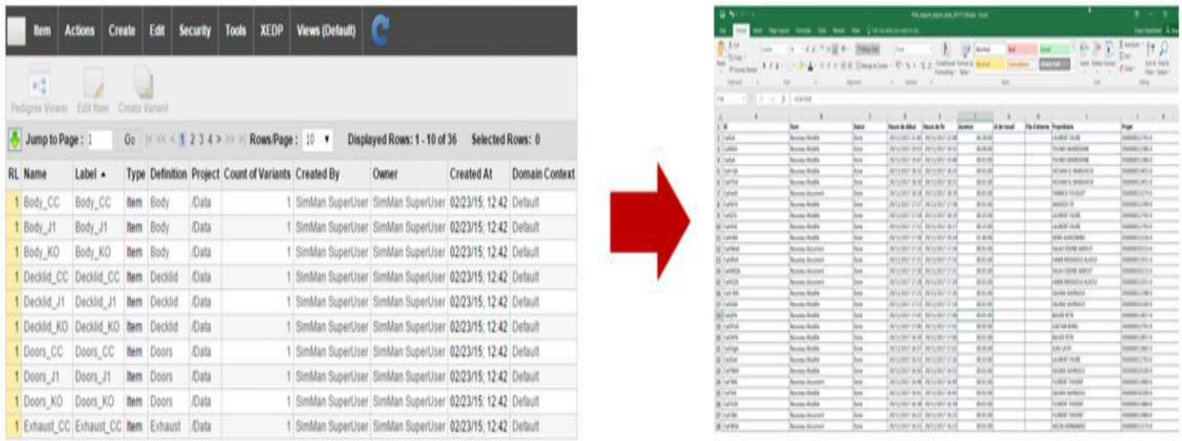

Figure 5-8: ELM Connection to external spreadsheet: from internal format to customer' one

5.3.3 Tool integration in ELM

ELM will allow for external applications or scripts to be called and executed as part of a SimActivity or SimProcess (actions or group of actions in ELM). For example, integrating a solver in ELM will allow submission of an input deck to a solver by ELM directly in the computing resource. The same concept applies to other applications as well. (Data enrichment, Model Assembly (variant generation along Virtual Learning sets generation), other Pre-Processing tasks, Post Processing, and Report creation).

ELM will be able to launch interactive tools on client workstation (using Java Web Start technology) or launch batch tools on an HPC. In both cases, outputs will be imported back to ELM using out-of-the-box import mechanism.

6 Conclusion

All domains of Digital Threads have been taken into account as presented here above.

Thanks to the robust State of the Art in respect of Simulation data and process management as well as materials lifecycle management from test to simulation via design phases, the consortium is very much confident in respect of specifications for implementation of the overall ELM of MANUELA Dashboard.

Of course, some of the refinement will appear in the curse of the project associated to parameters to be uncovered by the Machine Learning activity that has not started yet. However, no foreseeable impact is expected for the data structure.

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7 ANNEX 1 – Data Types Initial Review

7.1 Metal Laser Sintering machine

Process Name:		EOS M290				
Process description	Additive Manufacturing System - Metal Laser Sintering					
Main Input	Metallic Powder					
Main output	Metal component					
Controllable factors						
Name of controllable factor	**Format**	**Control - The Setting up is:**	**Modification - It is modifiable:**	**Standard?**	**Data Confidentiality**	**Additional data information**
EOS Process Name	Text	Controlled during job preparation phase	Offline/During a processing pause	Specific to our process	Public	
Laser Power	Single numerical value	Controlled during job preparation phase	Offline/During a processing pause	Specific to our process	Parameter fully confidential	Can be shared with Chalmers
Laser Speed	Single numerical value	Controlled during job preparation phase	Offline/During a processing pause	Specific to our process	Parameter fully confidential	Can be shared with Chalmers
Hatch Distance	Single numerical value	Controlled during job preparation phase	Offline/During a processing pause	Specific to our process	Parameter fully confidential	Can be shared with Chalmers
Layer thickness	Single numerical value	Controlled during job preparation phase	Offline/During a processing pause	Specific to our process	Public	
Flow	Single numerical value	Controlled during job preparation phase	Offline/During a processing pause	Specific to our process	Public	
Process oxygen content	Single numerical value	Controlled during job preparation phase	Offline/During a processing pause	Specific to our process	Public	
Dosing factor (short feed)	Single numerical value	Controllable only by an operator	Online/ During the processing at any time	Specific to our process	Public	
Nozzle	Text	Controllable only by an operator	Offline/During a processing pause	Specific to our process	Public	
Protective atmosphere (Aluminium)	Text	Controlled during job preparation phase	Offline/During a processing pause	Specific to our process	Public	
Building platform temperature (Aluminium)	Single numerical value	Controlled during job preparation phase	Offline/During a processing pause	Specific to our process	Public	
Powder sieving before job	Text (Yes/no)	Controllable only by an operator	Offline/During a processing pause	Standard for similar processes	Public	
Monitored factors						
Name of Monitored factor	**Format**	**The Data Transfer to dashboard:**	**Access - It is accessible:**	**Standard?**	**Data Confidentiality**	**Additional data information**
Build time	Single numerical value	Available in EOSTATE report (.pdf)	Offline / Only at the end of the process	Specific to our process	Public	
Powder recycling number (to monitor PSD and chemistry, amount of use cycles)	Single numerical value	Is a manual upload performed by an operator	Offline / At the end of the process or during a pause	Specific to our process	Public	
Powder lot	Text	Is a manual upload performed by an operator	Offline / At the end of the process or during a pause	Specific to our process	Public	
Recoating Blade	Text	Is a manual upload performed by an operator	Offline / At the end of the process or during a pause	Specific to our process	Public	
Building platform temperature (Ni, steels, Ti)	Single numerical value	Available in EOSTATE report (.pdf)	Offline / Only at the end of the process	Specific to our process	Public	
EOSTATE report	PDF document	Available in EOSTATE report (.pdf)	Offline / Only at the end of the process	Specific to our process	Parameter range confidential	Confidential within Manuela
PowderBed Images	Image (collected multiple times)	Is a manual upload performed by an operator	Offline / Only at the end of the process	Specific to our process	Parameter range confidential	Confidential within Manuela
Protective atmosphere (Ti)	Text	Is a manual upload performed by an operator	Offline / At the end of the process or during a pause	Specific to our process	Public	

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7.2 Electron beam AM machine

Electron Beam Melting (EBM)					
Process description	**Powder bed AM using an electron beam**				
Main Input	**A component design**				
Main output	**A metallic component**				
Controllable factors					
Name of controllable factor	Format	The Setting up is	Modifiable	Standard?	Additional data information
Component design	CAD file	Controllable both Remotely and by an operator	Offline/Before a new processing	Standard for similar processes	
Supports (e.g. position, amount,..)	CAD file	Controllable both Remotely and by an operator	Offline/Before a new processing	Standard for similar processes	
Build chamber pressure	Single numerical value	Controllable both Remotely and by an operator	Online/ During the processing at any time	Standard for similar processes	
Heating parameters (build volume start temperature)	Parameter file	Controllable both Remotely and by an operator	Offline/Before a new processing	Standard for similar processes	
rake travel (Powder dosing per layer)	Parameter file	Controllable both Remotely and by an operator	Online/ During the processing at specific intervals	Standard for similar processes	
Preheating parameters	Parameter file	Controllable both Remotely and by an operator	Online/ During the processing at any time	Standard for similar processes	
Scanning strategy (beam movement)	Parameter file	Controllable both Remotely and by an operator	Online/ During the processing at specific intervals	Standard for similar processes	
Melting parameters (e.g. current, scanning speed,..)	Parameter file	Controllable both Remotely and by an operator	Online/ During the processing at any time	Standard for similar processes	
ELO parameters	Parameter file	Controllable only by an operator	Online/ During the processing at specific intervals	Standard for similar processes	
Layer thickness	Single numerical value	Controllable both Remotely and by an operator	Online/ During the processing at specific intervals	Standard for similar processes	
Monitored factors					
Name of Monitored factor	Format	Data Transfer to dashboard	Accessible	Standard?	Additional data information
Build chamber pressure	Single numerical value	Can be automatic (e.g. through network)	Online / collected during the process continuously	Standard for similar processes	
Build volume temperature	Single numerical value	Can be automatic (e.g. through network)	Online / collected during the process continuously	Standard for similar processes	
Build height	Single numerical value	Can be automatic (e.g. through network)	Online / collected during the process continuously	Standard for similar processes	
Cathode information (e.g. operating time,..)	Parameter File	Can be automatic (e.g. through network)	Online / collected during the process continuously	Standard for similar processes	
Powder amount per layer	Single numerical value	Can be automatic (e.g. through network)	Online / collected during the process at specific intervals	Standard for similar processes	
ELO image	Image	Can be automatic (e.g. through network)	Online / collected during the process at specific intervals	Specific to our process	

7.3 X-ray tomography metrology

Process Name:					
Process description	**X-ray computed tomography analyses**				
Main Input	**A metallic component**				
Main output	**3D scan of the component's external and internal features**				
Controllable factors					
Name of controllable factor	Format	Control - The Setting up is:	Modification - It is modifiable:	Standard?	Additional data information
A metallic component	A component/workpiece	Controllable only by an operator	Offline/Before a new processing	Standard for similar processes	
Material	Single numerical value	Controllable only by an operator	Offline/Before a new processing	Standard for similar processes	Material knowledge simplifies adjusting the parameters of the X-ray CT
Drawing with dimensions and tolerances of the component	Drawing (PDF)	Controllable Remotely but only by an operator	Offline/Before a new processing	Standard for similar processes	For specific dimensional measurements
CAD file of the component	STEP file	Controllable Remotely but only by an operator	Offline/Before a new processing	Standard for similar processes	For nominal/actual comparison
Monitored factors					
Name of Monitored factor	Format	Data Transfer to dashboard	Access - It is accessible:	Standard?	Additional data information
Specific dimensional measurements	Single numerical value	Manual upload performed by an operator	Offline / Only at the end of the process	Standard for similar processes	Post analyses performed by an operator based on drawing
Part porosity	Parameter File	Manual upload performed by an operator	Offline / Only at the end of the process	Standard for similar processes	Post analyses performed by an operator, porosity parameters tbd
Nominal/actual comparison	tbd	Manual upload performed by an operator	Offline / Only at the end of the process	Standard for similar processes	Post analyses performed by an operator, color coded deviaion mapped onto CAD for qualitative analysis, deviation histogram, format tbd
Complete object geometry	STL file	Manual upload performed by an operator	Offline / Only at the end of the process	Standard for similar processes	With reservations: Creating an STL file is only possible with good data quality (small objects, low density,...), data size may be several GB