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COMPASS 101136940
A data-driven remanufacturing process for sheet metal and thermoplastic composites

Deliverable D6.1 – "Intermediate demonstration and evaluation"

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Dissemination Level		
PU	Public	X
SEN	Sensitive information	

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1. INTRODUCTION

This document presents an intermediate overview of the components currently under development within the framework of **WP3 – Data Collection Along the Circular Process**, **WP4 – Tools for Optimized Recycling and Reuse** and **WP5-Data transfer, security and sharing**. These components constitute the technological core of the project, addressing two critical aspects:

- **Data Infrastructure (based on WP3 & WP5)**- covering multiple aspects such as data handling capabilities, data security, data exchange mechanisms, and finally secure & selective access management. These elements collectively support the development of a robust and traceable Digital Product Passport (DPP), ensuring long-term data storage and integrity.
- **Technical components and tools**- focussing on the technical aspects such as selection, handling, planning, and execution of remanufacturing processes for both composite and metal use cases.

The document is organized as follows:
The initial section outlines the objectives of the demonstration activities, as defined in the Grant Agreement [**Project 101136940 — COMPASS**]. A contextual overview of WP2 is provided, referencing to the relevant deliverables [D2.1-D2.4] that establishes the context for the various components under development.
Next, each technical component is explained in detail covering the following aspects namely:

- **Description of the component**, detailing some technical aspects about the tool
- **Relevance to the project and functionality**, i.e. how it contributes to the overall goal of the project, its role in the project and its output.
- **Interdependencies:** interactions between the different tools
- **Maturity and progress:** The current development stated compared to the expected level based on the duration and beginning of the development as defined in the **grant agreement.**
- **Key performance Indicators:** For each component, based on the level of maturity, key performance indicators will be defined.

In the final section, a universal table containing all KPIs defined in the previous sections for each component is given. The table briefly describes the technology that is being measured and the target.

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2. OBJECTIVE

The stated objective of this intermediate demonstration as given in the GA is as follows:

> *"**Intermediate Demonstration** (month 16-18): The demonstration is still taking place at the level of individual processes. The main demonstrations will be the remanufacturing processes from WP4, which will be done on first sample parts, whose quality will be analyzed. In terms of digital tools initial versions of the manual repair assistant, the sheet metal reforming calculator, the process planner and the disassembly assistant (from WP4) will be demonstrated. Data acquisition, transferring data into the structures of the digital component passport (from WP3) and managing access to the data elements (from WP5) will also be shown. The demonstration also includes an initial version of the sensor system for lay-up monitoring during the manufacturing. "*

3. SCOPE

This demonstration will cover different aspects of the data infrastructure and the individual digital components that being developed within work packages WP3, WP4 and WP5. Being an *intermediate demonstration*, the scope will be limited to the individual components commensurate to the level of maturity based on the duration and start of each development task. This is important to note as can be seen in the table below:

COMPONENT	Relevant task	Period (project months)	Current Progress (fill level) Status (colour) (Progress according to plan Minor issues/delayed Major issues detected)
Data structures	Task 3.1, 3.2	6-15	100%
Data acquisition and exchange	Task 3.3, 3.4	13-30	
Data storage, data sharing and access management	Task 5.1, 5.2	6-27	
Digital product passport platform	Task 5.4	6-33	
Sheet metal reforming calculator	Task 4.2	12-27	
Manual repair assistant	Task 4.3	12-27	
Remanufacturing of Composite parts	Task 4.4	12-27	
Remanufacturing of Metal parts	Task 4.5	12-27	
Remanufacturing planner	Task 4.6	10-30	
Disassembly assistant	Task 4.7	13-30	

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4. USE CASE OVERVIEW

This section gives a short overview of the three different use cases namely the Sheet metal remanufacturing, Composite remanufacturing and data supported dismantling.

4.1. Sheet Metal Remanufacturing

Sheet metal forming is typically performed either directly from rolled and slit coils or from blanks successively cut from coils where variations in mechanical properties and sheet thickness within a rolled coil usually change slowly and steadily. This allows the forming process to be controlled using statistical process control, and corrective action can be taken if control limits are violated (figure 4.1.1, left).

When reusing sheet metal materials from stamping scrap, defective formed parts, or end-of-life components, stamped blanks must be fed into the deep-drawing process as individual parts. Here, this consistency in the change in properties is no longer present. In the best case, it is possible to trace back to an original material batch with its own characteristics – however, the resulting variation in properties is randomly distributed among the individual scrap sections and the reuse blanks produced from them (figure 4.1.1, right).

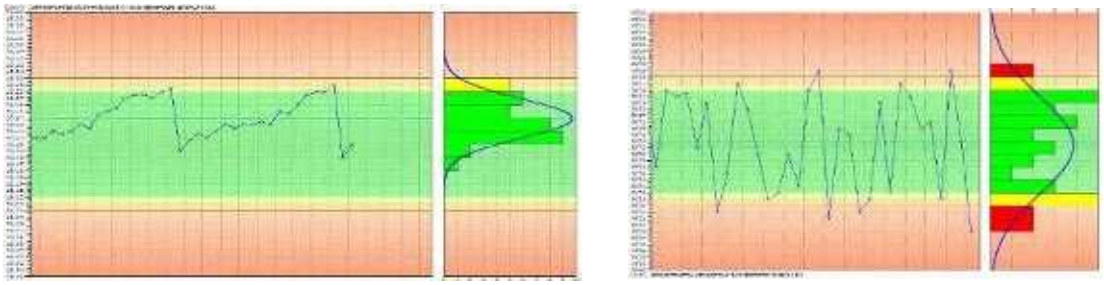


Figure 4.1.1: process with slowly and steadily changing material input (left) and process with randomly changing material input(right)

This requires a different approach to process monitoring for the forming of these sheet metal pieces. Instead of statistical process monitoring by measuring samples, it must be possible to determine whether each individual manufactured part is according to specification or not with respect to characteristic parameters of the forming process. Such process parameters can include forces on the tool components, temperature, sound emissions from the forming process, vibrations and accelerations, energy consumption of the forming presses, etc.

To assess the potential for directly using recycled sheet metal, it is therefore not enough to simply demonstrate its formability on a few scrap sections – rather, it must also be demonstrated that it is possible to conduct a qualitative assessment of the parts based on the recorded and evaluated characteristic values of the processes. For this purpose, the tools for reforming of the parts selected for the demonstration are equipped with comprehensive sensor technology with the measured signals being constantly evaluated and an attempt is made to derive a quality statement for the individual formed part. To map the associated material and data flows, the origin and condition of the scrap must also be considered (figure 4.1.2).

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Further, a distinction in the feedstock must be made between:

- *Scrap from blank production* which is almost undeformed; the original batch of the material and its properties are known
- *Scrap from primary forming* which can either come from trimming the formed parts or from defective parts from production. Relevant work hardening already has taken place, which is why individual areas with different properties must be separated. However, the data for this is available in the form of forming simulations, material data, and batch certificates of the material and
- *Scrap from end-of-life parts (EoL parts)* is the third type which represents the most difficult situation because there is usually no information on the local material properties. This means that reference parts must first be characterized for their local properties through material analysis before they can be assigned to reuse forming processes. Furthermore, these parts usually have functional surfaces or coatings that must first be removed before reuse.

Once there is sufficient knowledge on the local properties of the components to be used in reforming, assignment to the reforming parts that can be made from this scrap- material is done by means of digital tools. These tools, developed by EDAG and LKR, include a Sheet Metal Reforming Calculator (SMReC), a Cutting Planner and a Remanufacturing Process Planner.

The output of these tools is information on how the scrap has to be sectioned, treated and clustered and how nesting of the blanks for the new components has to be done. Derived from the gathered information, properties of the defined blanks, which will be condensed in batches and not on single component base, will be sent to the digital product passport (DPP). This means that values for properties are given in ranges, not as a single value.

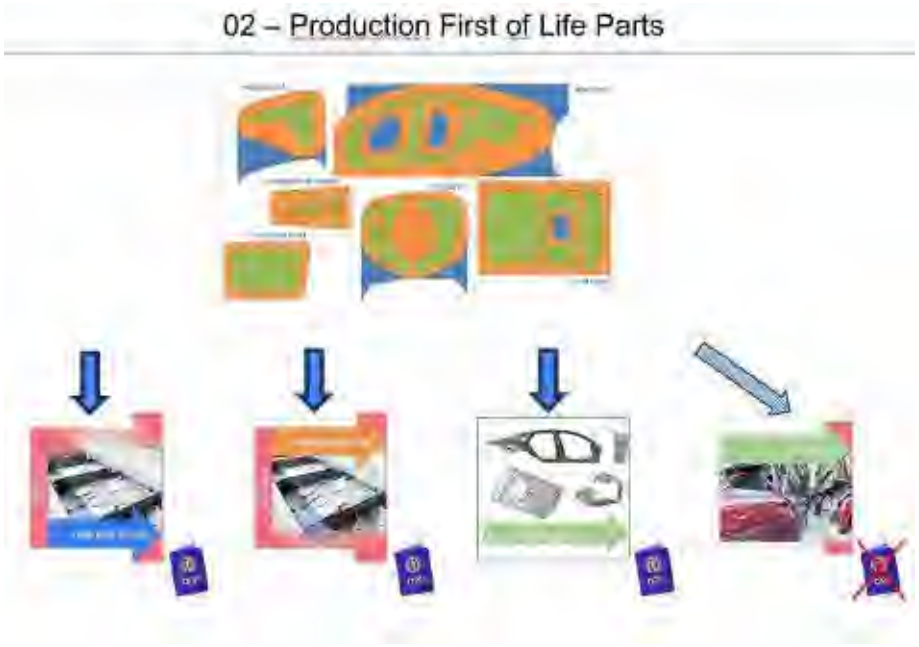


Figure 4.1.2: The different types of scrap derived from “First of Life” parts

Furthermore, recommendations are made on reforming strategies for the targeted parts. At least the data provided by the DPP must cover the actual documentation needs for automotive industry, which is not only chemical analysis and mechanical properties, but also data related to legal compliance topics like REACH and RoHS.

For the steel use case, cut-offs from the forming of automotive exterior body parts were selected, which are in an undeformed state. The main challenge for reuse will be the variation in the material properties of the blanks punched from these sections for the deep-drawing operation.

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In the aluminum use case, an EoL engine hood is being examined for its suitability for reforming. Due to a lack of data, complete material characterization must also be carried out beforehand.

Both, the reconditioning of the material for forming and the surface preparation will play a role. For e.g., nesting of the re-forming blanks must avoid areas with extensive pre-deformation or sections which are difficult to separate from joined components.

Key performance indicators:

Technology With description	Aspect	Target	Measurement procedure
Sheet Metal Parts - Blanking Scrap	Measure the dimensions of the blanking scrap.	The deviation of dimensions between the actual scrap and CAD data must be less than 10%. The dimensions will be measured at 5 points in 5 samples.	The CAD data will be used to determine the dimensions
	Minimal Surface Damage	In-line Automatic camera systems will be used to detect surface damage on 20 parts per batch. The damaged surface area must be less than 10% of the total surface area of the scrap.	The damage will be measured with inline quality control systems.
	Mechanical Properties Evolution	Thickness variation of processed sheet compared to the feedstock steel sheet measured over 3 points in 5 samples is not more 10%.	The change in mechanical properties such as elongation, thinning % will be measured using FEM and indicated via reports or drawings. The change in mechanical properties will be done as a continuous process for all the scrap that is being delivered to external companies.

4.2. Composite Remanufacturing

The composite use case deals with the remanufacturing of carbon fiber reinforced thermoplastic (CFR-TP) composite parts used in aerospace. In this project, mainly structurally defective parts from manufacturing (manufacturing scrap) will be used as feedstock for remanufacturing. Various data will be made available in the DPP. For the process planner (see section 6.3) that defines the nesting for remanufacturing parts from 'structurally integral' or 'defect-free' areas, the design data (CAD) of the feedstock (manufacturing scrap) as well as thorough non-destructive inspection data that is carried out to characterize the defects including the size, location as well as the depth in the part from methods like ultrasonic, active thermography and X-ray radiography) needs to be provided. In addition to this, prior to manufacturing the raw prepreg (pre-impregnated woven fabric) is also

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inspected and characterized with a sensor and this data is also included for consideration by the process planned. The above data will help process planner to define regions that can be potentially remanufactured.

The technical data of the material that will aid in the thermomechanical reforming process such as composition, chemicals used, characteristic temperatures, etc will be provided. Here in this, much of the material data is available although some of which might be protected IP. The process of remanufacturing is carried by AITIIP on the part provided by FACC based on input provided by the process planner developed by EDAG along with all necessary data integrated in the DPP developed by Circularize (aided by NLR).

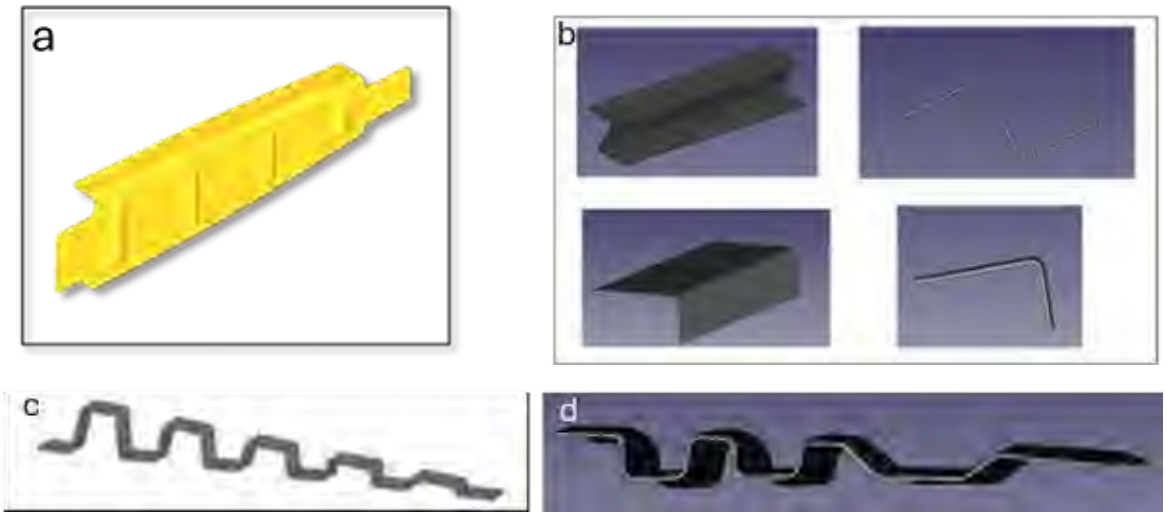


Fig.4.2.1. The different parts that are chosen for demonstrating remanufacturing in the project namely (a)the TPC-rib, (b)Z-L profiles and (c), (d) the CFRTP waffle family.

As for the data in the DPP, the DPP will contain supply chain information, technical information as well as part specific information. The former will ensure traceability through commercial and technical

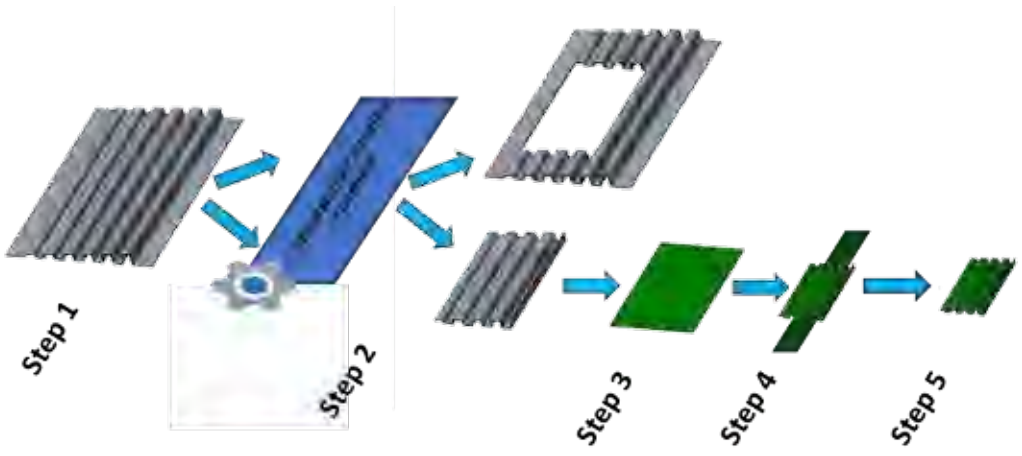


Figure 4.2.2. Schematic of the remanufacturing process. Step 1: Disassembled part; Step 2: Remanufacturing planning; Step 3: Flattening process; Step 4: Reforming process; Step 5: Finishing process.

information necessary to trace back details of the materials used in the construction of the part. Technical information will aid remanufacturers choose suitability of the part for remanufacturing through answers for specific questions in the DDP platform, while part-specific data such as process

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and raw-material relevant characteristics as well as manufacturing and end-of-line defects from NDT data aids the process planner by EDAG to decide the remanufacturing part design. The DPP platform ensures that the data is not only streamlined, processable but ensures secure data transfer, remains tamper-proof and ensure right level of access to each partner.

Key performance indicators:

Technology Partner responsible	Aspect	Target	Measurement procedure
Thermoplastic part manufacturing: Press forming	Shape of the part	Target1: < 2mm deviation from CAD model in the final shape. Target2: <0.5mm deviation from CAD model on the bonding surface	T1: 20 arbitrary points will be measured and compared with the real CAD model using CMM.The average deviation will be calculated form this. T2: Bonding areas
	Quality of the part	Target1 : <5% porosity for all parts	Ultrasonic measurement of the laminates and no higher than 18dB attenuation compared to a non-porous area identified on a reference standard
	Cycle time	Target1: <120 mins for layup. Target2:<240 mins for complete manufacture incl Layup (layup+pressforming + debagging	T1: Time taken by worker to layup from the first until the last layup (average of 5 parts). For T2: average time of 5 parts from layup is brought into the thermopress until debagged.

4.3. Disassembly Of Larger Structures

The activities regarding disassembly of larger structures are focussed on upgraded recycling methods, specifically, the reuse of sheet metal extracted from fuselage skins.

In general, the vast majority of the current end-of-life (EoL) aircrafts exhibit airframes and other structural members from recyclable Aluminium (Al) alloys. During dismantling and scrapping, the remainders of aircraft structures are collected as mixed fractions of different Aluminium alloy families, very often in irregular shapes of formerly riveted assemblies of skin sheet, frames, ribs, stringers and clips. A typical dismantling procedure and the resulting kind of mixed alloy scrap are shown in the following figures.

Randomly torn apart remainders of the aluminium airframe (Fig. 4.3.1) or cut airframe/wing sections are subsequently transported to a recycling partner for shredding. Post-shredder analysis of the chemical composition is technologically feasible in principle by applying sensors like optical emission spectroscopy (OES), X-ray fluorescence (XRF) and laser induced breakdown spectroscopy (LIBS). Of course, such a measurement is limited to a certain area from which the results is gained. But already torn apart subassembly can still contain two different aluminium parts (e.g. remainders of a stringer and a skin sheet, both from different alloys) bonded by adhesives or joints by rivets. Steel rivets and/or titanium straps (integrated as crack stopper elements) are likely to be part of mixed metal scrap of

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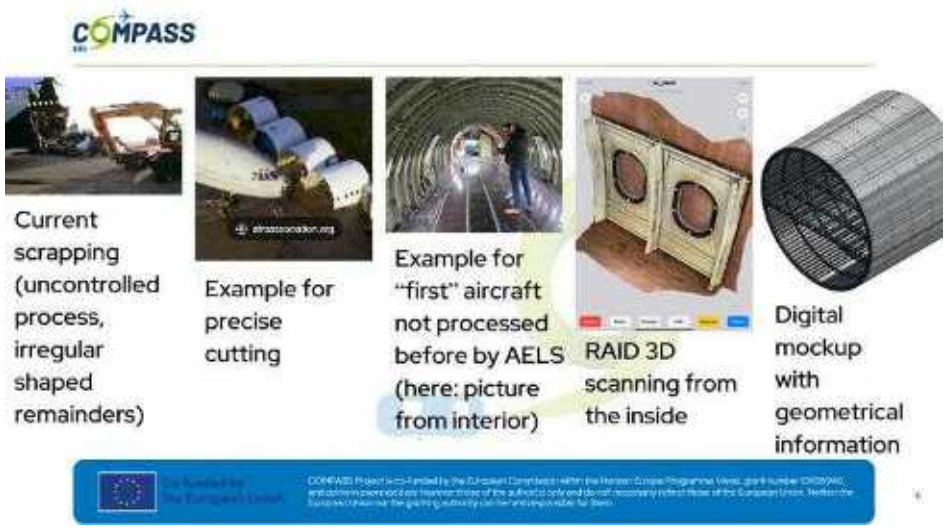


Figure 4.3.1. Schematic of the current irregular & regular scrapping processes (2 left pictures); status of a fuselage after removal of all interior and insulation installations ready to be evaluated for DPP data (middle); digital representation of skin sheet cutouts (2 right pictures).

aerostructures. Therefore, correctly separating scrap of different, chemically non-compatible Al classes in the stream of shredded waste is technically challenging; the economic viability is currently questionable. COMPASS is researching technologies which enable a (semi-)automatic identification and separation of structural assemblies into batches of known chemical composition (Fig. 4.3.2). Methods capable of identifying the main structural members of major aircraft sections (e.g. fuselage) from the outside in EoL conditions (painted, degraded) combined with camera systems as well as existing knowledge (data from previous projects; data from MRO / OEM, …) shall create a digital geometrical model allowing to generate a robot handling of dismantling (cutting) processes (Fig. 4.3.3) as well as precise separation of main aircraft structures by waterjet cutting. Precise sectional cutting can be a valuable part of the future procedure of EoL aircraft management companies, providing specific segments from which feedstock for metal reforming can be retrieved (Fig. 4.3.4).



Figure 4.3.2. Schematic of the additional input data from scanning plaquettes via Optical Character Recognition (OCR) as well as Laser-induced breakdown spectroscopy (LIBS) (2 middle pictures).

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Figure 4.3.3. Early concept of a cutting planner and augmented reality-supported interaction to the cutting & handling devices.

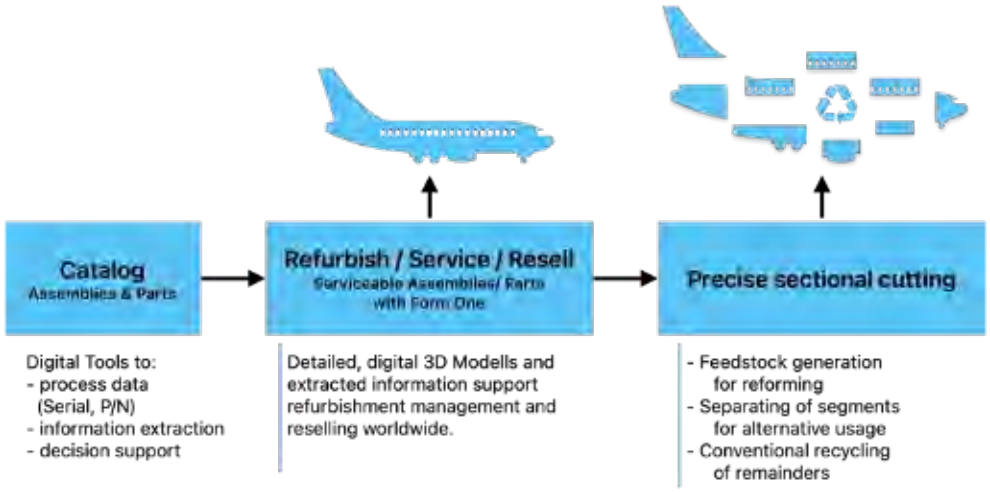


Figure 4.3.4. Aircraft end-of-life process focussing reuse of structural elements as feedstock for reforming.

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5. DEMONSTRATION OF THE REMANUFACTURING PROCESSES

This section describes the preparation steps, tools and processes for the direct conversion of metallic sheet and composite scraps into new components by the re-manufacturing/re-forming process in more details. In the case of composite remanufacturing, production scrap is exclusively used. However, materials for metal re-manufacturing could be primary scraps from blanking, trimming operations in the production process, EoL panels from vehicles or airplanes as well as metallic parts with partial damages or other out-of-spec shortages could be converted directly into new components without the need for re-melting or thermal recycling.

The remanufacturing planner should assemble all the material data needed for the tracking and characterization of the scrap materials and match them with the target requirements of the new re-forming components. A disassembling assistant helps to identify the right sections which can be used for the re-forming process. By help of a cutting planner, homogeneous areas for the nesting of the blank shapes can be selected and the corresponding blanks can be cut and prepared for the re-forming operation (e.g. cleaning, paint stripping etc.). The sheet metal reforming calculator advises the most cost and resource-efficient re-forming process for steel or aluminium substrates, while different integrity checks have to be made in the case of composite materials prior to shaping them into new geometries.

5.1. Sheet Metal Remanufacturing

For demonstration of reforming capabilities within the COMPASS project, two demonstration parts were selected, derived from the most common metallic materials in the aircraft and automotive industries – steel and aluminium. These examples represent typical parts of the sheet metal forming industry, respective for deep drawing process, where there are higher demands on the formability of the material than in other processes like stamping.

If the reforming process works for the selected demonstrators (figure 5.1.1), it is expected that most other sheet metal forming processes will work as well. Steel grade is a CR5 mild steel with zinc coating, while the aluminum is a 6016 grade in condition T4.

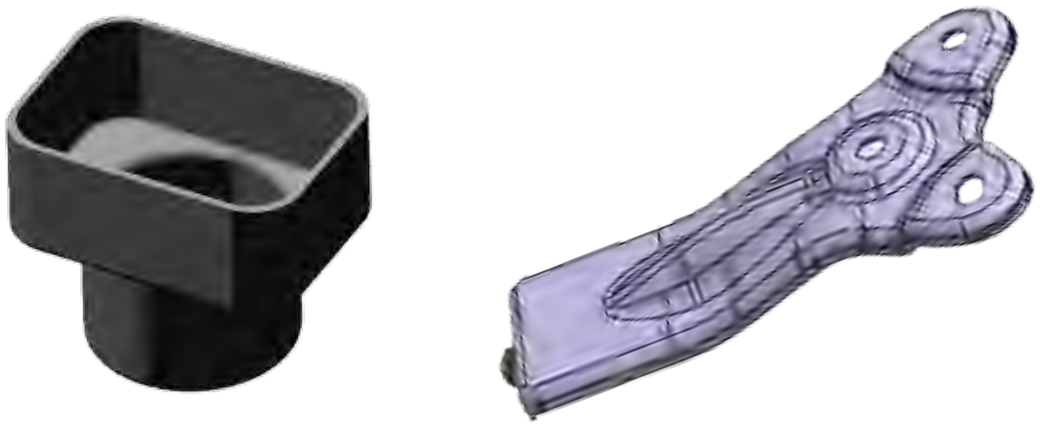


Figure 5.1.1: DEMO parts: Steel – shielding (left hand side), Aluminium – Bumper bracket (right hand side)

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For both demonstration parts new tooling must be designed and built. For principal examinations LKR also uses their existing experimental cross die tool. In the end, the remanufacturing process has to demonstrate, that clustering and processing of the scrap parts and processing of the re-use blanks has been done accordingly for a stable and quality-assured production of new parts. Furthermore, process monitoring must be re-designed to accommodate the sudden changes and the wider range of property values of the re-use blanks.

5.1.1. Steel Sheet Remanufacturing

In this project, MARK Metallwarenfabrik GmbH takes on two different roles in the "steel sheet metal" use case, which are covered typically by different companies in the "real" case of direct sheet metal recycling:

- *Scrap processor role*, which, based on the instructions provided by the digital tools (Sheet Metal Reforming Calculator, Cutting Planner, etc.), generates reuse blanks for deep drawing from the available scrap (figure 5.1.1.1, sections 04 and 05).
- role of *sheet metal former*, which ultimately forms "second life" deep-drawn parts from these reuse blanks (section 06 in figure 5.1.1.1).

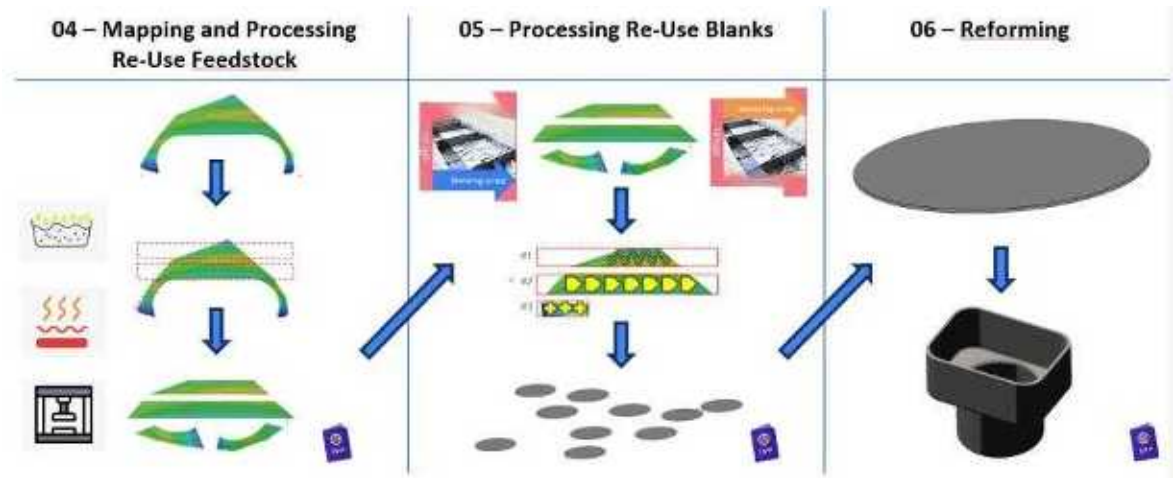


Figure 5.1.1.1: Material and data flow in the Sheet Metal Use Case

For the role of scrap processor, a modular punching tool was built, with which blanks with a diameter of 65 mm stamped from the sheet metal cut-outs provided by voestalpine MFD (figure 5.1.1.2 (left)). In the initial approach, the geometries were still mapped onto the scrap manually; later, this will be done using digital tools. The forming of the demonstration part takes place on a transfer press with 110 tons of pressing force and 11 forming stations (figure 5.1.1.2 (right)).

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Figure 5.1.1.2: Stamping tool for blanks Ø 65 mm (left) and the forming press (right)

To feed the individual blanks, an automatic blank loader had to be developed and built. This transports the blanks from a magazine to the storage area for the first forming step, cupping (figures 5.1.1.3).

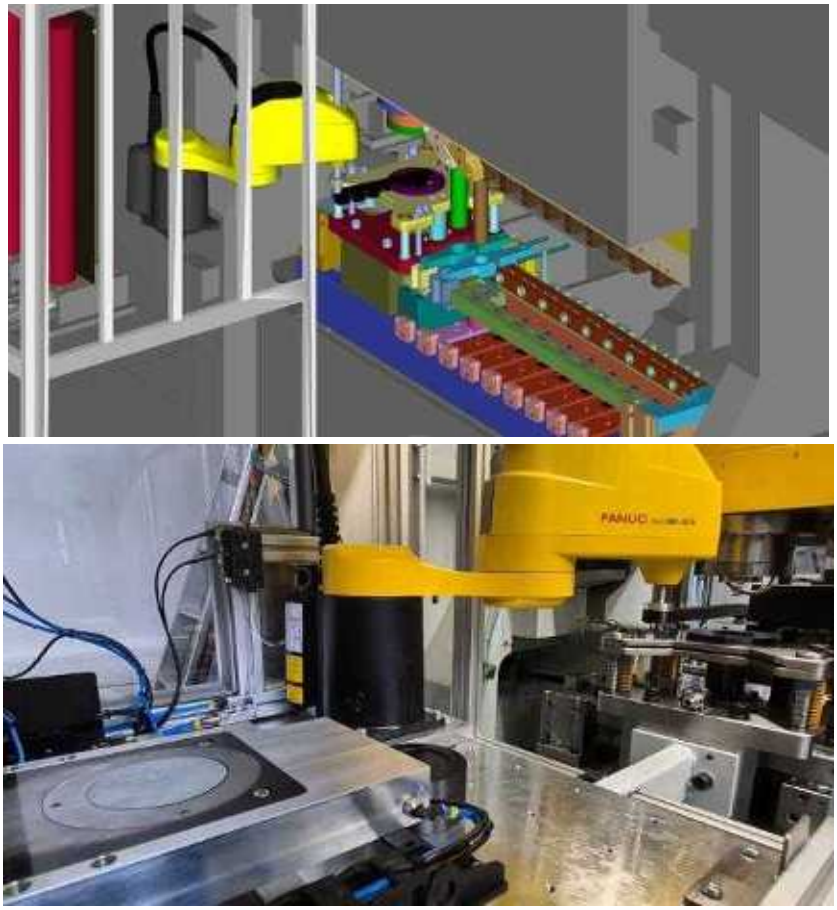


Figure 5.1.1.3: Blank loader – design draft (top) and Blank loader – implementation(bottom)

To produce the demonstration part, a complex forming tool with nine processing steps was designed, and the first three forming steps were initially built (figure 5.1.1.4, top to bottom). The tool was equipped with extensive sensor technology and measurement data acquisition to record the process conditions (figure 5.1.1.5).

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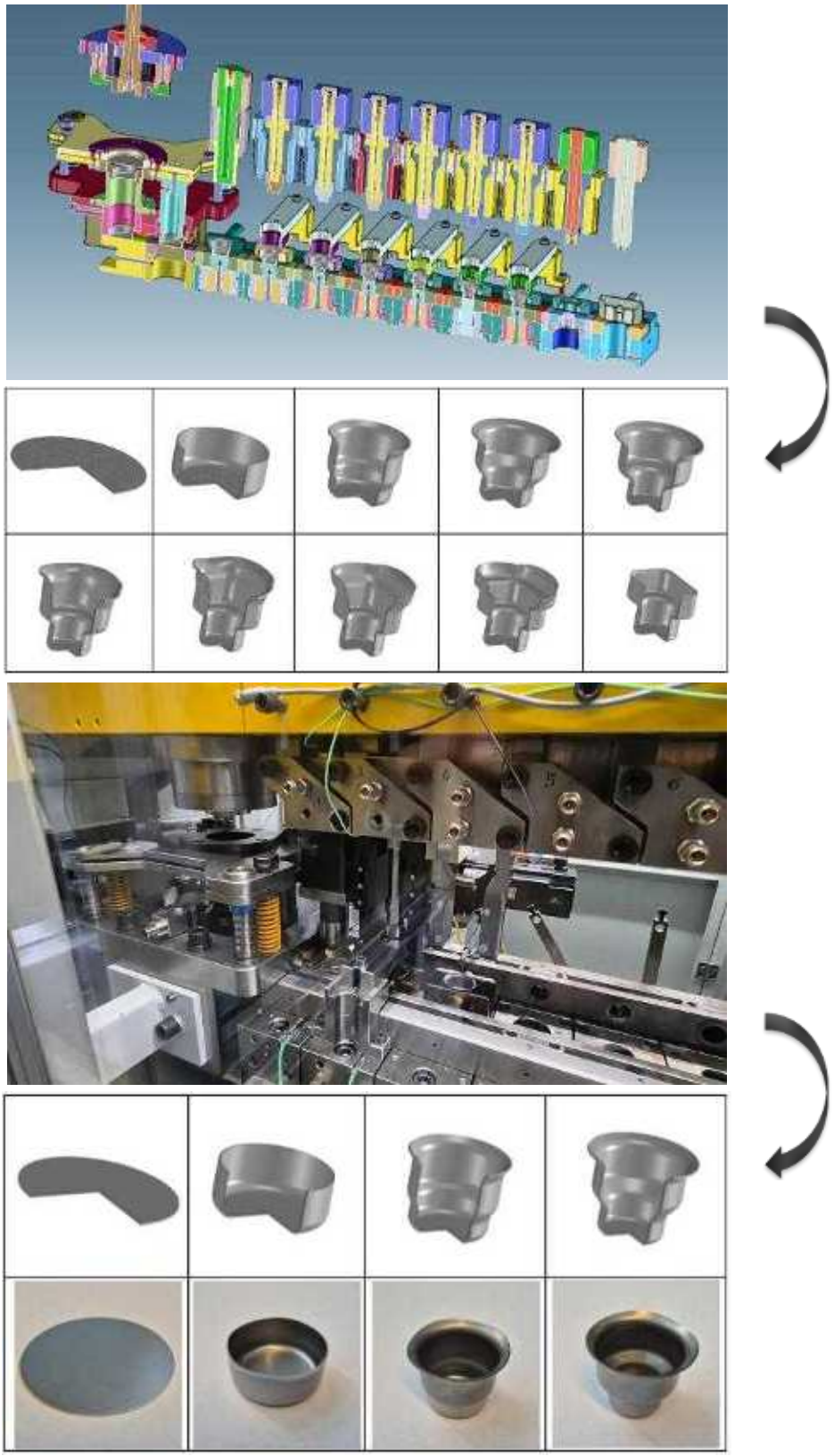


Figure 5.1.1.4: Design draft of the deep-drawing tool (top), Planned drawing sequence of the demo component (second from top), Implementation of the first three deep-drawing stages (second from bottom) and Implementation of the first three drawing stages and comparison with the geometry according to the FEM simulation (bottom).

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In an initial test run lasting several hours, the systems were already tested, and initial process data was recorded. It became apparent that the sensors' high sampling rates for typical production speeds quickly push the hardware and software to their limits, and that there is still considerable room for optimization in the data acquisition system.

In summary, the basic components and steps are set to demonstrate the reforming process for steel sheet metal (figure 5.1.1.6). After verifying the tooling and sensor- concept with the first 3 stations, this will be enrolled to the other forming stations.



Figure 5.1.1.5: Deep-drawing tool equipped with sensors.

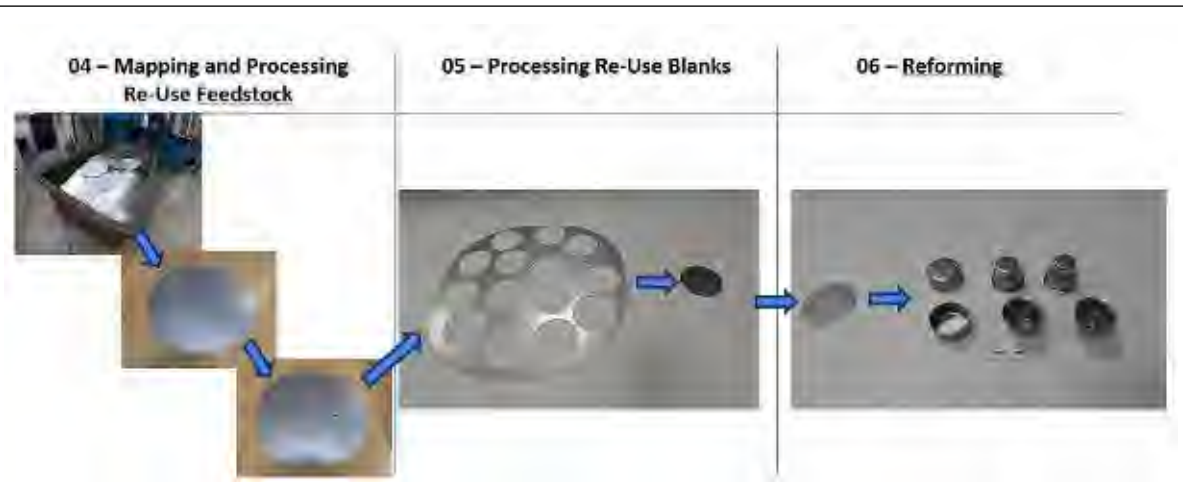


Figure 5.1.1.6: Actual material flow for sheet metal use case – steel

Key Performance indicators

Technology With description	Aspect	Target	Measurement procedure
	Range of roughness	The surface roughness should be within a product-specific range (tolerance) across a batch of blanks.	Use of a surface roughness measuring

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Cutting of blanks: Cutting the classified scrap sections into defined blanks for the further deep-drawing process		This can influence the late possible component surface.The permissible value must be defined for each blank group.	device (optical or ductile)
	Range of sheet metal tickness	The fluctuation range of the sheet thickness must be within a batch-specific range.	Thickness measuring system
	Range of cutting force	The cutting force provides information about a possible variance in the material property. This should be as low as possible for a subsequent successful deep-drawing process.	Inline force measurement in the cutting punch
Deep Drawing: Customer-specific components are produced from the previously cut blanks in this forming process (deep drawing)	**Variablity of part dimensions**	Compliance with component-specific tolerances in relation to a wide range of dimensions (length, diameter, etc.). The component conformity and the possible fluctuation range can be ensured and evaluated by these KPIs.	Various measuring equipment suitable for industrial use (3D measuring machine, caliper gauge, micrometer, ...).
	Process stability of the pressing forces in the individual tool stages	By recognizing the individual tool forces, a statement can be made about the material properties or the tool condition. Different threshold values can be used for this (min./max., force curve, ...).	Inline force measurement of the different active tool elements. Subsequent filtering and data processing
	OEE comparison	The OEE of a production with a first of live material is used as the reference value. This must be achieved or exceeded. OEE calculation: quality x performance x availability	Comparison of the respective OEE of a production with first of live material (sheet metal coils) and a production in which reused sheet metal is applied.

5.1.2. Aluminium Sheet Remanufacturing

Painted aluminium EoL engine hoods from a German OEM car were bought from a spare part provider (figure 5.1.2.1). For the re-forming process, a de-coating process after pre-blanking is necessary. Steel slag blasting yielded a rough substrate surface, which showed coarse surface grain (orange peel effect) after forming in the re-solutionized temper. CO_2 blasting resulted in incomplete removal of the paint layer, while peening with walnut shell resulted in a comparatively smooth surface (figure 5.1.2.2 and figure 5.1.2.3). First forming tests were done with an existing cross die tool.

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Figure 5.1.2.1: EoL engine hood (painted) – outer sheet (left hand side) which will be used for blanking; inner sheet (right hand side) which needs to be separated; joining areas between inner/outer sheet which contain adhesive strips can´t be used easily for re-forming blanks



Figure 5.1.2.2: Mechanical de-coating tests: Blasting with CO2 (left), steel slag (middle), and walnut shell(right).

Additionally, direct re-forming was tested at an elevated temperature of 200°C (tool and blank), without prior de-coating. The lacquer layer developed fume during and showed bubbles after the forming process (figure 5.1.2.3).



Figure 5.1.2.3: Left: Detail orange peel surface after deep drawing of steel-slag peeled sample. Right: EoL painted blank drawn in a warm forming process at 200°C, strong fuming and partial de-composition of the lacquer was observed

For the aluminium re-forming demonstrator, a non-structural part was selected by EDAG. It carries the plastic cover on the rear bumper of an EV sedan vehicle. The heatable tool was constructed from S360 steel and features heating elements for warm forming up to 200°C (figure 5.1.2.4).

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EDAG performs the corresponding nesting of the blank geometry on pre-defined areas of the EoL engine hood. Blanking can be done by cutting tools, waterjet-cutting or by laser.

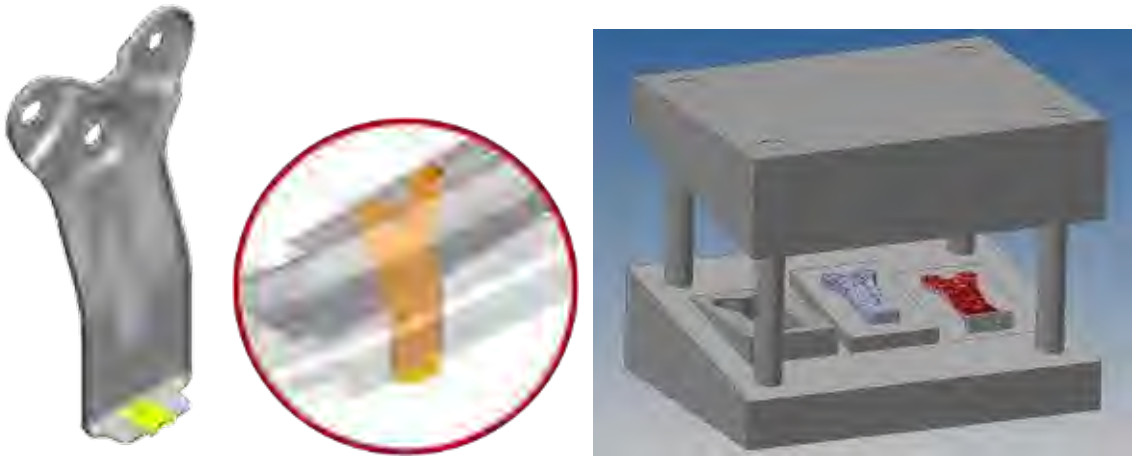


Figure 5.1.2.4: Aluminium re-forming demo part: Bumper bracket and corresponding tool (real tool is currently under construction)

Blanking or stamping 6xxx automotive scrap material without any additional heat treatment (corresponding to aluminium heat treatment temper T4) usually can be formed at room temperature. Of course, pre-deformation will alter the remaining formability of the re-manufactured blanks cut from the scrap stock material. Depending on the pre-forming strains (uniaxial vs. biaxial, straining direction vs. forming direction), formability can be enhanced or reduced (figure 5.1.2.6). The same applies for 2024 T3 sheet material used for outer skin of aerospace applications (e.g. fuselage or wing skin).

For the re-forming of scrap sheet material, three forming processes were established (figure 5.1.2.5). EoL scraps are coated with different layers of primers and lacquers after forming and joining processes.

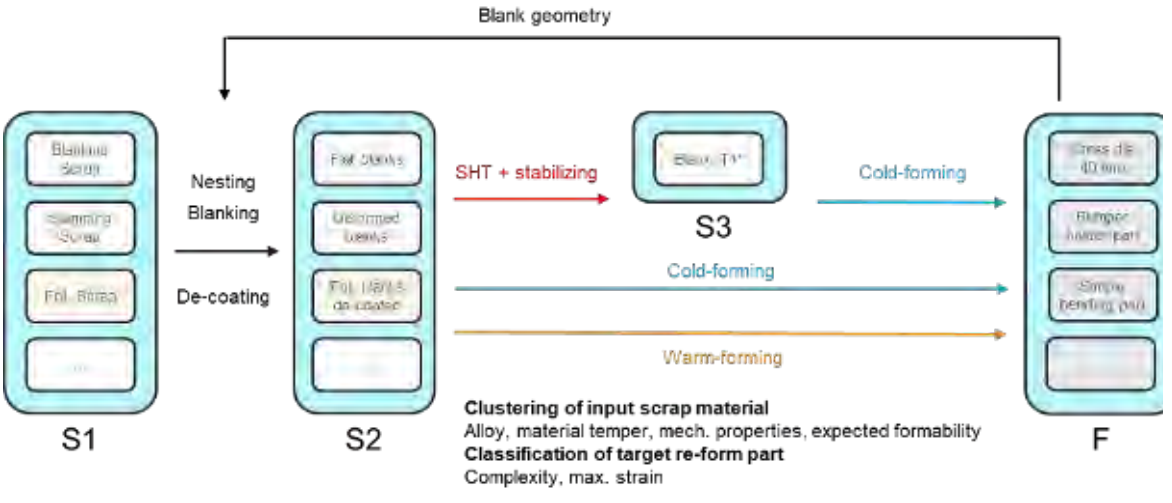


Figure 5.1.2.5: Process routes for re-forming of aluminium scrap materials

Paint curing concomitantly enables hardening of the aluminium substrates and material strength nearly reaches peak strength values (temper T62 in the case of paint bake hardening, tempers T6 or

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T8 for peak strength materials). Such hardened aluminium sheet materials need a fresh solution heat treatment to re-gain room temperature formability. Alternatively, warm forming at about 200°C (with the help of heated dies and blanks) allows direct forming of peak strength aluminium materials. This avoids meticulous solution heat treatment processes and is also advantageous in terms of economic and ecological considerations.

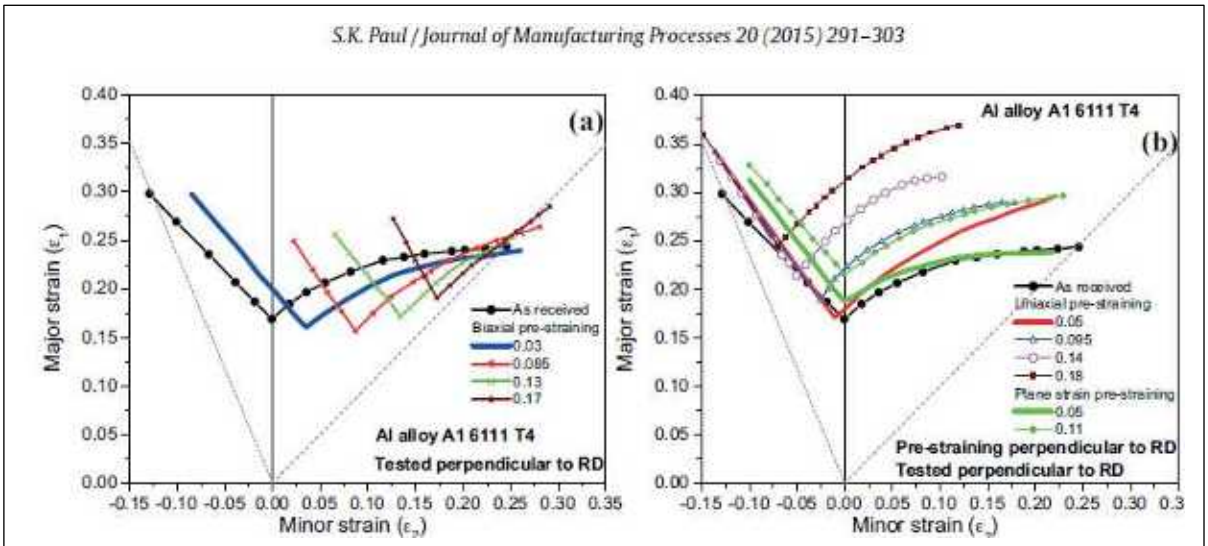


Figure 5.1.2.6: Path-dependent formability of AA6111 T4 automotive alloy

Table 5.1.2.1 shows the mechanical properties of the different types of aluminium scraps under investigation for the re-manufacturing process and table 5.1.2.2 the chemical composition.

Table 5.2.1.1: Properties of aluminium scraps investigated

Scrap type	Material	Thickness [mm]	Surface	Deformation state	Temper	YS [MPa]	UTS [MPa]
Blanking Scrap	6016-T4 sheet old LKR	1,2	EDT	unformed	T4 or T4*	165	277
Stamping Scrap	Voestalpine scrap hood	1,0	EDT	as formed	T4 or T4*	179	263
EoL Scrap Automotive	Audi A6 hood (blue)	1,26	coated	as formed	T62 (T4+paintbake)	204	238
EoL Scrap Aircraft	Alclad 2024/1050	2,0	coated (CrVI !)	stretch-formed	T3 + paint-cure	385	465

Table 5.2.1.2: Chemical composition of aluminium scraps

Sample	Alloy	Si [%]	Fe [%]	Cu [%]	Mn [%]	Mg [%]	Zn [%]	Ti [%]	V [%]	Al [%]
Blanking Scrap	6016	1,07	0,16	0,06	0,06	0,39	0,01	0,02	0,01	98,2
Stamping Scrap	6005A	0,92	0,24	0,10	0,17	0,45	0,03	0,03	0,04	98,0
EoL Scrap Automotive	6016	1,23	0,20	0,06	0,06	0,41	-	0,02	-	98,0
EoL Scrap Aircraft	2024/1050 4 %	0,07	0,16	4,20	0,65	1,60	0,05	0,03	-	93,3

5.2. Composite Remanufacturing

As part of the intermediate demonstration activities, AITIIP is contributing to the composite remanufacturing process within the COMPASS project, focusing on the reuse of thermoplastic-based composite components from the aerospace sector.

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5.2.1. Initial and Target Part Description

The part supplied by FACC for this stage of the project is a thermoplastic rib component made from unidirectional carbon fiber with poly(ether ether ketone) matrix (UD CF-PEEK). Two variants of this rib have been identified: one made entirely of CF-PEEK, and another that includes a final bonded layer of glass fiber at one end. This distinction has been considered during the design of the tooling and in the adjustment of process parameters. This part, originally manufactured for structural aerospace applications, was selected due to its thermoformable nature and its suitability for testing different remanufacturing scenarios.

To adapt the component to the final use case, which involves the production of smaller brackets (some of which are highlighted with red circles in Figure 5.2.1.1.) for the aeronautical sector, the original rib was cut into multiple segments. These brackets are intended to serve as support elements for non-critical functions, such as wire holders, where mechanical requirements are less stringent and re-certification is more feasible. This strategic segmentation enables the revalorization of the rib in forms more aligned with typical applications for secondary aircraft structures.



Figure 5.2.1.1. CAD representation of the original TPC-rib part and potential bracket geometries derived from it. Red-circled parts represent candidate brackets for secondary aeronautical applications such as wire retention.

5.2.2. Trimming of the part

The first stage of the process consists of the preparation and adaptation of the initial part to allow it to be reshaped. For this purpose, the rib component was segmented by cutting it into smaller sections. This operation allowed isolating different regions of the part and obtaining individual segments that could act as preforms for the flattening process.



Figure 5.2.2.1. The original rib-shaped composite part received from FACC was cut and prepared for flattening. The red rectangle shows areas where the cut could be made as an example.

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As shown in Figure 5.2.2.1., depending on the position along the rib where the cut is made, the resulting segment may present different bottom geometries. Some sections have a flat bottom surface, while others show a concave profile. These geometric variations were key aspects considered during the design of the flattening tool, as they directly influence how the part will respond to heat and pressure during the reshaping process.

5.2.3. CAD Design of the Flattening and the Forming Tool

Over the past few months, AITIIP has made significant progress in designing and developing the necessary tools for the remanufacturing of thermoplastic composite components. In particular, the CAD design work includes two essential tools:

- **Flattening Tool**: Specifically designed to geometrically adapt the rib sections for reshaping operations. It is depicted in Figure 5.2.3.1. This tool is currently under validation through preliminary trials.
- **Forming Mold**: Planned to be fabricated using Wire Arc Additive Manufacturing (WAAM) and equipped with integrated internal cooling channels to enhance thermal performance and reduce processing cycle times.

Both tools have been dimensioned to handle composite parts within the 1–4 mm thickness range, in line with the specifications outlined in Deliverable D2.1. The design process accounted for critical issues such as fiber disaggregation in very thin laminates and the formation of wrinkles in parts thicker than 4 mm. As a result, the tooling aims to mitigate these defects through controlled shaping and thermal uniformity.

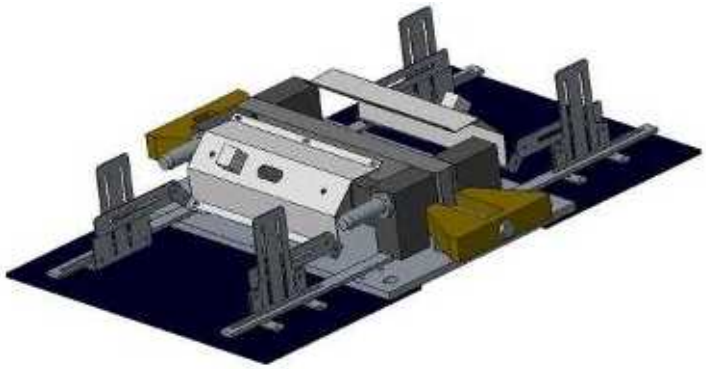


Figure 5.2.3.1. CATIA-based CAD model of the flattening tool developed by AITIIP, showing the structural frame and arrangement of the modular infrared heating system.

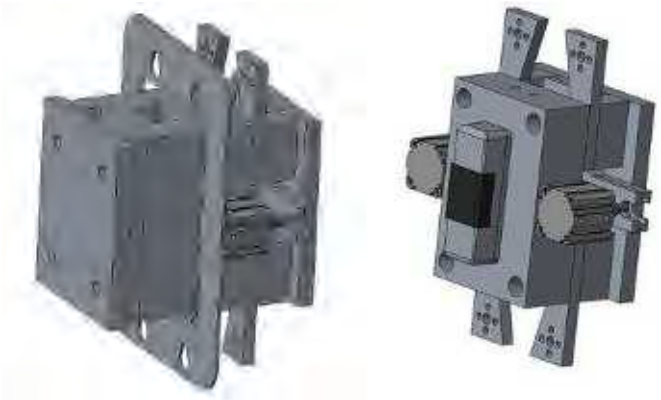


Figure 5.2.3.2. CAD views of the composite forming tool designed for post-flattening shaping. The model includes both the core and cavity components.

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The forming tool is used in the stage following the flattening process. In this case, a forming tool has been designed with two main components: the core and the cavity. The composite preform, obtained by cutting the previously flattened material to size, is placed in the central area of the tool using a tensioning frame. The tool is equipped with a conformal heating system to provide uniform thermal distribution. Subsequently, an infrared heating system preheats the preform prior to the pressing phase.

5.2.4. Fabrication of the Flattening Tool

The flattening phase is a critical step in the remanufacturing of thermoplastic composite parts. Its purpose is to transform the incoming rib geometry into a more manageable flat preform, suitable for later reshaping into the final bracket design. To achieve this, AITIIP has developed a custom flattening tool designed to accommodate variable part geometries and to integrate with a modular infrared heating system.

The flattening tool developed by AITIIP has been physically manufactured and assembled as part of the intermediate steps toward enabling thermoplastic composite remanufacturing. This tool is designed to adapt the initial trimmed rib parts geometry, originally complex and curved, into a flat preform, suitable for subsequent reshaping operations.

The tool includes a robust metallic structure that holds the component during the heating and flattening process. One of its most innovative features is the integration of a modular infrared heating system, composed of independently controllable infrared lamps. These lamps are strategically positioned to follow the varying curvature and thickness of the composite parts, ensuring precise and localized heating.

This modular approach allows dynamic adjustment of the thermal profile applied to the part. By tuning the power of each lamp individually, AITIIP can create custom heat zones tailored to the specific geometry of each rib segment. This is essential to achieve uniform heat distribution, prevent overheating, and avoid common defects such as fiber distortion or thermal gradients that could compromise the structural integrity of the part.

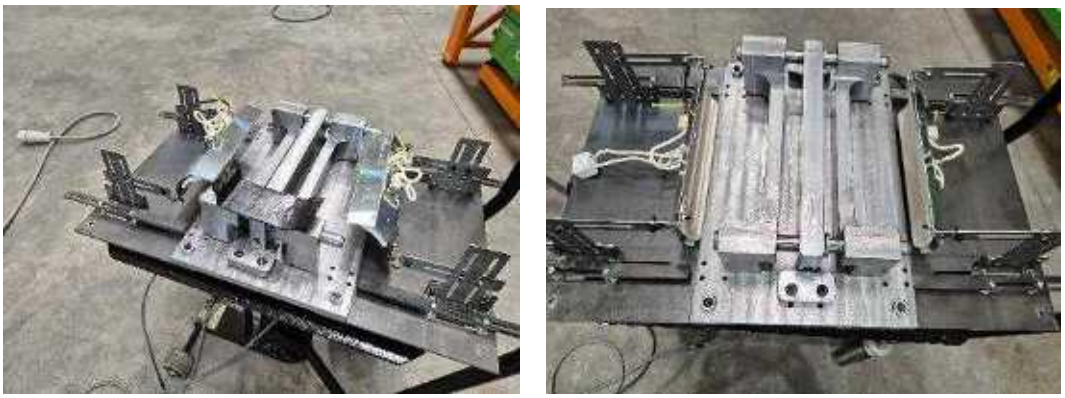


Figure 5.2.4.1. Different views of the physical flattening tool developed by AITIIP, showing the modular structure and arrangement of the infrared lamps used for controlled, localized heating of composite rib segments.

5.2.5. First Trials

AITIIP has conducted initial flattening trials using the custom-designed flattening tool. The trials were performed only in one of the variants of the rib component provided by FACC: in the one with an

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additional final layer of glass fiber. These structural differences required adjustments in the thermal zoning strategy to ensure consistent material behavior and uniform flattening.

Key observations from the first trials:

- A progressive improvement in flatness and surface quality was observed as thermal profiles were optimized.
- The infrared system demonstrated **high adaptability** to different starting geometries and laminate configurations.
- Heating zones were fine-tuned to minimize distortion, preserve fiber alignment, and avoid thermal defects such as warping or material degradation.

These preliminary tests confirmed the technical feasibility of the flattening approach. The treated parts exhibited clear improvements in geometric uniformity. While process parameters and tooling details are under refinement and will be documented later, the images of the flattened parts resulting from early trials can be seen in Figure 5 to illustrate the progress made.

The flattening tool is currently in its final validation phase. Once this step is completed, the focus will shift to reshaping the flattened preforms using the advanced forming mold produced via Wire Arc Additive Manufacturing (WAAM).

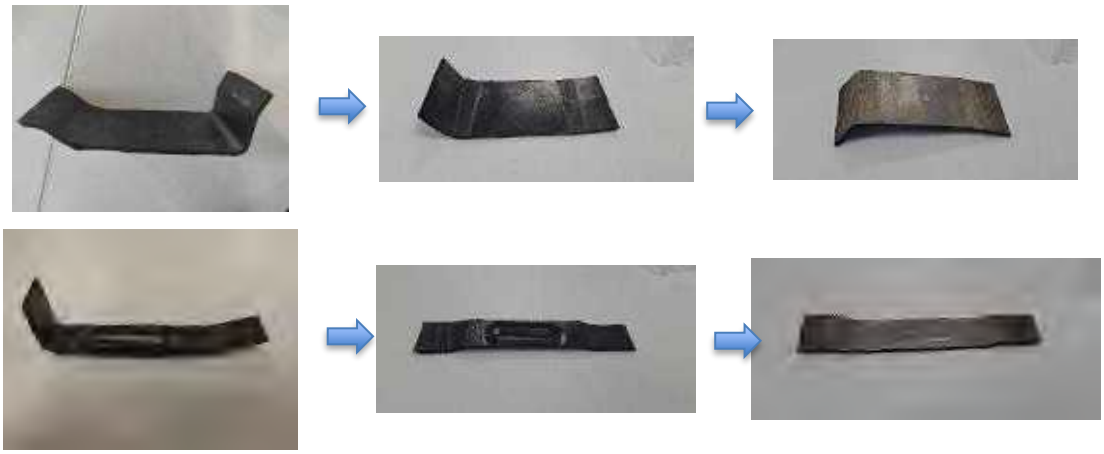


Figure 5.2.5.1. Several reshaping tests have been conducted using a custom infrared heating setup, adjusting the heating zones to evaluate the feasibility of achieving a uniform flattening. Given above are the results of the trial on the two cut parts shown in figure 5.2.2.

Key Performance indicators:

Technology With description	**Aspect**	**Target**	**Measurement procedure**
Flattening using infrared heating: Flattening composite LM-PAEK using infrared lamps for heating and press for flattening.	**Time to flatten**	<15 minutes from heating start to pressing completion.	**Record the time** taken from start of heating with infrared lamps to completion of pressing. Average calculated for 3 trials.
Infrared-assisted molding system: An advanced molding process utilizing infrared heating to preheat	**Time to complete preheating**	<10 minutes for a 100x100mm composite sheet.	**Record time taken for heating** using process sensors. Average calculated for 3 trials.

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composite materials for faster, more uniform heating.			
Final forming process:	**Heating efficiency**	Composite reaches forming temperature (<350°C) within 5 minutes.	Use **thermal camera** to monitor heating time for composite. 5 number of points for each trial. Average calculated for 3 trials.
	Cycle time efficiency	Total process time <20 minutes (heating, pressing, cooling).	**Record total process time** from heating start to finished part removal over 5 trials (cycles).
WAAM Mold with Cooling Cavities: Additively manufactured mold for reshaping composite, with internal cooling channels to control crystallization.	**Cycle time**	Cooling time <20 minutes for composite to reach removal temperature.	Measure cooling time for 3 trials (cycles) with **embedded temperature sensors** in the composite material. 5 number of points for each trial.
Final product quality: Final shaping of the flattened composite into the remanufactured part using press and WAAM tooling.	**Dimensional accuracy (tolerance)**	≥90% of remanufactured parts (brackets) within ±1.5mm dimensional tolerance compared with the target shape of the remanufactured part (bracket).	3D scan of 5 remanufactured parts compared against CAD model using metrology software. Deviations analyzed for critical dimensions.

5.3. Sensor System For Lay-Up Monitoring

A sensor system for layup monitoring was developed inhouse by Profactor GmbH as shown in 5.2.1. It consists of a modular sensor called **Fscan-M**, a central processing unit, a display, a linear axis, tray to hold the carbon fiber in place and line of sight safety mechanism to protect human accidents.



Figure 5.2.1: Illustration of inhouse developed layup monitoring system. A carbon fiber material of interest is place on the tray which moves with the linear axis. A Fscan senor captures the photometric stereo images and relays them to the central processer for further processing.

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The core of this layup monitoring setup is the Fscan-M sensor which consists of 9 photometric stereo cameras developed inhouse as show in Fig. 5.2.2. Each camera is encompassed with a circular LED ring

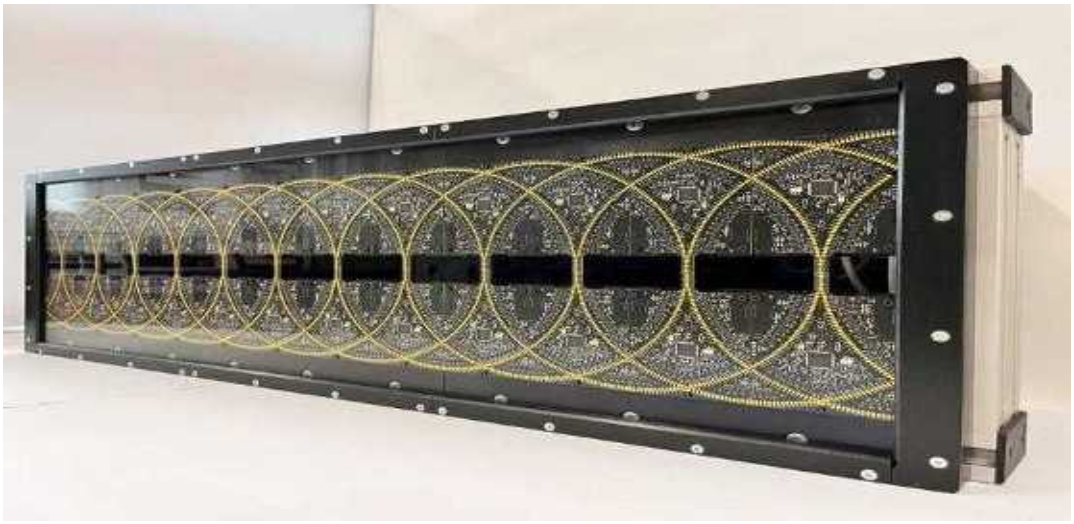


Figure 5.2.2: Illustrates an extended modular photometric stereo system developed in-house. The system comprises nine photometric stereo cameras, each positioned within a dedicated LED ring to enhance illumination consistency and depth perception.

to ensure better computation of fiber orientations. Every image captured is processed by dedicated central processor and the monitoring of the processed information is visualised on a monitor. A linear axis carries carbon fiber tray and a camera trigger. This enables the stationary sensor setup to scan the entire carbon fiber material in a synchronous manner. Each camera outputs 5 computed feature modalities (azimuthal, specular, fiber refractivity, polar, diffuse) based on the intensities of reflected rays (Fig. 5.2.3).

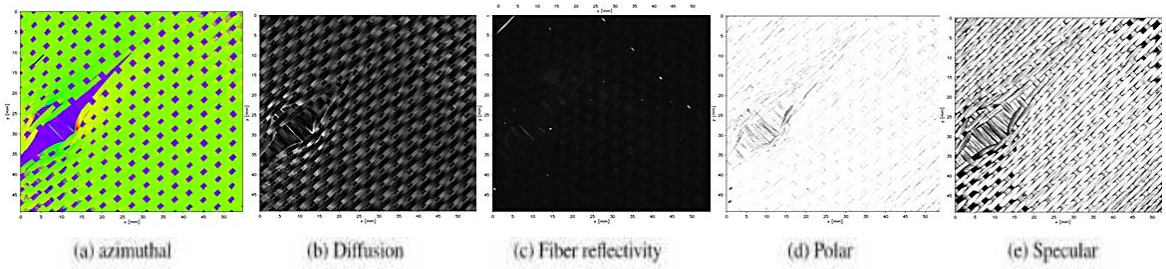


Figure 5.2.3: Illustration of all the five feature modalities of a carbon fiber with a gap defect captured using the inhouse developed photometric stereo sensor.

These computed features are robust and precise for multiple carbon fiber material types such as non-crimped fabric material (NCF) made from virgin fibers, NCF made from recycled materials, woven materials and unidirectional fibers. A sample illustration of these 5 features is shown in 3 for a gap defect.

Given the basic monitoring setup, processing of defect localization consists of following steps as listed below:

- Scanning the carbon fiber material - a carbon fiber material of interest is placed on the tray and once the hardware trigger is pressed the linear axis moves along the designated axis and speed. The captured raw images are transferred and processed over the central processer. This processing

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of individual patches can be visualized on the monitor. An illustration of the developed tool shown in Fig. 5.2.4 represents the fiber orientations and the defects are represented in the yellow bounding boxes.

- Defect localization – Once the features are computed for all patches, parametric methods can identify the type of defects from a single patch. These parameters can then be used to detect the desired defects across the scanned carbon fiber. The tool shown in Fig. 5.2.4 provides these developed methods for user application. The identified defects are stored for further process.

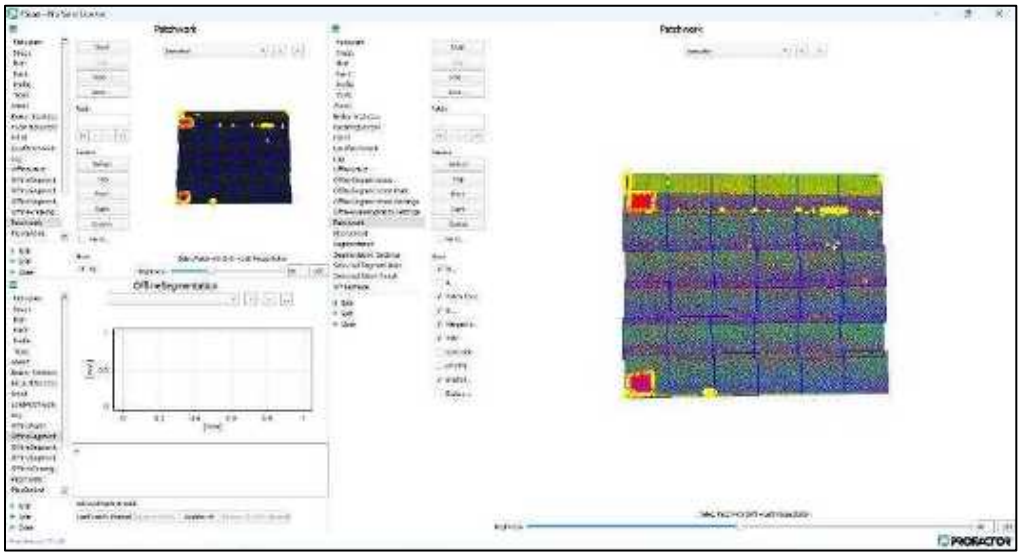


Figure 5.2.4: An illustration of inhouse developed tool that measures the fiber orientations and defects. The defects are represented in yellow bounding boxes. Each blue square represents a patch captured from a single camera in the sensor array and then stitched.

Given the information of defect and its localization, each defect is overlayed on to the carbon fiber material's STP file with or without the dedicated part information. 5.2.5 illustrates the defect information onto the STP file with the known dimensions of scanned material. The information of the desired part is also overlayed onto the STP file for better understanding of the defect location given the shape of the part. This enables the user to assess how the defect might influence the final part.

Key Performance indicators

Technology With description	**Aspect**	**Target**	**Measurement procedure**
Segmentation and Classification of Defects Defect segmentation and classification using parametric methods	**Classification**	Above 90% classification accuracy	Cross-validate sensor output with verified defect labels from human inspection
	Segmentation	95% of Blob Contour should be correctly mapped from 2D to 3D,	Percentage of cases where visual defects identified by human inspectors align with features extracted by the sensor modality. Based on the entire material scanned.

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		assuming no downsampling	
Mapping Defect Feature Modalities to Defect Positions Coordinate Projection from 2D feature modality data to 3D Defect Position	**Feature modality Accuracy**	95% of Blob Contour should be correctly mapped from 2D to 3D, assuming no downsampling	Percentage of cases where visual defects identified by human inspectors align with features extracted by the sensor modality. Based on the entire material scanned.
Aligning with provided .stp of proposed part Coordinate Alignment of Defect Positions with proposed Part	**Defect Position**	>98% Alignment	Calculation of Misalignment via Coordinates of part .stp and Defect coordinates. Based on number of defects present on the whole scanned material.
Extraction of Defect Bonding Boxes, Defect Contours and Export STEP file Extraction of best fitting Bounding Boxes and Contour based on Defect Shape and Creating .stp containing necessary Data of Defects and Part	**Complete Enclosure of Contour with Bounding Box**	>90% of Contour lies within Bounding Box	Comparison of Rectangle Coordinates to Contour Coordinates.
	.json-File Export	100% of detected Defects are present in .json-File	Comparison of .json-File with FscanM Segmentation blobs.

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6. INITIAL VERSION OF DIGITAL TOOLS

In the following section, the initial version of the individual digital tools that have been developed are described.

6.1. Manual Repair Assistant

The Manual repair assistant is a component which will support the digitization of manual repair information, such that it can be persisted semi-automatically inside a digital product passport. Technically, it adds tracking capabilities to the used repair tools, which allows to transform and store their positions as well as work piece interactions directly in the provided CAD coordinate system.
It is an important part of the project, as it ensures contradiction-free representation of repair information inside the digital product passport. Without this tool the worker would have to enter all information manually after the repair, which is time-consuming and prune to incompleteness and errors.

Regarding interdependency, the manual repair assistant is coupled with the composite use case but not limited to it. Therefore, and to have a consistent intermediate demonstration, currently a metal part is used as work piece. Interfaces are designed to be utilized also with other project components. So, in the intermediate demonstration, data is passed to the VR Disassembly Assistant of AIT for visualization. The components maturity is at 40%, proofing that all sub-components fit together. It will be elaborated further in the coming months.

As initial version of this tool, an existing 6D Tracking Infrastructure (OptiTrack) in the laboratory of PRO has been utilized to showcase the feasibility of the approach (Fig. 6.1.1). With OptiTrack it is possible to localize any tool (e.g. for grinding) in 6D by attaching markers (reflective precision spheres) for tracking. For demonstration purposes this is done in laboratory with a pen as 6D Tracking Instrument.

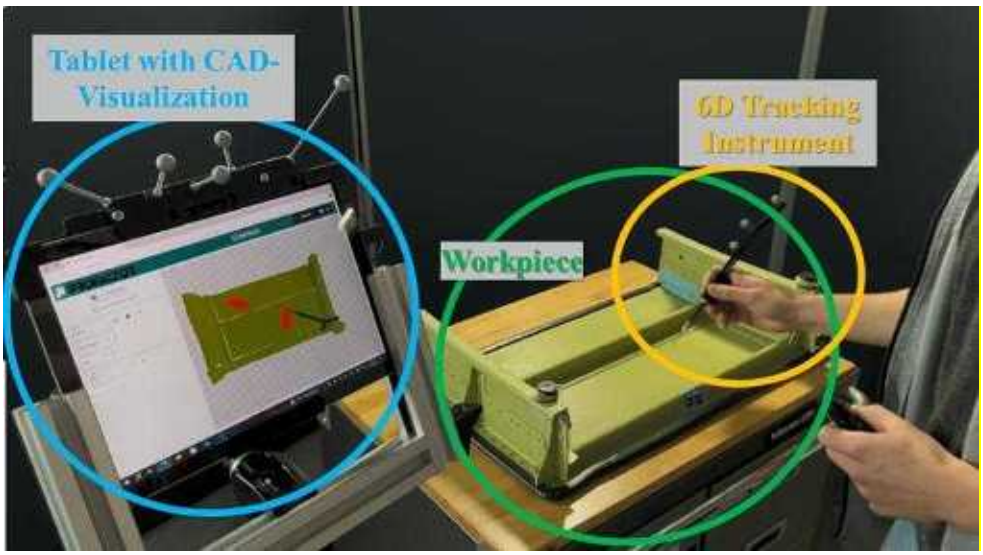


Figure 6.1.1.: Demonstration setup of Manual Repair Assistant, illustrating its main components. Data can be recorded directly into the CAD File with the 6D Tracking Instrument.

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To enable an interaction with a workpiece, the workpiece must be calibrated first to the CAD file, such that movements of the Tracking Instrument can be represented in part coordinates. This allows to add information at the right position in the CAD data. Literature research revealed that for our setup the calibration method of Kabsch[1] is most suitable, which has been implemented. For the operator the calibration routine is kept very simple: the operator only must tap with the pen at three points on the workpiece. From this moment on, all transformation is done automatically. An additional Graphical User Interface (GUI) has been developed to visualize both the calibration points and the recorded information in the CAD data (Fig. 6.1.2).

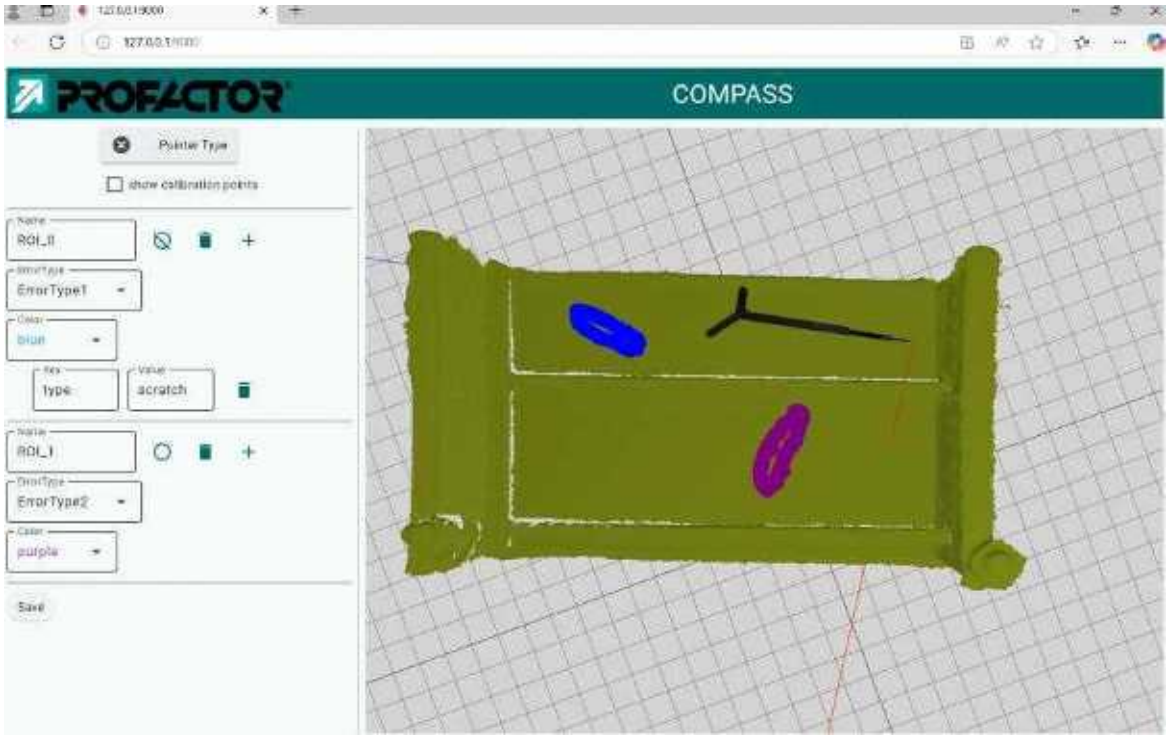


Figure 6.1.2: Graphical User Interface developed to interact with the CAD information of the work piece.

With the touch-display of a tablet, the worker can attach additional information to the recorded CAD regions. These are represented internally as key/value-pairs, to be open for any future development. Also, existing information, like the defect type, can also be visualized. All data is stored together with the 3D model. As the software layer for the digital product passport is currently in development, temporarily an intermediate exchange file format is introduced during development, the *GL Transmission Format Binary (GLB)* format. This is an optimal choice, because it can bundle all CAD and DPP information into a single file, which makes it compact, easy to share and simple to transfer between project partners. Further, the format is widely supported on different software platforms. A switch to the STEP file format of the DPP is already in preparation and will be performed, as soon as its software layer is available.

Figure 6.1.3 shows the currently used template of how the calibration points CU, CV, and CW, as well as the key-value pairs (e.g. Name, Color, Errortype) are coded inside a CAD node hierarchy.

[1] Lawrence, Jim; Bernal, Javier; Witzgall, Christoph (2019-10-09). "A Purely Algebraic Justification of the Kabsch-Umeyama Algorithm" (PDF). Journal of Research of the National Institute of Standards and Technology. 124: 124028. doi:10.6028/jres.124.028. ISSN 2165-7254. PMC 7340555. PMID 34877177.

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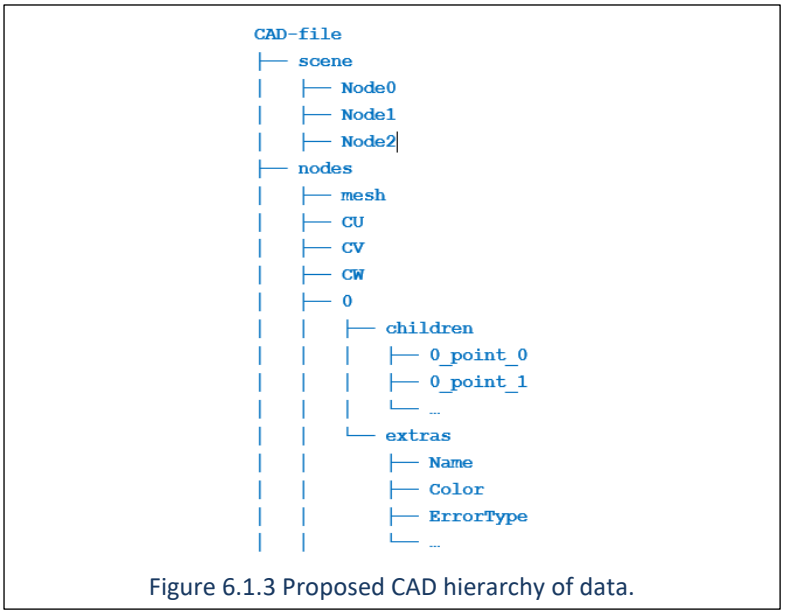


Figure 6.1.3 Proposed CAD hierarchy of data.

The described functionality of the Manual Repair Assistant has been fully demonstrated on a provided metal part from LKR and the interaction has been recorded as video. The gathered repair information could already be imported in the VR Disassembly Assistant of AIT using GLB. Further tests with inputs from FACC are planned.

Currently the focus of the work is to stabilize the software and identify potential alternatives to the OptiTrack infrastructure, as this might not be available on all partner sites. There are no unforeseen problems, and the development is in line with the plan.

Key Performance indicators

Technology With description	**Aspect**	**Target**	**Measurement procedure**
Registration of CAD to Tracking System of MRA: Registration of the Product Passport CAD to the Manual Repair Assistent Tracking System via KABSCH Algorithm	**Part Position**	Inner class std. dev. of 5 registrations <2°	The same part is registered 5 times with the same procedure whith reproducable registration results
	Processing Time	< 2s	Pure computational processing time measuread without human interaction is evaluated 5 times on the same part
Record Repair Process: The repair process is digitalized with the Manual Repair Assistant	**Number of trackable tools**	>=3	The number of trackable tools which is supported by the MRA (2 different camera positon layouts with 3 tools)
	3D position update rate of trackable tools	60Hz	Time between 3D position updates should not limit maximum movement speed of worker
	Working area	5x5x3m	Area will be validated by 10 dummy meaurements at the borders

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6.2. Sheet Metal Reforming Calculator

A selector tool was designed to allow an easy and fast preliminary assessment of the expected formability of steel and aluminium scraps.

In the re-manufacturing section (5.1.2), some basic considerations on the formability of different types of aluminium scraps (blanking/stamping/EoL scraps) were described. Chemistry and mechanical properties of the 4 different scrap types indicate that the automotive blanking and stamping scrap sheets (T4 tempers) should possess enough formability at room temperature, while the corresponding EoL scraps show nearly peak aging strength (T6/T8 tempers). This can be used for a general estimation of aluminium scrap formability used for the "Sheet Metal Re-Forming Calculator" (SMReC).

The scrap dealer informs potential customers on basic properties of available aluminium sheet metal scraps. This allows for fast and easy classification into 3 formability classes.

Blanking/stamping scraps from regular production: "T4 < 1 year"

Blanking or stamping scraps are generated during the fabrication of automotive or aircraft raw parts. Those materials generally are used within 6-12 months after solution heat treatment performed on coil material at the rolling mill. Hence, temper designation "T4 < 1 year" is applied to those relatively "fresh" scrap categories.

Aged sheet material: "T4 > 1 year"

Another use case would be material which was stocked longer than 1 year for different reasons. Material could be quarantined due to quality reasons, such as surface defects, wrong lubricant or out-of-spec geometrical or physical properties. Logistic problems could arise especially for material shipped intercontinentally. Those materials might show a reduced formability in comparison to standard material and hence might be used for less demanding deep drawing applications.

Aircraft 2xxx T3 material: "T3"

Aircraft 2xxx material is often shipped in T3 temper (solution heat treatment and slight stretching applied in the rolling mill). This material can be shaped into simpler geometries at room temperature. If more demanding forming operations are required, intermediate solution heat treatment and immediate W-temper forming is applied for T3 material. Annealed 2024 O material shows the best formability, independent of storage time, but needs a subsequent solution heat treatment of the formed parts. Alternatively, warm forming (e.g stretch forming at about 200°C) is successfully applied to produce curved panels for fuselage sections.

Painted EoL automotive or aircraft scraps: "T62" or "T6/T8":

Painted end-of-life aluminium scraps from automotive or aircraft applications show nearly peak strength. Hardening is achieved during paint curing cycles (temper T62) or by additional heat treatments after forming (temper T6/T8). Those materials show a low formability at room temperature.

After surface preparation (mechanical or chemical de-coating), a fresh solution heat treatment can reverse the hardening process and restore room temperature formability. A smarter way might be warm forming at about 200°C, which allows the production of not-to-demanding part geometries,

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while retaining the high mechanical strength of the material. For thicker material, heating of the sheet might be sufficient, while for thinner sheet sections, also the forming die needs to be heated.

A big disadvantage for the re-forming process of painted EoL scraps is the de-coating process, which involves costly and burdensome procedures and generates waste materials (contaminated blasting media or chemical de-coating solutions). Especially, aircraft primer and coatings still rely on highly toxic chromium-VI which adds to complexity and costs for the re-manufacturing of this kind of EoL scrap materials. Therefore, scrap sorting and re-melting might be a better option for this kind of EoL aircraft scraps.

Structure of the Sheet Metal Re-forming Calculator (SMReC):

Figures 6.2.1 to 6.2.9 show the basic structure of the SMReC. By input of basic information about the scrap material and the target re-forming part, the calculator suggests possible process routes for the sheet re-manufacturing and estimates associated costs and the environmental impact.

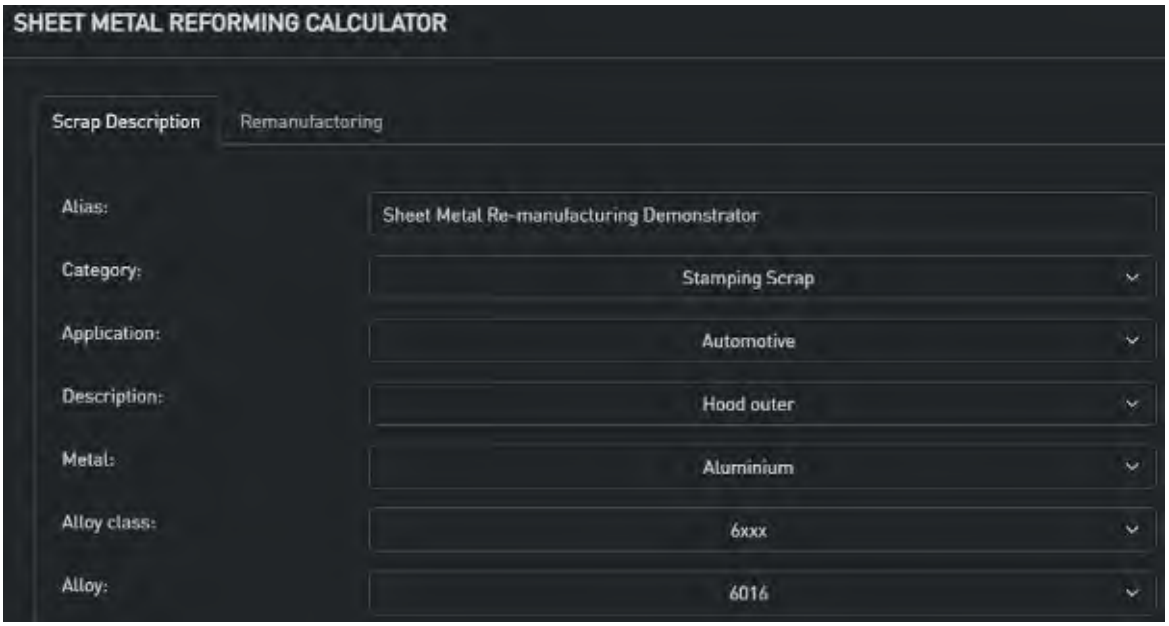


Figure 6.2.1: Sheet Metal Re-forming Calculator – Input mask

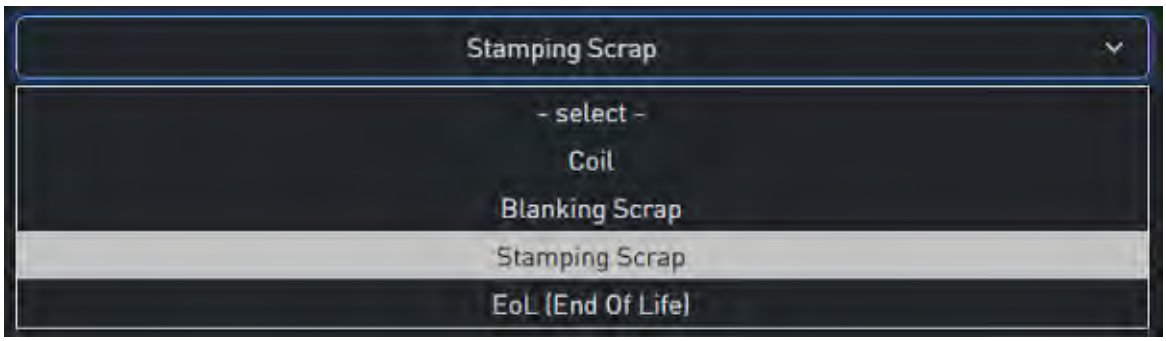


Figure 6.2.2: Selections for scrap ”Category”

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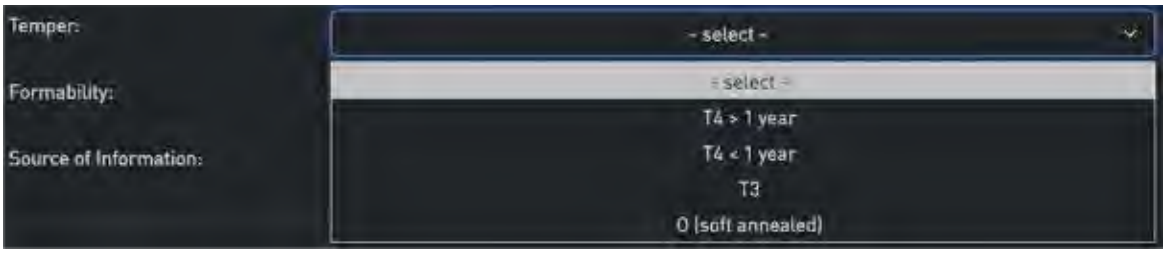


Figure 6.2.3: ”Temper” selections for scrap category ”Stamping Scrap”

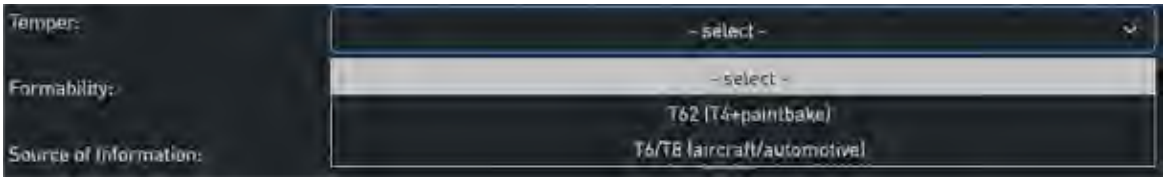


Figure 6.2.4: ”Temper” selections for ”EoL (End of Life)”

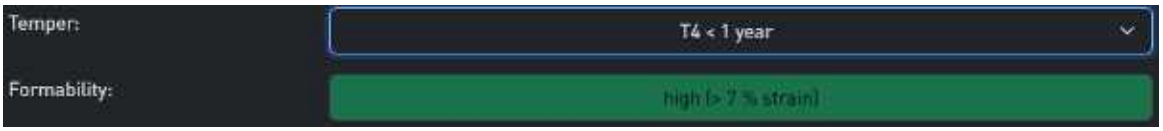


Figure 6.2.5: Formability classification of stamping scrap with selected temper ”T4 < 1 year”

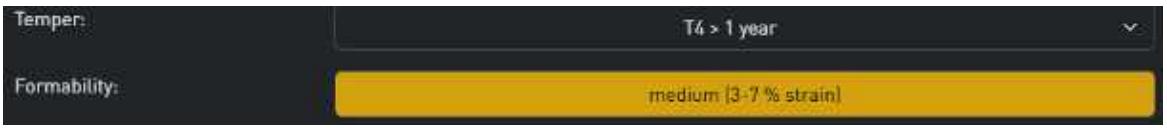


Figure 6.2.6: Formability classification of stamping scrap with selected temper ”T4 > 1 year”

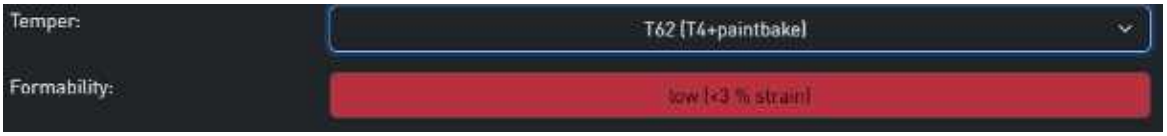


Figure 6.2.7: Formability classification of EoL scrap with selected temper ”T62”



Figure 6.2.8: Output SMReC for EoL scrap with selected temper ”T62” (CO2 and costs not validated)

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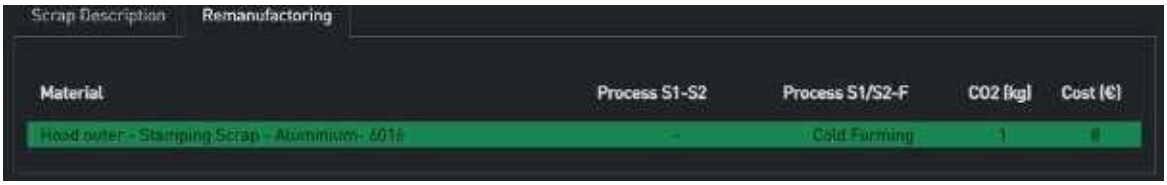


Figure 6.2.9: Output stamping scrap with selected temper ”T4 > 1 year“

With this simple tool, the SMReC allows scrap dealers and other parties involved a fast evaluation of the processability of typical aluminium sheet scraps extracted from automotive or aircraft skin materials.

Formability of Steel and Stainless Steel Substrates:

The room temperature formability of galvanized steel and stainless steel materials is considered as sufficient, hence a direct cold forming process is suggested in all cases.

For steel substrates which show too high pre-deformation it is assumed that the blanking process won´t yield flat panels anyway, which wouldn´t allow for a proper action of the blank loader during feeding of single blanks into the progressive deep drawing tool.

Key performance indicators

Technology With description	Aspect	Target	Measurement procedure
Sheet metal reforming calculator: Classification of scrap based on formability, process route recommendation	Material required for characterization	<15% compared to Nakajima testing	The material required for characterizing the material should be significantly lower compared to standard characterization methods for virgin material (i.e., Nakajima testing).
	Computational effort	<10% compared to FEM	The classification and process route recommendation should require only negligible computation time.

6.3. Remanufacturing Process Planner

The remanufacturing process planner aims to efficiently combine new components to be produced with existing scrap parts. This complex process takes place in several closely interlinked process steps, which are controlled by structured and automated workflows.

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The first step is to analyse the existing scrap parts in detail. The data captured using 3D scanning is read in and subjected to a geometric analysis. This is followed by a systematic classification, within which a zone-specific categorisation is carried out for each component and areas are delineated. These zones form the basis for categorisation into so-called reuse clusters, which enable targeted and quality-oriented subsequent use.



Figure 6.3.1: Remanufacturing Process Planner - clustering

The new components to be manufactured have specific requirements, particularly with regard to the minimum material requirements. Based on these requirements, a suitable scrap part that fulfils the necessary properties is selected from the appropriate reuse cluster.

The new blanks are then patterned on the selected scrap part using a nesting workflow. This optimises material utilisation and determines the exact positions of the blanks.

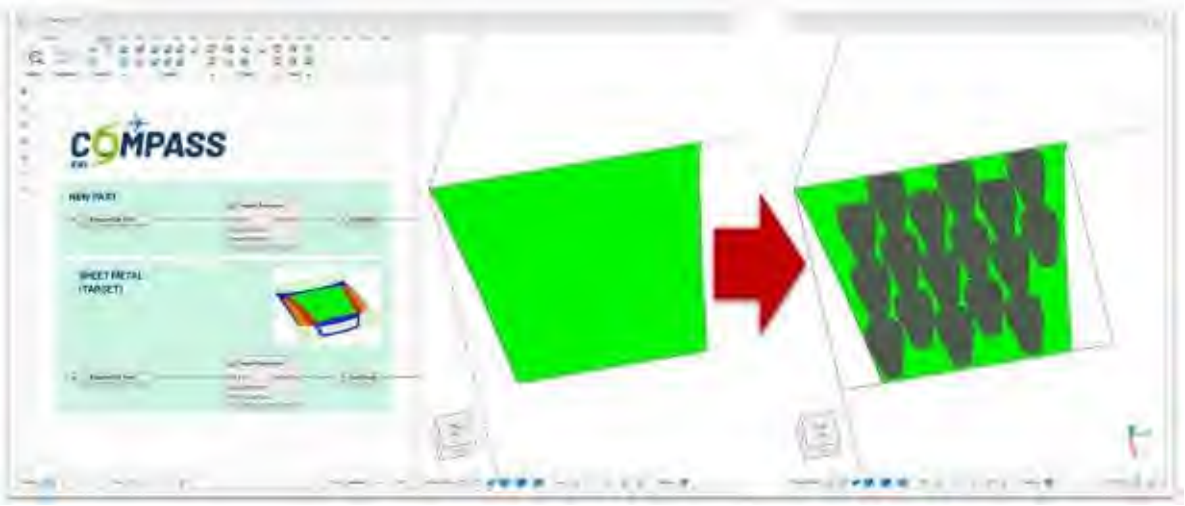


Figure 6.3.2: Remanufacturing Process Planner – nesting

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The individual component patterns generated in this way can be used to derive precise contour cuts in the form of line curves, which serve as the basis for the separation process. Depending on the requirements, this can be carried out using laser or water jet cutting. For frequently recurring, identical contours, the use of a punching tool can also be an economically viable alternative.



Figure 6.3.2: Remanufacturing Process Planner – new component

Key performance indicators

Technology With description	**Aspect**	**Target**	**Measurement procedure**
Remanufacturing process planner: Nesting of components for remanufactures based on defect free location	Minimise scrap	to be determined (minimum)	The amount of scrap material must be minimised. Percentage in relation to the initial scrap. However, damaged and unusable areas must be excluded from the assessment.
	Number of nested parts	tbd. (maximum)	Based on a scrap component, the maximum possible number of components is to be nested
	Lead time / processing time	tbd. (minimum)	The lead time between receipt of the order and the provision of the result. This lead time must be determined during the Compass project duration and continually optimised (minimised). Depending on the amount of data.

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6.4. Disassembly Assistant

The Dismantling Assistant, developed by the Austrian Institute of Technology (AIT), is an Augmented Reality (AR)-based tool designed to support the precise and safe dismantling of end-of-life (EoL) aircraft structures. The tool relies on AR technology delivered via AR glasses to project critical dismantling information directly into the operator's field of view. Through this interface, technicians receive visual guidance layered directly on the aircraft structure, encompassing material-specific data, previous repair history, hazardous zones, cutting instructions, and potential reuse areas. This enhanced situational awareness is fundamental to avoiding errors, improving safety, and enabling optimal material recovery in accordance with circular economic principles.

The Dismantling Assistant functions by combining 3D aircraft models, either obtained from Original Equipment Manufacturer (OEM) data or generated via 3D scanning technologies, with AR overlays rendered through Unity, a powerful 3D engine. These overlays are to be dynamically linked to a central knowledge base, which stores critical data to ensure the disassembly process follows safe, standardized, and sustainable procedures. The application is being developed using a human-centered design approach, ensuring that the interface remains intuitive, effective, and suitable for real working environments. To date, the tool has been tested on a limited aircraft section to refine key functionalities thereby establishing the basis for future scaling to entire aircraft structures.

The tool plays a central role in fulfilling the objectives of the COMPASS project by enabling a sustainable, reforming-based remanufacturing process for EoL aircraft components. Within this context, dismantling is more than a preparatory task; it is a critical enabler of circularity. The Dismantling Assistant contributes to the overall digital strategy for aircraft disassembly, translating digital dismantling plans into actionable, operator-friendly guidance projected directly onto physical structures. This not only increases the precision and efficiency of dismantling operations but also reduces the risk of human error and the amount of material waste. By combining dismantling-relevant data integration and AR technology, this digital tool offers a better alternative to conventional dismantling methods, ensuring that disassembly actions are both safe and aligned with long-term sustainability and reuse goals.

In doing so, the tool directly supports the improvement of both the quality and traceability of recovered materials by enabling precise component-level separation. This in turn facilitates the reintegration of parts into the aerospace value chain through remanufacturing and reuse, while also significantly increasing their retained economic value. As a result, the Dismantling Assistant enhances overall process efficiency, reduces the risk of cross-contamination in materials, and supports the preparation of high-quality feedstock suitable for circular aerospace manufacturing.

The tool's functionality depends on integration with other digital systems and datasets within the broader COMPASS ecosystem. It relies on the availability of accurate 3D models of the aircraft, sourced either from OEM-provided CAD data or generated through advanced 3D scanning technologies from project partners such as Schild und Partner. These 3D models are enriched with layered metadata containing information such as material characteristics, repair history, hazard indicators, and structural annotations. All this information is accessed via a centralized knowledge platform, the Digital Product Passport (DPP), which enables secure and structured data exchange.

The Dismantling Assistant also works in close connection with the Cutting Planner, a tool that defines dismantling strategies for structural components based on factors such as material compatibility, repair history, and cutting efficiency. The Assistant visualizes these pre-defined cut lines and related

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metadata through its AR interface, enabling safe and accurate execution by the operator. The aircraft sections used in testing and demonstration are supplied by project partner AELS. In addition, the tool is supported by the Manual Repair Assistant, which facilitates the automated tracking and localization of previous repair work on specific aircraft components. This repair data is transformed into a 3D CAD model and subsequently displayed as a virtual overlay within the AR view of the Dismantling Assistant.

The development of the tool is advancing in accordance with the milestones outlined in the COMPASS grant agreement. Initial feasibility was demonstrated during the SUSTAINair project, where small-scale AR-guided dismantling scenarios served to validate the core concept and technology. SUSTAINair is a European Horizon 2020 project aimed at advancing circularity in aviation and aerospace sectors while tackling the increase in resource consumption, waste and emissions along the entire aviation component value chain.



Figure 6.4.1 The AR overlay on a plane panel, demonstrated for the SUSTAINair project at the Paris Air Show

Building on these foundations, the tool has progressed to an intermediate stage of development under COMPASS, with particular focus on extending the tool's application to larger aircraft sections and integrating complete, real-world datasets.

Development activities are being carried out under Task 4.7 (Disassembly Assistant, led by AIT), and have initially concentrated on a limited aircraft section to allow for controlled, iterative testing.

At this stage of development, the tool is capable of displaying key information, including material composition, hazardous areas, historical repair data, and cutting instructions via AR overlays. This functionality currently relies on simulated datasets. Integration of real operational data is planned for future development phases.

Figure 6.4.1 illustrates the operator's point of view when using the Dismantling Assistant. The interface projects contextual information directly onto the physical structure, enabling decision-making based on relevant digital data.

In the current demonstration, the visualized interface overlays several key data elements extracted from the Digital Product Passport (DPP), including material composition, historical repair zones, identified cut areas, and sensitive/dangerous regions (Fig. 6.4.2). These overlays are visualized as intuitive graphical markers, helping the operator distinguish between structurally critical areas, suitable cutting paths, and zones requiring special attention due to safety or reuse constraints (Fig. 6.4.3).

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For instance, cut zones are highlighted to guide separation in a manner that preserves material integrity and enables reuse, while sensitive areas mark locations that may pose a safety risk or require handling under specific procedures. Repair history overlays provide insights into previously modified or reinforced parts of the structure.

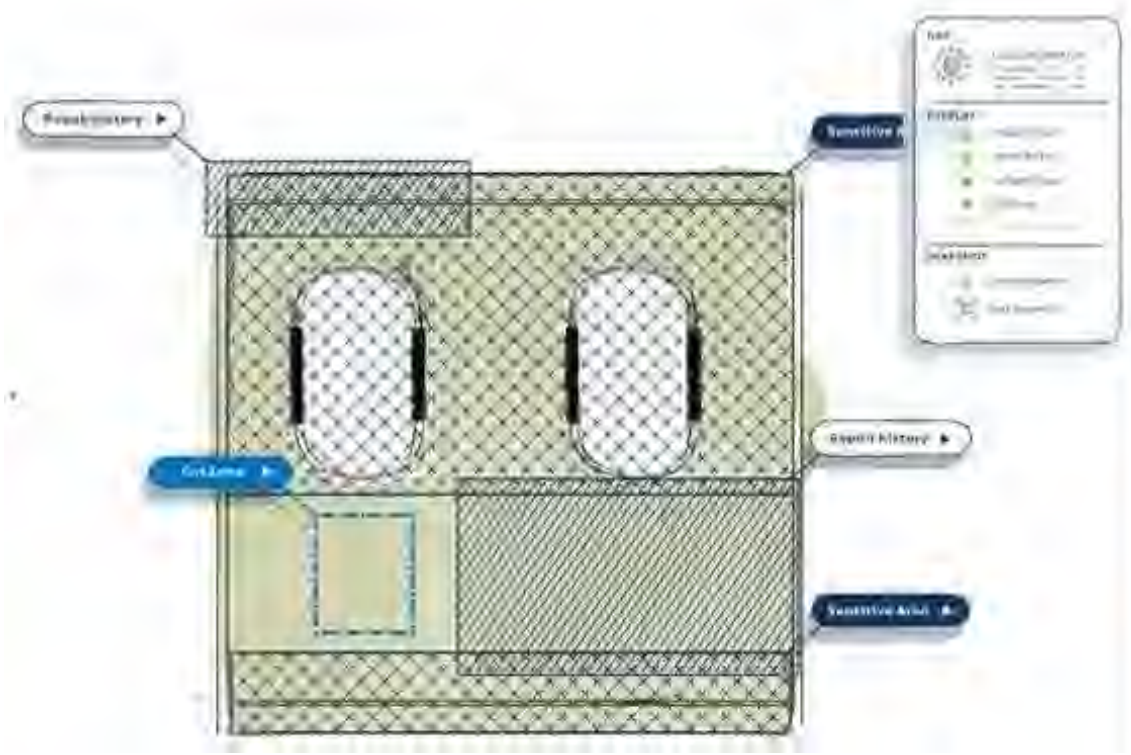


Figure 6.4.2 Operator's POV illustrating the AR interface, displaying contextual information on an EOL aircraft component

On the right-hand side, the interface includes a control panel allowing selective display of different data categories, such as annotations, sensitive areas, and historical repair data, along with a snapshot function that enables operators to record the current state of the AR view for traceability and documentation purposes.

At the current stage of development, the information displayed in the AR interface is based on simulated datasets. This approach supports iterative interface testing and functionality refinement under controlled conditions. In subsequent development phases, the system is intended to integrate operational data sourced from the DPP platform, enabling the Dismantling Assistant to operate in live environments and support full-scale dismantling workflows (Fig. 6.4.4).

The application is built on the Unity game engine, which offers advanced capabilities in 3D rendering and interactive spatial design. The tool's interface is being developed in alignment with user-centered design principles, applying established UX and UI methodologies tailored to the specific requirements of complex industrial environments. Particular attention is given to optimizing the human-machine interaction, ensuring that the system remains intuitive and effective under operational conditions typical of aircraft dismantling processes.

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Overall, progress to date indicates that the Dismantling Assistant is on track within the defined project timeline. Upcoming phases of development will focus on technical validation at scale, broader system integration, and demonstration in real-world end-of-life scenarios.



Figure 6.4.3 User's POV inside the Magic Leap, repair and cut zones toggled, overlayed in with marked blue lines



Figure 6.4.4 Testing the Dismantling Assistant AR application at the current state of development using the Magic Leap MR devices

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Key Performance indicators

Technology With description	Aspect	Target	Measurement procedure
AR Dissembly assistant: Augmented Reality Technology used as a digital enhancer to aid the disassembly process.	Implementation of the 3D Scans	Successful implementation of accurate 3D scans of the selected area. - Visual inspection of scan quality for any gaps or distortions. - User feedback on ease of integration or usability of the scans.	Verify the resolution and accuracy of the scans; compare scans to real-world dimensions; confirm compatibility.
	Integration with the DPP	Successful integration of the relevant Digital Product Passport (DPP) data into the AR application. -User feedback on the workflow and data integration. -Observations about system behaviour during the integration process (e.g., identifying potential bottlenecks or errors).	Test the upload, retrieval, and mapping of 3D scan data within the DPP; confirm metadata (e.g., dimensions, materials) is correctly linked to the scans.
	Digital Overlay functioning IRL (on a specific section of the plane)	The overlay correctly displays the intended information when applied to the specific section of the plane in a real-world environment. -User perception of overlay clarity, usability, and overall experience. -Feedback on how well the overlay aligns with the physical counterpart.	Test the alignment and scaling of the overlay using AR devices; verify accuracy in various lighting and environmental conditions; validate the user interface for end-users.

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7. DATA ACQUISITION, TRANSFER AND ACCESS MANAGEMENT OF DATA ELEMENTS

7.1. Data Acquisition

Acquisition of important and different kind of data is included in the DPP in order to ensure, among other things, long-time untampered traceability, assessing remanufacturability, planning remanufacturing processes as well as assessing safety in handling hazardous chemical components if applicable.

Data about upstream partner information (supplier details), material batch and serial information(date of delivery/expiry, condition and chemical information etc), part data (CAD, surface data, mechanical properties as well as data during production process such as curing cycle, end of line NDT and many more will be provided in the case of the sheet metal and composite use case. While for the sheet metal remanufacturing use case, the feedstock is sourced from both blanking, stamping scrap as well as end-of-life parts, the composite remanufacturing sources parts primarily from defective parts as feedstock. Therefore, data such as attempted repairs, non-destructive testing (NDT) results, and sensor-based NDT data from the layup during the nesting stage (provided by Profactor) are also included. For the part dismantling use case, much of the data will focus on the design (3D CAD, point cloud, images) and composition (plane model, component specific alloy composition, data about possible dangerous chemicals etc.).

Acquisition of data in the DPP will occur in one of automatic, semi-automatic or manual mode. While automatic mode requires significant software integration efforts and, in some cases, significant costs. In other cases, most of the upstream data and testing data is available as PDFs, thus acquiring

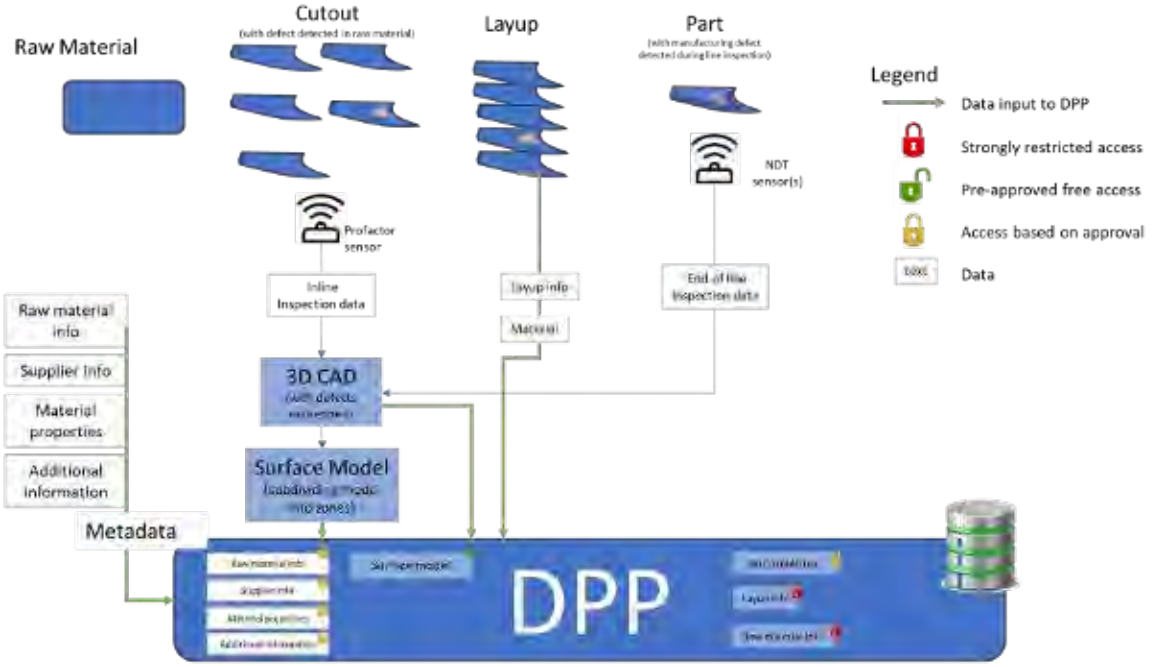


Figure 7.1.1. General schematic explaining the data collection and flow in the composite use case.

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individual data points is difficult however, the whole document is uploaded manually into the DPP and made available. The types, format and the maximum size of data is predefined for each data point in collaboration with NLR and CIRC, and with feedback from downstream stakeholders. A general description of the data acquired for the Composite use case is given in fig. 7.1.1.

7.2. CAD Data Handling

One of the important data needed for remanufacturing defect-free parts is the CAD model including the position of the defects. The defect data is needed for the downstream processes (especially process planner) for deciding on the areas which are defect free to do the nesting of remanufactured parts effectively.

A representation (or superposition) of the defects on the part CAD file identifying the location, size and depth is the straightforward solution to this. However, the part CAD is also sensitive information and often contains IP that may belong to upstream partners (e.g.: OEM who may have provided the CAD and contracted the composite manufacturer to manufacture the part). In such cases, the access management plays a major role. Currently this is managed in collaboration with NLR and CIRC by defining the template structure based on which the DPP will be created.

Further, the NDT data is generated as images or in other proprietary native formats, which still need to be incorporated into the CAD data. For instance, the data from the FScan sensor is an important NDT data that needs to be incorporated, and the process planner be made aware of the defect

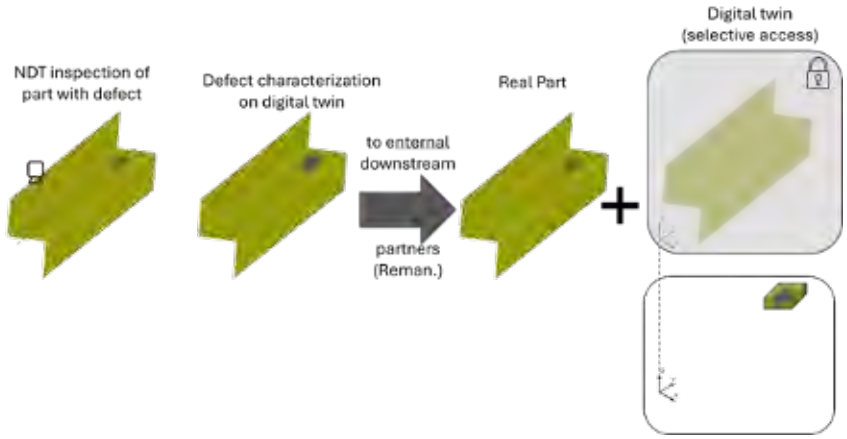


Figure 7.2.1: Schematic showing the separation of the CAD files of the part and the defects in the case of a digital twin in DPP. The NDT data here is from EOL NDT, however, this is equally applicable to the NDT inspection during layup (F-Scan).

location, however it is generated in different formats but not as CAD. In these cases, the output files (detailed in section 5.2.7 above) are exported and provided as a standalone step file (.stp, .step) giving all necessary information which can then be imported to the same workbench where the part CAD is imported. The existence of two separate files on the other hand ensures that the sensitive part CAD file is sent only to reliable sources while sharing the defect file to any interested downstream partners without extensive vetting. This is shown graphically below in fig.7.2.1.:

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7.3. Data File Exchanges

Brics is a tool that supports definition and smooth execution of chains of tools (i.e. workflows) across organisations, and as such facilitates cross-organisation collaboration at the level of tools and data files. It supports transformation of separated local tools, services, and tool chains into multi-partner collaborative workflows, while complying with security and connectivity constraints. It manages the orchestration of possibly distributed tasks, including the notification of remote engineers, the automated secure exchange of data among the tasks, and the synchronisation of the distributed tasks. The application of Brics in establishing a multi-partner collaborative workflow is depicted in Figure 7.3.1.

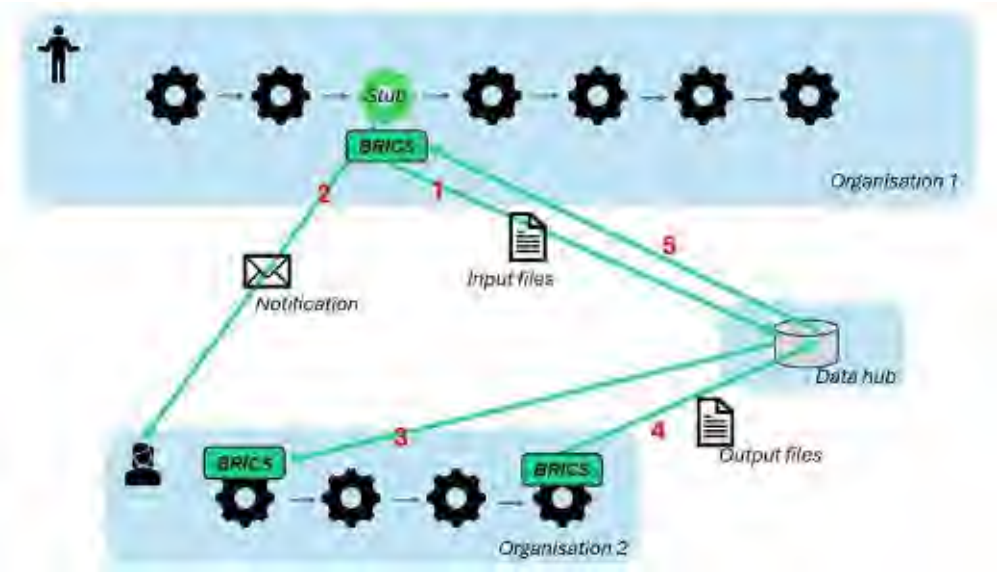


Figure 7.3.1: Application of Brics in establishing a multi-partner collaborative workflow. The Stub in Organisation 1's workflow represents Organisation 2's workflow. Once the *Stub* is activated, (1) the *Input files* are copied to the *Data hub* and (2) a *Notification* is sent to an engineer at Organisation 2. If the request for execution is accepted, the engineer starts the workflow, which (3) fetches the *Input files* from the *Data hub*, runs to completion, and finally (4) uploads the *Output files* to the *Data hub*. Finally, the *Stub* takes care of downloading the *Output files* and finalises its execution as a tool in Organisation 1's workflow, which then runs to completion.

Brics is an NLR key technology for achieving efficient, cross-organisation collaboration at the level of tools and data files. Brics encompasses NLR's experiences and technologies gained during the past 15 years of realizing multi-partner collaborative tool chains across organisational borders, while complying with the increasingly strict security and connectivity constraints typical of contemporary industrial settings. Brics has proven itself to be sufficiently open and flexible to being applied in various settings and situations, and to cater for new settings and situations with minimal effort.

Brics is available for the COMPASS project, to facilitate the exchanges of data files across organisation borders between the WP3 and WP4 tools on the one hand and the DPP Management System on the other hand. As such, Brics is part of the "Legacy System Interfacing" subsystem of the DPP Management System. Brics enables the tools developed in WP3 and WP4 to use and update the data that constitutes the digital component passports. As such, it is envisaged as a potential complement to the data file exchange capabilities of the DPP Platform, viz. the Circularise system, as part of the DPP Management System, and as such to cover any data file exchange needs that might be identified.

For the intermediate demonstration, the Circularise system provides the capabilities for the required data file exchanges between the WP3 and WP4 tools on the one hand and the DPP Management

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System on the other hand. Consequently, application of Brics is not strictly needed for completion of the intermediate demonstration. However, Brics is still available for COMPASS demonstrations and use cases to cover any additional data file exchange needs beyond those already provided by the Circularise system.

Key Performance indicators

Technology With description	Aspect	Target	Measurement procedure
Brics: tool that supports definition and smooth execution of chains of tools (i.e. workflows) across organisations. As part of this functionality, it caters for secure data file exchanges among partners.	**Secure data file exchange not supported by Circularise's Data sharing system**	Facilitate all data file exchanges among the partners and the Digital Component Passport Platform that is not yet supported by Circularise's Data sharing system	In case of need: demonstrate the secure data file exchange.

7.4. Data Storage, Sharing and Access Management

The Circularise platform is a key part of the COMPASS project, offering a Software-as-a-Service (SaaS) tool that ensures supply chain traceability. The platform aims to make the future of manufacturing more connected and sustainable by giving companies the tools they need to share data confidentially, without the fear of losing their competitive edge. The traceability platform supports secure data sharing among stakeholders in the value chain. This system leverages blockchain technology to ensure data integrity and transparency across the supply chain. Our solution empowers companies to remain in control of their data, ensuring seamless compliance with regulations, as well as with customers' data demands, while saving their valuable resources for organisational growth and success. Companies no longer need to struggle with the overwhelming task of keeping up with ever-changing legal requirements or changing data needs from actors. Circularise's constant support enables effortless navigation of the legal and data demands landscape, fostering trust and demonstrating our organisational commitment to transparency.

Within COMPASS, Circularise's tool aims to help actors in the composite and metals remanufacturing value chains, including the automotive and aerospace industries, gain better insight into the properties and status of components (Fig. 7.4.1). The aim is to improve remanufacturing practices and processes, ensuring following the best standards and new business models. In the end, this fosters greater trust and transparency in the circular economy, supporting more sustainable practices.

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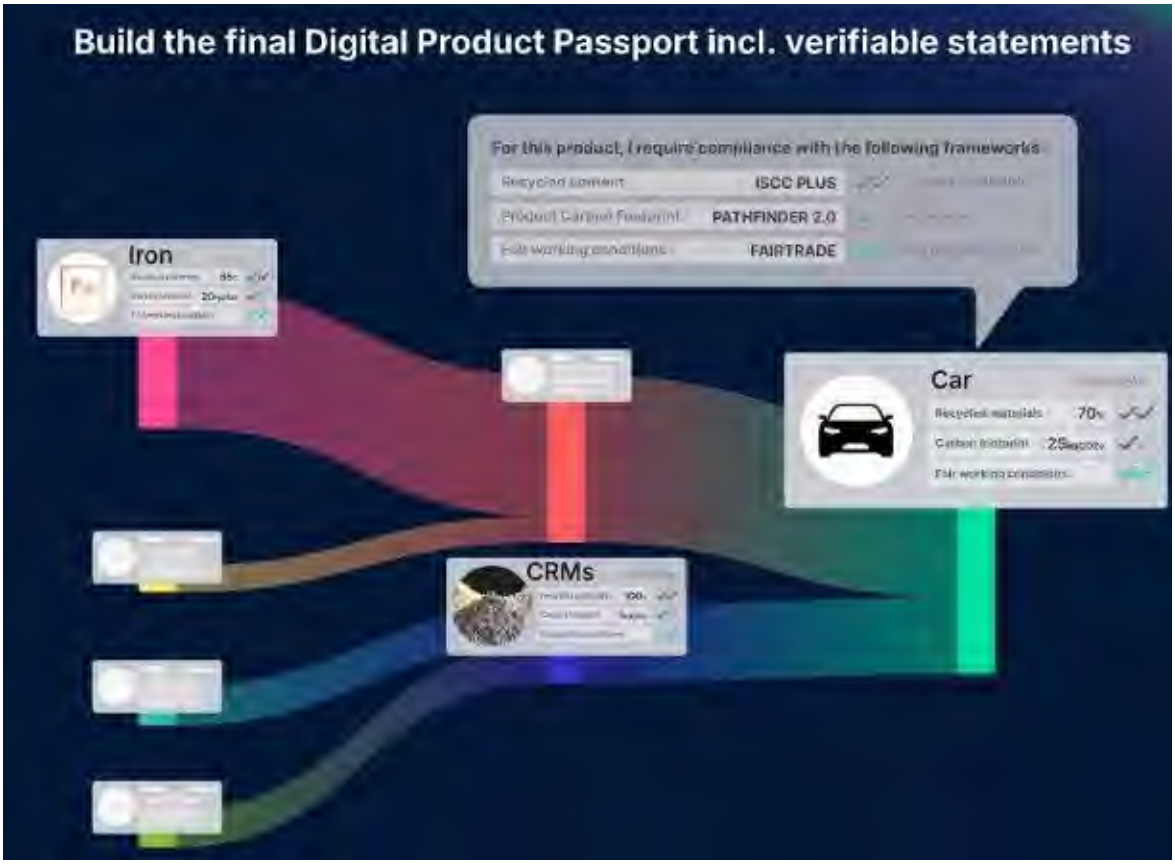


Fig 7.4.1. Circularise's secure data-sharing method, based on zero-knowledge proof technology (patented Smart Question technology), enables a user to provide an answer to the question without disclosing the original answer, protecting in turn core IP and sensitive information from stakeholders.

The platform development within COMPASS includes a tamper-proof data storage module, which increases data protection, leverages new data storage software infrastructure and supports blockchain. This guarantees a reliable record of the product's life cycle, an essential aspect for traceability and checking the safety of materials. This also supports the goals of having secure and transparent Digital Product Passports (DPP) shared throughout value chains. Moreover, Circularise's work on improving encryption and scaling technologies enables maintaining data security and avoids breaches or information being intercepted or ending in the wrong hands (e.g. competitors) see Fig. 7.4.2).

One of the standout features to be developed in COMPASS for the Circularise's platform is its data sharing and access rights management tool. Advanced data sharing and access management scale the data gathering, sharing and displaying functionalities. Furthermore, it increases the amount of functionalities concerning managing the type of actor and the detail of data accessible to them. By using the system, actors can manage who can see different kinds of information and remain in control of the access even further downstream. This function is crucial for keeping competitive information safe while still sharing what's needed.

The Circularise platform outcomes from COMPASS also play a significant role in increasing material safety verification and auditing. With its developments, it becomes easier to follow strict industry standards and build trust among partners in the aerospace supply chain by providing clear information about where materials come from, how they've been processed, and their quality.

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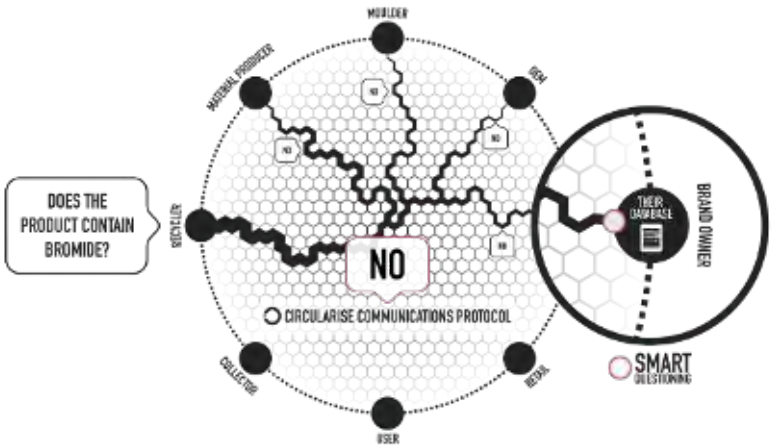


Fig. 7.4.2. Each actor provides information about their products. When this information is shared among the value chains, the different stakeholders will not necessarily see the exact percentage input by partners, but rather an answer to the question of whether the component contains or not bromide, or even if the percentage is lower/greater than or in between some values. The Smart Question technology enables a user to provide an answer to the question without disclosing the original answer, protecting, in turn, core IP and sensitive information from stakeholders.

Additionally, the tool will improve the communication of repair, remanufacture, and maintenance steps by making sure accurate and essential details are easily shared. For example, data on the existing defects of parts, through CAD files, repair documentation, the resin and fibre types, among others. This helps all stakeholders involved to follow these important stages accurately, which can help make components last longer, support the use of resources more sustainably and make better decisions (see fig 7.4.3).

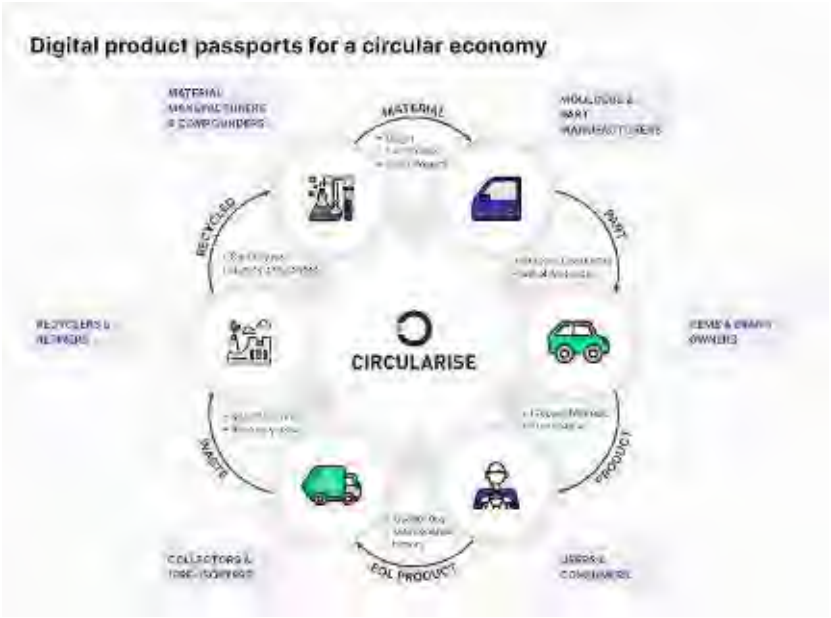


Fig. 7.4.3. Circularise creates a decentralised network where product and material data can be shared in a harmonised way via customised DPPs per OEM or even industry, as compliance is relevant to all actors in the value chain. Stakeholders thereby receive certified answers to their material questions from the suppliers of the material or component across the whole supply chain. Blockchain enables verifiable proof of data correctness.

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Circularise has determined the requirements from partners in terms of the data needs, as well as what the technology should support. This input is based on the use cases defined by the project, including the composite and the metal remanufacture. The composite use case starts with defective composite parts from FACC, which are then analysed by EDAG and AITIIP to determine a suitable next usage and the correct way of maximising their use. In the end, AITIIP makes the required changes to produce a new component from the damaged part. The metal-related use cases involve multiple flows, starting from either aerospace (AELS) or automotive (voestalpine) parts, and then moving ahead in the value chain for analysis for the best way to handle these parts, and finalising with the remanufacture of the parts done by companies such as MARK and LKR.

Circularise has conducted multiple consultations with partners from the abovementioned use cases, to define the specific information that should be traced within the value chains for each component flow. Moreover, these needs have been translated into system requirements and data points, which Circularise has included accordingly and adjusted its system where needed. Additionally, Circularise has created accounts for partners from most of the remanufacturing use cases (for the composite and four of the metals from automotive parts) and onboarded partners on the system. The system is being actively used and tested by partners by creating components and their DPPs and sending them to all the required stakeholders in the value chain (starting from the EoL parts and going all the way until the final product). Most partners are working directly through Circularise's main interface, interacting with the system, uploading the relevant data in their accounts to be shared accordingly, through the DPPs. Additionally, the API is being used by EDAG to assess its viability. COMPASS-specific functionalities developed on the system so far entail identity-protecting mechanisms, as well as higher performance and resiliency of data storage. Further developments are expected from Circularise to continue working on the scalability and improvement of the technology.

Key performance indicators

Technology With description	**Aspect**	**Target**	**Measurement procedure**
Data sharing system extension: Improvement of "Software-as-a-Service" system that allows the connection of decentrally	Data defined and traced in the platform	Target1: more than 80% of the partner's requirements (for the selected demo to trace), which are in-scope for the project, are fulfilled Target2: Question lists (DPP data points) that respond to the requirements, are incorporated into the system	When using the system and creating Digital Passports, it should be possible to provide input (data provider/sender) for the information previously defined, as well as see this data (receiver)

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stored sensitive data, which remains accessible during the lifetime of the component, for the automotive and aerospace sectors	Creation of Digital Passport and sharing among value chain stakeholders	Target1: Create digital passports of 2 components Target 2: Share the digital passport with 2 stakeholders	Through the creation of accounts on the Circularise's system, it will be possible to verify the creation, sharing and receival of the digital passports
	Privacy and disclosure levels are correctly defined	Target1: Data is visible to only the required/selected stakeholders	In the Circularise's account, when receiving a Digital Passport, the data seen is only the one agreed by the supplier, maintaining confidentiality of sensitive data

7.5. Digital Component Passport Platform

The Digital Component Passport Platform is being implemented in the form of the COMPASS Digital Product Passport (DPP) Management System. The term “Digital Product Passport” (DPP) refers to the same notion as the envisioned “Digital Component Passport” in COMPASS, but is a terminology considered to be more in line with similar European initiatives, developments and projects around the notion.[2] In addition, the term “Management System” is considered to be more generic than “Platform”, in the sense that the envisioned system should not only implement DPPs (based on fixed definitions of their contents), but also support (1) use of the DPPs in the context of the envisioned COMPASS use cases involving data and tools in chains of partners, (2) more generic definitions of DPP contents in terms of DPP templates, and (3) management of those DPP templates.

The DPP Management System in its entirety is targeted towards providing a smooth integration of the partners’ data and the partners’ tools and processes along COMPASS’ circular process, thereby using DPPs as pivotal elements. Here, “smooth integration” refers to applying DPPs to their intended purpose (i.e., supporting decisions about remanufacturing at the End-of-Life of components) with minimum – and preferably zero – administrative overhead for each partner. As such, smooth integration deserves some analysis of how DPPs actually fit within the processes, data, and tools used by the collaborating partners. To this end, we consider a DPP from a component’s point of view.

During a component’s lifetime, from cradle to cradle, data about the component are produced and collected. Some data are useful or even necessary for manufacturing, operation, and maintenance purposes. Other data are mandatory, e.g. due to regulations and for certification purposes. The data are usually stored on paper, in databases and in such data management systems as ERP or PLM systems, and are usually dispersed among multiple stakeholders. For example, design and manufacturing data reside with the component’s manufacturer; and operational data reside with an end-user (or even with the component itself, as is the case for modern cars).

Also, during the component’s lifetime, it is subjected to numerous processes, starting with design and manufacturing, followed by installation into a system (e.g., car, aircraft, system), being put into operation, being maintained and repaired, and finally being evaluated for reuse, remanufacturing, or recycling. Each process may involve multiple actors from different organisations. An actor wants to,

[2] The European Commission defines a Digital Product Passport (DPP) as a "structured collection of product related data" accessible via electronic means through a unique identifier. [https://cirpassproject.eu/dpp-in-a-nutshell/]

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or must, use data associated with the component, and commonly also produces data to be associated with the component.

To facilitate collaboration between the actors of processes around a component, agreements about such aspects as time, costs, responsibilities, and data sharing need to be settled. COMPASS focuses on the data sharing aspects. Agreements about data sharing in multi-partner collaboration involve answering questions like: What data shall one partner provide and does another partner need? Who may access, add, and update which data? What data formats and units to use? How to procure and provide data? How to ensure long-term availability of data? And, how to share data securely in order to preclude the unintended acquisition of, or tampering with, possibly sensitive, shared data?

In Compass, the DPP Management System facilitates securing, as well as honouring, agreements about data sharing in processes concerning the possible remanufacturing of components, thereby providing technical answers to the aforementioned questions.

The DPP Management System for the COMPASS project is still under development at the time of the interim demonstration, with progress as planned. System needs have been collected in collaboration with the COMPASS partners and subsequently analysed. This analysis resulted in a list of system requirements and the identification of four subsystems: *DPP Platform, DPP Data Definitions*, *DPP Template Platform*, and *Legacy System Interfacing*.

The *DPP Platform* provides the notion of DPP and enables partners to use DPPs in their collaborative chains of activities and tools. In the COMPASS project, the DPP Platform is implemented as the Circularise Platform with COMPASS-specific extensions and is currently being extended to fulfil the system requirements as formulated for the DPP Management System for the COMPASS project and relating to the DPP Platform; cf. the “tamper proof long-term data storage” described in section 7.4

The other subsystems of the DPP Management System support a more integrated application of DPPs in use cases involving chains of collaborating industrial partners, such as envisioned within the COMPASS project.

The *DPP Data Definitions* comprise the definition of sets of data points that constitute DPPs. The DPP Data Definition of a particular type of DPP needs to be settled before DPPs of that type can be created and used. When a DPP is created and used in a chain of partners, values need to be assigned to the data points. For the interim demonstrations and in the short term, DPP Data Definitions of DPPs for use in the COMPASS use cases were created using “data collector sheets” during collaborative sessions with the partners involved. In the long term, DPP templates can be composed and fed to the DPP Platform using the *DPP Composer*.

The *DPP Template Platform* supports partners in collaboratively setting up and managing DPP Data Definitions, or DPP templates, that define DPPs. A DPP template is a formal specification of the DPP Data Definition for a specific type of DPP for a particular purpose. In the COMPASS project, the DPP Template Platform will be implemented as *DPP Composer*, which is a web-based tool where data owners can build DPP templates from scratch and manage those DPP templates. A demo version of the DPP Composer is available for the interim demonstrations; see Figure 7.5.1. To test the DPP Composer’s applicability and basic functionality, the DPP Data Definitions as created for the interim demonstrations (using the aforementioned data collector sheets) have also been created as DPP templates using the DPP Composer. Subsequent versions of the DPP Composer may include, for instance, reusing parts of templates as building blocks based on standards, regulations, or other commonalities.

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Legacy System Interfacing supports integration of the DPP Platform with legacy systems and practices familiar to the COMPASS partners. It serves to support integration of the application of DPPs across the various partners' data, tools, and processes, with minimal – or even zero – separate administrative actions requiring explicit user interaction. For example, the integration may involve the use of application programming interfaces (APIs) to feed DPPs with values automatically, at certain points in the chain of activities. The *Brics* technology described in section 7.3 is also available as a Legacy System Interfacing capability.

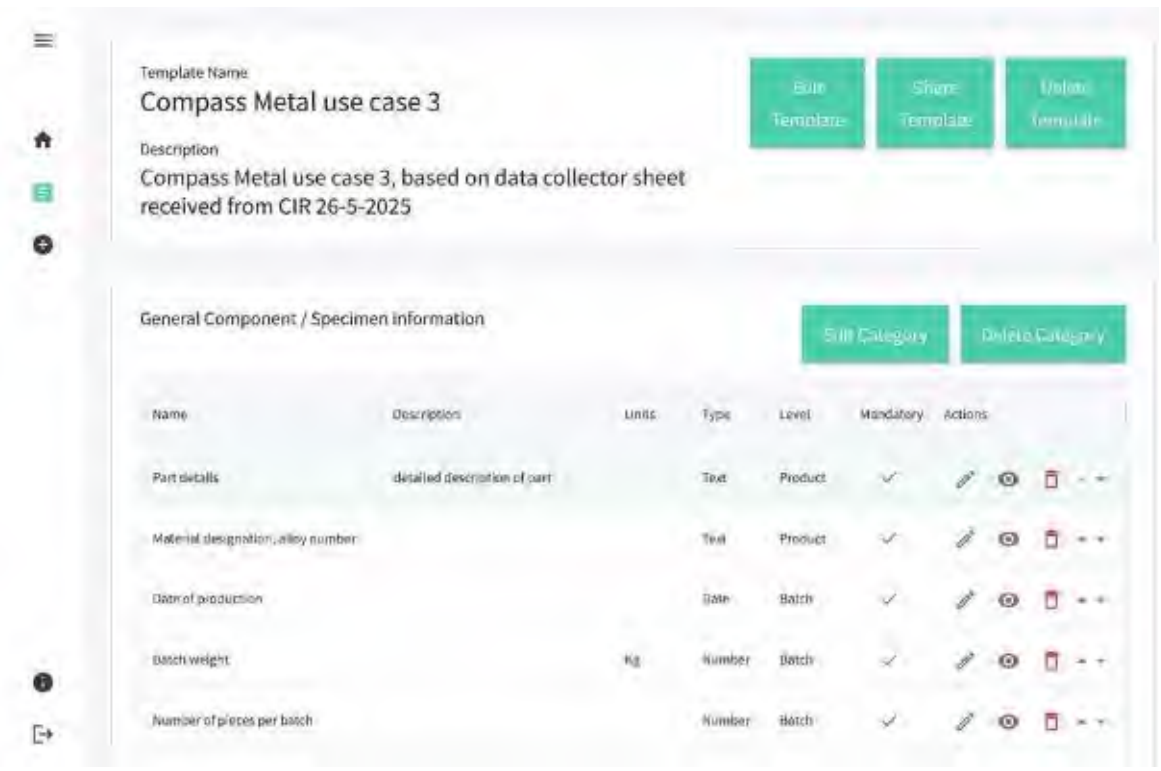


Figure 7.5.1: screenshots of DPP Composer with relevant pieces of a DPP Data Definition for Compass Metal use case 3.

Implementation of the subsystems of the DPP Management System is ongoing. In short, a functional version of the DPP Platform is already being used, DPP Data Definitions for the interim demonstrations of the COMPASS use cases have been set up, a first version of the DPP Template Platform is available, and essential capabilities of the Legacy System Interfacing have been created and are available for the purpose of the interim demonstrators.

The DPP Management System in the context of the COMPASS project is mainly used via manual interactions, such as composition of DPP templates, specifying values for data points in DPPs, and consulting DPPs through visual tools such as Sankey diagrams for being able to answer questions about reusability and manufacturability of components at their ends of life. In the intermediate demonstrations, the only direct interaction between the DPP Management System and partner tools is the data connector for connecting tools from EDAG with the Circularise platform as DPP Platform, to demonstrate the capability of the extended Circularise platform for establishing connections among tools at API level. This data connector is part of the Legacy System Interfacing subsystem of the DPP Management System.

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Key Performance indicators

Technology With description	Aspect	Target	Measurement procedure
DPP Template Manager, or *DPP Composer*: a web-based tool for collaboratively setting up and managing DPP Data Definitions, or DPP templates, that define DPPs for particular purposes.	**Applicability**	Target = 2 pts	NLR will create one DPP Template, as defined by CIR, FACC, and AITIIP for the M15/M18 intermediate demo, using the DPP Template Manager prototype (1 pt), and will check with CIR that the exported information in a format that is acceptable as input for CIR(+ 1 pt).
	Compatibility	Target = 100 % (i.e., all stakeholders in the process)	Percentage of DPP templates as needed for the M15/M18 Intermediate demo that has been created using the DPP Template Manager prototype by NLR.
	Usability	Target = yes	One DPP Template can be defined by one of the other (i.e. non-NLR and non-CIR) Compass partners using the DPP Template Manager prototype (with instructions)

8. CONCLUSSIONS

An intermediate review of the development status of the different digital components were covered in this deliverable. After an explanation of the different use cases in chapter 4, the remanufacturing processes of steel, aluminium as well as carbon fibre composites were detailed in chapter 5. Important to be noted is that the metal reprocessing is an extension of processing, which is a process that is far more advanced and established. In comparison thermoplastic composite processing (thermoforming) of high-temperature materials like the ones used in the process is still in the early stages of development and the maturity level is still low. Nonetheless, both technologies offer huge promise for material reuse and thus environmental sustainability.
In chapter 6, all the digital tools that are being developed in the project are reviewed individually at a component level. The current level of maturity of each tool is demonstrated along with the interdependencies and interplay, as well as its relation and pathways how it helps the project achieves its goals. A table of Key performance indicators and targets of each developed technology are also included to demonstrate the success level of each component quantitatively.

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