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Deliverable D3.7. Digital Fablab Kit

Fraunhofer FIT

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Abstract	This deliverable is an extended version of deliverable D3.6 which reports about diverse activities that are all aiming at improving FabLab-internal processes. This involves improving training processes and supporting the interaction of users engaged in a co-creation/co-production activity. This mainly includes the Knowledge and Training Framework, the Process Automation Tool and the Training Support Tool. The focus of the new version is on software tools and components developed in the frame of T3.4.

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Executive Summary

This deliverable is an extended version of deliverable D3.6 which reports about diverse activities that are all aiming at improving FabLab-internal processes. This involves improving training processes and supporting the interaction of users engaged in a co-creation/co-production activity.

We conducted user research to find out about needs towards training and production modelling. This is the baseline for all activities in the scope of this deliverable.

The knowledge and training framework revolves around training concepts that teach makers how to get from idea to prototype in a more human-centered way. Two training sessions are defined: The Design Thinking Introduction for Makers and the Human-Centered Prototyper. Furthermore, training material for additive manufacturing has been created and used for conducting a training on that topic. Finally, a framework for teaching Fused Filament Fabrication (FFF) 3D-printing is defined.

The Process Automation Tool acts as an orchestrator of the collaboration between the actors of co-design and co-production. It is primarily targeted to processes with some underlying 'structure', that is the business logic of this interaction can be formalized in a BPM model and repeated over different products. We show an example of this interaction with the application of the Process Automation Tool on the Spanish cMDF.

The Training Support Tool is a software, which bundles the subcomponents cMDF Training View, cMDF Training Flow, Video Intelligence and Digital Twin Development Kit. All subcomponents are integrated so that the user can navigate from one component to the other. A plan is laid out, how the Training Support Tool will be applied at OpenEdge.

This deliverable reports additionally about the further development and integration work related to the Training Support Tool and to the Process Automation Tool. The resulting software components are also part of this deliverable.

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List of Abbreviations

3D	3-dimensional
AM	Additive Manufacturing
AWS	Amazon Web Serivces
API	Application Programming Interface
APK	Android application package
AR	Augmented reality
BPM	Business Process Management
BPMN	Business Process Model and Notation
cMDF	collaborative Manufacturing Demonstration Facility
CAD	Computer-aided Design
CNC	Computerized Numerical Control
CRUD	Create, update, delete
DLP	Digital Light Processing
DT	Digital twin
DED	Direct Energy Deposition
EB	Electron-beam
EWF	European Federation for Welding, Joining and Cutting
EIT KIC	European Institute of Innovation & Technology, Knowledge and Innovation Community
FDM	Fused Deposition Modeling
FFF	Fused Filament Fabrication
GUI	Graphical user interface

MVP	Minimum viable product
NLP	Natural Language Processing
NLU	Natural Language Understanding
OP	Operating procedure
PDE	Process Design Execution
ProM	Prototyping lab of Trentino Sviluppo
REST	Representational State Transfer
SLM	Selective Laser Melting
SME	Small or medium-sized enterprise
SLA	Stereolithografie
TPU	Thermoplastic polyurethane
UI	User interface
VR	Virtual reality

1. Introduction

This Deliverable describes the diverse activities of the iPRODUCE task *T3.4 - Digital Fablab Kit and Production Workflow and Simulation*. These activities are related directly to the processes inside a FabLab or a maker space. All activities aim at improving different internal processes, which the iPRODUCE consortium has identified within the six cMDFs. However, the individual objectives are quite diverse and therefore we divide the T3.4 results into three main parts.

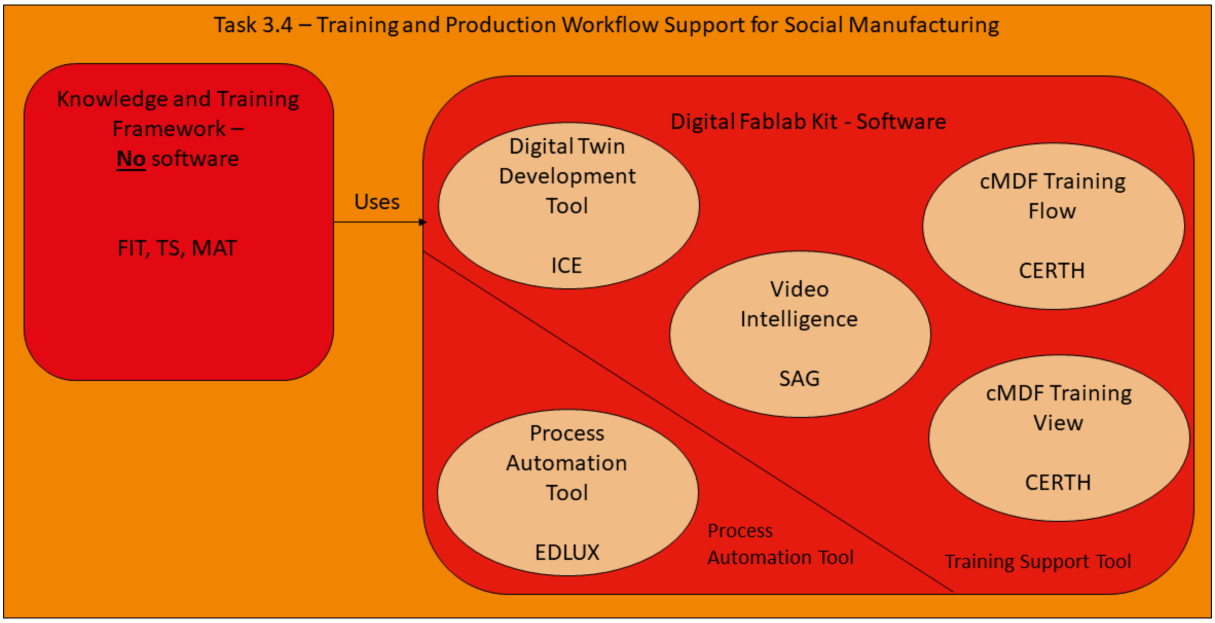

Figure 1: Structure of the T3.4 results

First of all, we divide between a part in which software is developed and another part in which training contents and methods are developed. We call the software part the *Digital Fablab Kit* and the non-software part the *Knowledge and Training Framework*. The Digital Fablab Kit must be again divided into two parts. Firstly, there is the *Process Automation Tool* - a software tool that helps modelling FabLab processes. Secondly, there is the *Training Support Tool* - a software tool that supports training processes within maker spaces. As such, the Training Support Tool is partly used by the Knowledge and Training Framework. The described task structure is depicted in Figure 1.

This Deliverable is structured in line with the T3.4 structure. But first, we start in Chapter 2 to report about how the requirements for the T3.4 activities were gathered. Then, we describe the current results of the Knowledge and Training Framework in Chapter 3. In Chapter 4, the Process Automation Tool is presented. Chapter 5 details the current results of the Training Support Tool, with the main subcomponents *Digital Twin Development Tool*, *Video Intelligence, cMDF Training Flow* and *cMDF Training View*.

2. Analysis of FabLab-internal Process Needs

This chapter describes how the need for the T3.4 activities were gathered and how they were converted into feature requirements for the T3.4 results.

2.1. Training Needs

Training people how to use machinery is a major part of the work within maker spaces. In order to understand the pain points during those training processes, we started an interview series with four representatives from the three cMDFs in France, Germany and Denmark.

The interviews were set up as semi-structured online interviews over Zoom. Each interviewee was confronted with one interviewer and one notetaker. All interviewees had hands-on experience in training processes because they take the trainer role in their respective maker spaces.

After the interviews, we analysed the responses by reviewing and clustering them. As a result, we identified nine different pain point clusters. Nearly all of them were mentioned by more than one interviewee. More details about the identified pain points can be found in Table 1.

Table 1: Training pain points

#	Pain Point	Description
1	Asynchronous information exchange	Complex tools (like CNC machines) with a lot of traffic require asynchronous information exchange between multiple users in order to ask questions about who has experience with specific use procedures and to share reference data files with course participants.
2	Predefined settings / best practices exchange	Complex tools (like CNC machines) allow for a large variety of settings. The users exchange those predefined settings / best practices in order to save time when performing similar and recurring tasks.
3	Reference files up to date	The reference files (tool library) provided by the instructors need to be updated regularly, and users need to make sure that they use the latest version.
4	Safety instructions & access control	Users need to understand and sign safety and security instructions before using the machinery. Machinery access control is required.
5	Starting and closing instructions are FAQ	Instructors need to repeat starting and closing-down instructions often.
6	Understand the mode of operation	Users need to understand the machines' mode of operation - to then optimize their use and production.
7	User pre-selection	Users need to have a basic skillset (e.g., handling CAD program, study engineering) to get access to machinery.
8	Administrative support for participant management	Instructors need administrative support for participant management, including payment, cancellation, and material/information providing options.
9	Project documentation	Instructors need to document their projects, as their expertise increases with every project completed.

2.1.1 Ideation on how the identified needs can be addressed

We followed up with an ideation session for creating ideas how the pain points listed in Table 1 can be addressed by iPRODUCE tools. Participants from the German and Danish cMDF were present as well as people with the necessary background knowledge about the potential capabilities of the T3.4 tools. The ideation session was hold online using MURAL[1] as a virtual whiteboard.

Figure 2: MURAL board as high-level impression of the ideation session

[1] https://www.mural.co/

We listed the nine pain points with their descriptions on the MURAL board. In the first step, we brainstormed for potential solutions for these pain points without restricting ourselves about the T3.4 tool capabilities.

In the second step, we reviewed the brainstorm results and tried to filter and map them to the T3.4 tool capabilities. During this step, we already divided the solutions between the Training Support Tool and the Knowledge and Training Framework. Figure 2 gives a high-level impression of the ideation results on MURAL. Results are detailed in Section 2.1.2.

2.1.2 Tool Feature Requirements as Ideation Results

As basic functionalities, the Training Support Tool should allow for the creation, management and provision of virtual training material. The training material would be:

- Use procedures and manuals
- Predefined settings and reference data files
- Best practices
- Mis-use-cases and worst practices
- How to handle errors
- Safety and security instructions
- Machine maintenance
- Explanations about the internal functioning of machines
- Instructions how to start and close down machines

Table 2: Feature requirements for main components of the Training Support Tool

Component	Feature Requirements
cMDF Training View	• Connection of virtual training content to physical machine • Visually appealing and fun provision of instructions • AR functionality for demonstrating instructions
cMDF Training Flow	• Training content authoring
Video Intelligence	• Video tutorials • Video collections • Search within videos • Search within video collections
Digital Twin Development Tool	• Simulation of machine behaviour without the risk of damaging machines • Explanations about the internal functioning of machines • Playful machine introduction • Simulation of production settings • Demonstration of mis-use-cases
Knowledge and Training Framework	• Knowledge proofs before being allowed to operate a machine, e.g. skills certificate about basic use and safety • Dedicated trainings about how to get from idea to prototype in a more human-centered way • Training focus on additive manufacturing

Furthermore, some concrete feature requirements were thought out for the main components of the Training Support Tool as indicated in Table 2.

2.2. Process Automation Tool User Needs

The Process Automation Tool is used, under iPRODUCE, to orchestrate the co-design and co-production process. Since its operation is based on the model of the underlying process, the tool is adapted to the normal way of co-designing / co-producing, which is followed by the particular type of cMDF examined. The 'type' is associated with the nature of the end-products, i.e., the industry-type (furniture, automotive, medical, hobbyists, etc.) and the size of the involved entities (manufacturing companies, individuals). The Process Automation Tool is intended to cover as many co-development processes as needed. The tool focuses on the cMDF that develops consumer products with the participation of industrial end-users.

FabLabs and maker spaces have proven to be particularly appealing to single users or small teams with an interest to quickly prototype their ideas. These processes often include cyclic iteration of the design thinking process, that is understand user-needs, define them, ideate, prototype and test phases. When this approach is brought to the industrial production context, that is in an environment where actors are industry professionals, this interaction assumes a more concrete structure, which can be defined in a Business Process Model. The goal is the same, to engage in cycles of co-design and co-creation, but the difference is that the actors' responsibilities are clearly delineated, the process from ideation to prototyping has a defined structure and the methods used are inherited from the standard day-to-day practice.

The Process Automation Tool delivers value to the actors when (a) the workflow can be brought to a BPM type of model and (b) the interaction between the actors can be digitized. Based on an 'industry standard' the Process Automation Tool has been tested extensively and accepted by actors from the industrial domain in similar EU-projects.

The composition of the Spanish cMDF, in terms of the professional activity of the actors implicated, is directed towards the industrial domain:

- AIDIMME provides engineering, quality verification and standardization services for products targeting the industrial domain (furniture)
- LAGRAMA is a producer of furniture
- VLC is a FabLab with expertise in the design and prototyping

Based on the scenarios defined by the Spanish cMDF, the application of the Process Automation Tool has been investigated in terms of user requirements by starting from the actors' day-to-day workflow. Figure 3 in the following, depicts the first version of the users' interaction (as seen from the end-users' side). It implicates four entities: (a) AIDIMME, (b) LAGRAMA, (c) VLC and (d) target group (to provide feedback on the final prototype).

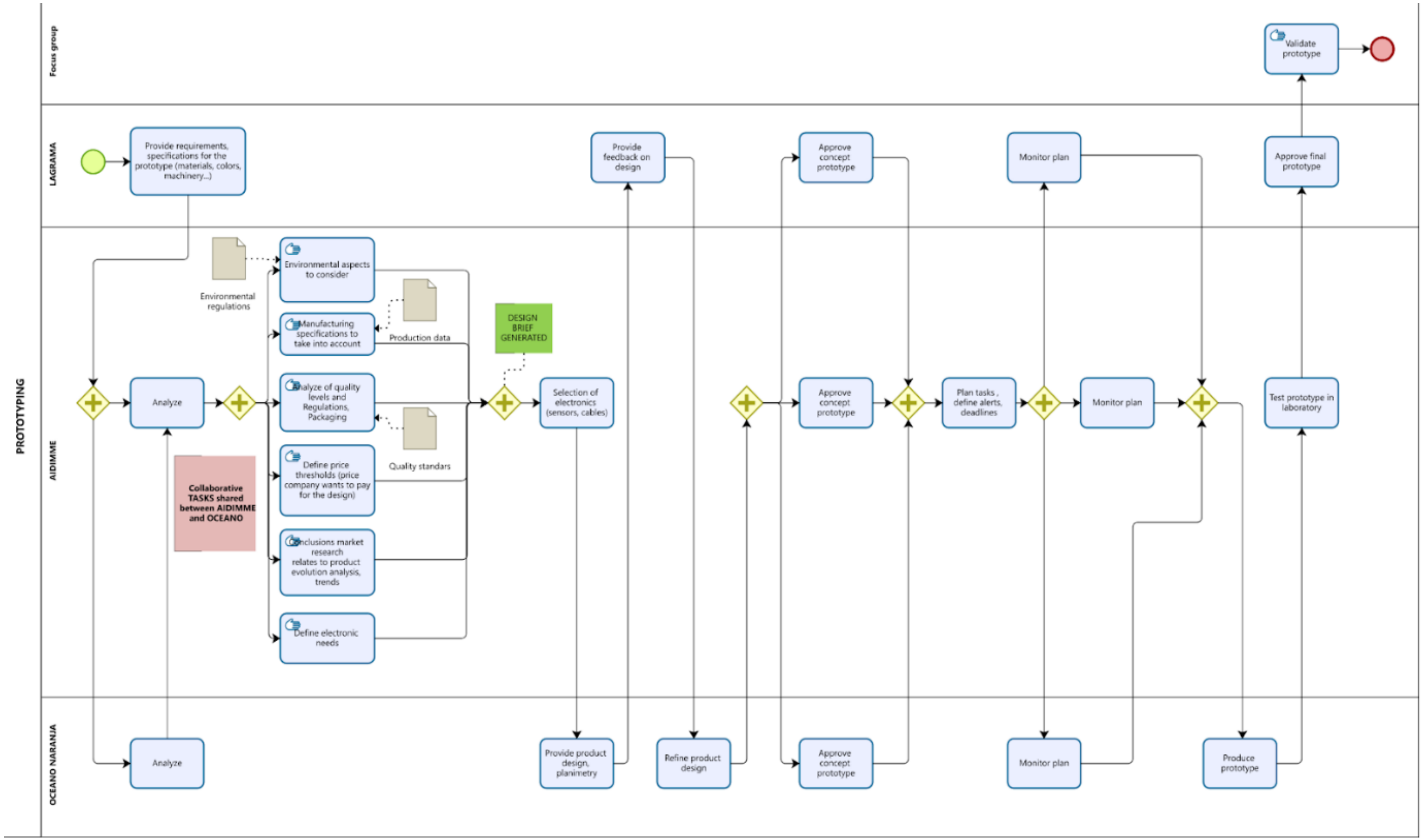

Figure 3: Business Process Model from the end-users' side

The workflow and the specific user requirements have been discussed with the end-users in a collaborative way (using online digital canvas tools and BPM modelling tools), as shown in Figure 4.

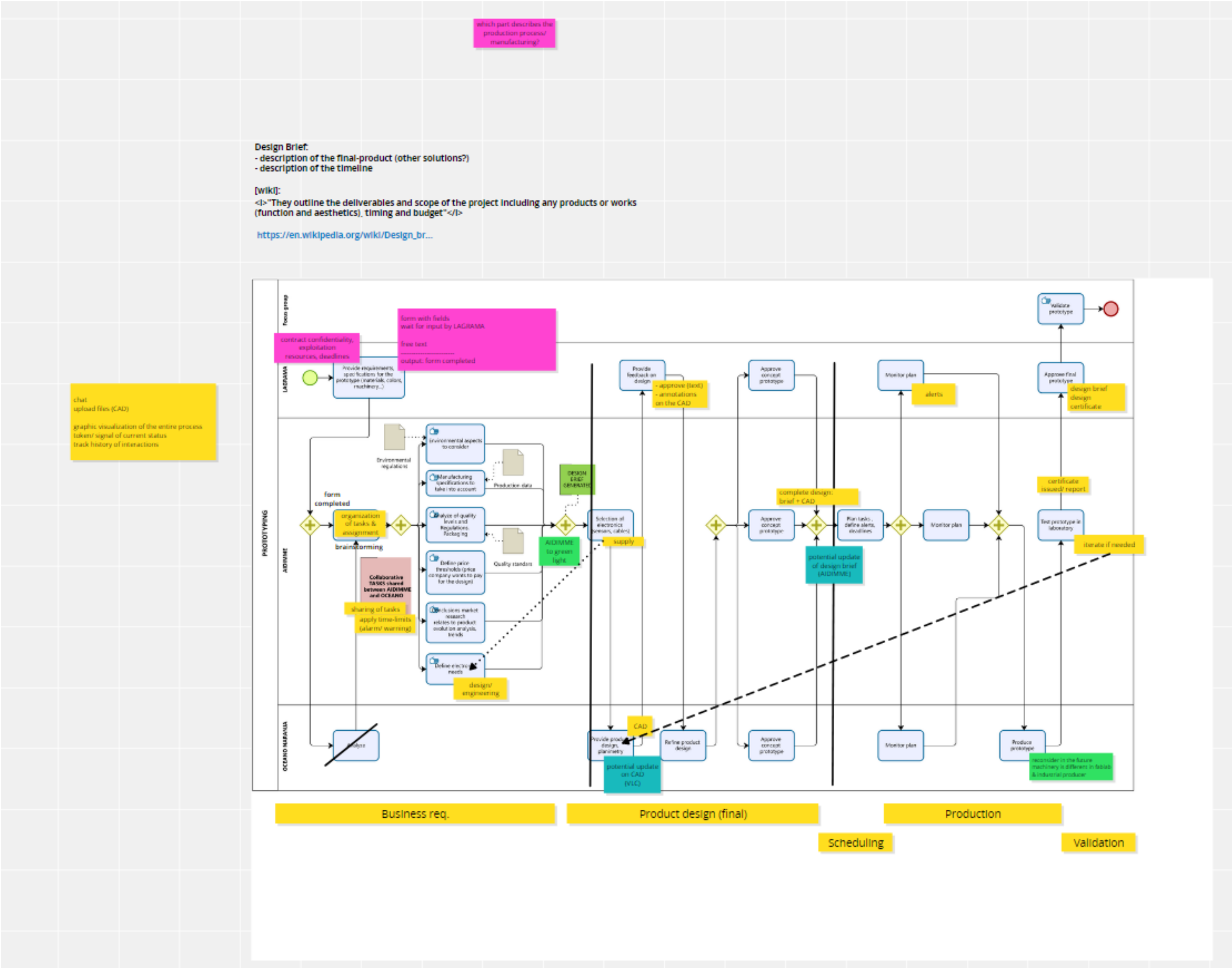

Figure 4: Working on the workflow modelled by the Process Automation with the end-user

In broad terms, this requirements elicitation activity resulted in the following points:

- The production process (from ideation until the delivery of the prototype) can be grouped in four sets of activities; each phase ends with a clear result:
    1. Definition of the product's requirements: the result of this interaction among users is the definition of a set of product requirements that are summarized in a document named 'design brief'; it considers all aspects covering aesthetics, usability, compliance to engineering standards & environment protection regulation [result: design brief]
    2. Definition of the final design of the product, considering all specification and restrictions from the design brief (for example with respect to the selection of the materials used, presence of electronics, etc.) [result: product design]
    3. Organization and scheduling of the prototyping process: definition of the stages for the delivery of the prototype and scheduling for proper monitoring of the prototype's production [result: production plan]
    4. Prototype production, testing and delivery - including lab test and focus group validation [result prototype]
- The actors have distinct roles in the process, i.e., 'customer' (LAGRAMA), 'engineering manager' (AIDIMME), 'designer' & 'developer' (VLC), but the interaction between the actors can be iterative in some of the production phases (for example a design/ CAD model is passed over the relevant actors in a loop as new ideas are evaluated)
- The process is not necessarily linear, there are situations where sections of the design brief or the design need to be updated (thus creating a branch in the BPM from one state to past states)
- Multiple prototyping processes can happen in parallel: the prototyping is not sequential (one product after the other), but different products may be at different stages of the prototyping process
- The main problem in this interaction is the communication between the actors: the collaboration between the actors requires the exchange of files, messages (currently done by e-mails) and speech interaction (phone calls) - mainly for monitoring and reminding the assigned responsibilities

These points were used to derive the digitized version of the process model, which is described in the next Section. The main value proposition of the Process Automation Tool towards the end-users of the Spanish cMDF is that actors co-create in a structured way, this way enabling them to carry-out multiple activities in parallel without losing track of their progress and without sustaining delays due to improper coordination. Following the finalization of the adaptation of the process automation tool for the Spanish cMDF, other relevant use-cases will be explored within the project.

3. Knowledge and Training Framework

The Knowledge and Training Framework represents the non-software part of the iPRODUCE task 3.4. In Section 3.1, we report about two trainings, which have been tested and evaluated. Section 3.2 presents training material for additive manufacturing and the training session that used this material. Section 3.3 describes the concept for a training on Fused Filament Fabrication 3D printing.

3.1. Human-Centered Method Trainings for Maker Spaces

As laid out in Chapter 2, one of the identified feature requirements was to set up training sessions that teach makers how to get from idea to prototype in a more human-centered way. This is because makers often do not have knowledge about such approaches and develop “in the wild” instead. This can often cause good ideas to fail because they are not tailored enough to the actual users’ needs.

In order to address that feature requirement, we have set up and tested two trainings from the Design Thinking background. Both trainings were adopted to the specific maker space settings.

3.1.1 Introduction Design Thinking for Makers

Many makers and in general many people, do not know much about methods which help assure that developments are better oriented on users’ needs. So, the *Design Thinking for Makers* training is meant as an entry point in human-centered development processes in general and Design Thinking in particular. It teaches a particular mindset of always putting users and other stakeholders to the center of development activities. And it teaches selected methods for different phases.

As we found out during a focus group session with Makerspace Bonn people[2], makers see most potential for improvement in the earlier phases of the process, whereas they feel quite confident about their skill in prototyping and evaluating. So, we focussed the Design Thinking for Makers training on the first phases of the Design Thinking process, namely empathize, define and ideate. The phases prototype and evaluate were just briefly mentioned.

The training session took place as a one-day online training over Zoom. We used MURAL[3] as a virtual whiteboard. Five persons from the ecosystems of the German and French cMDFs participated.

Figure 5: General Design Thinking principles

[2] Focus group session is described in Section 3.2 of Deliverable D5.11 - Collaborative Testing and Training, M18
[3] https://www.mural.co/

After a warmup exercise, we first introduced general principles of Design Thinking, explaining the different phases and the double diamond metaphor (cf. Figure 5).

After presenting the challenge for the day and motivating the empathize phase, the participants had to perform two exercises. After reflecting about their own experiences, they had to perform semi-structured interviews and document the results on the MURAL board (cf. Figure 6).

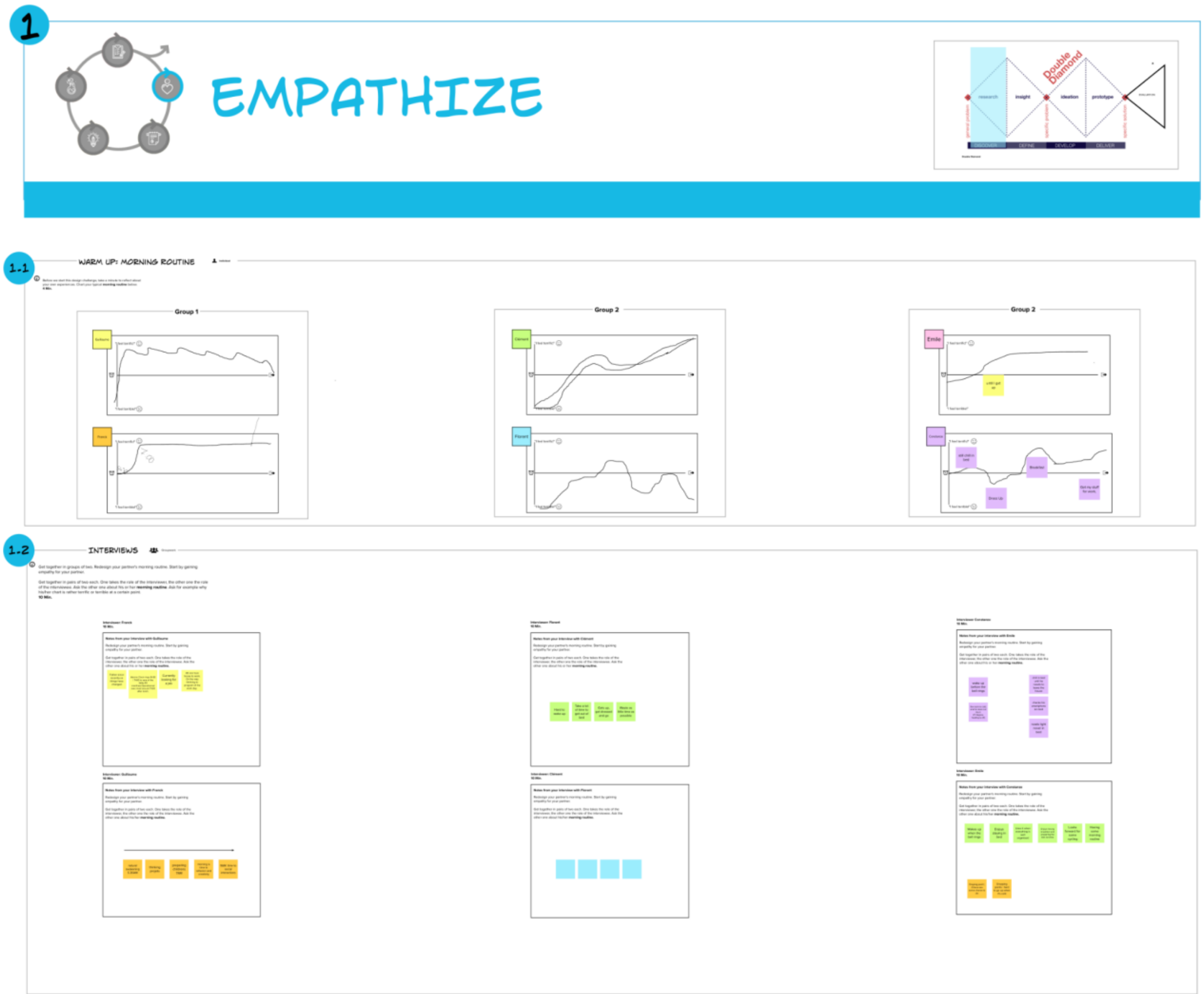

Figure 6: “Empathize” exercises (details not relevant)

The Define phase was also introduced by a theory part before the participants had to perform another two exercises. First, they had to structure and reframe the statements of their interview partner, using a template around *goals & wishes* as well as *pains & gains*. After that, they had to define a problem statement. An impression of the exercises is shown in Figure 7.

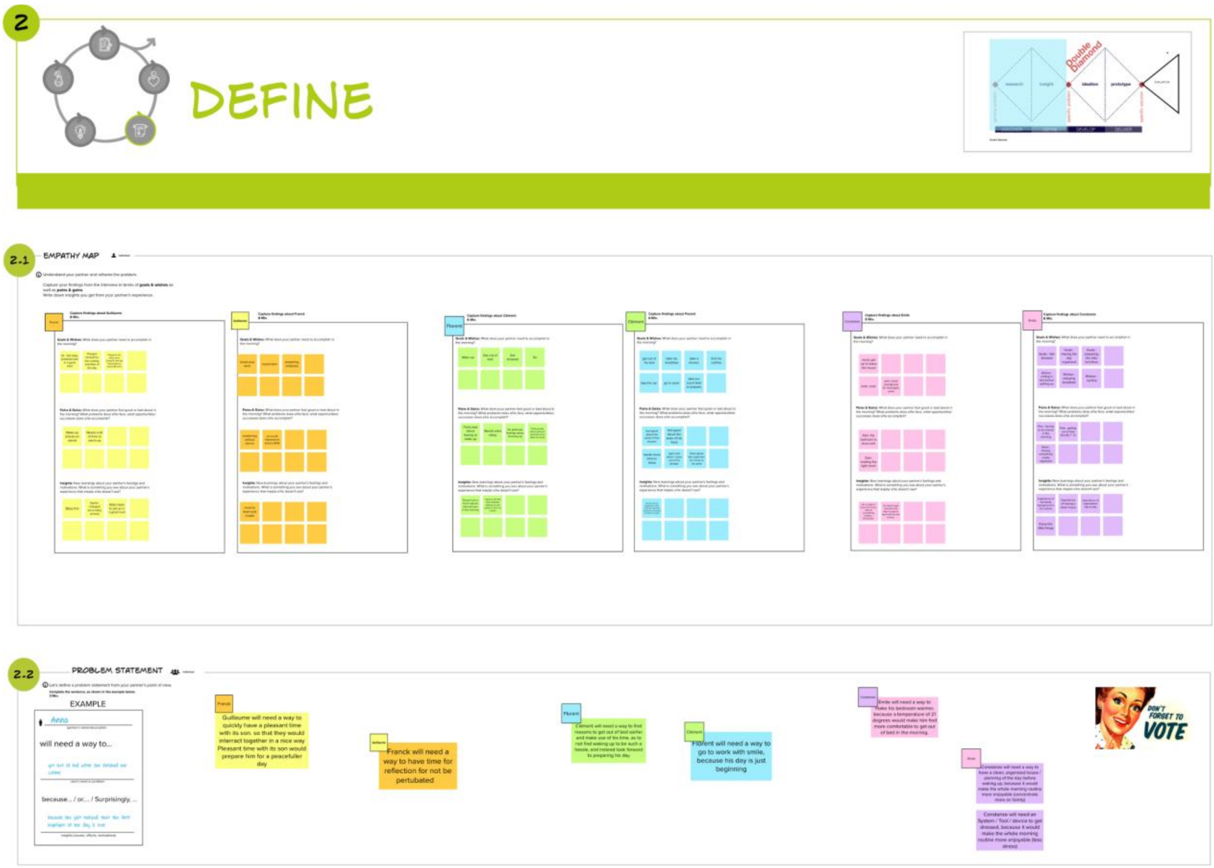

Figure 7. “Define” exercises (details not relevant)

The ideation phase had a similar setup as the two phases before. After a theory part, two exercises had to be performed. A brainwriting was followed up by an “Optimist vs. Pessimist”[4] session for assessing the ideas. The results are shown in Figure 8.

[4] For details of this and other methods, please refer to Section 3.5 of Deliverable D5.1 - Assistive and Collaborative Designing Methods and Tools

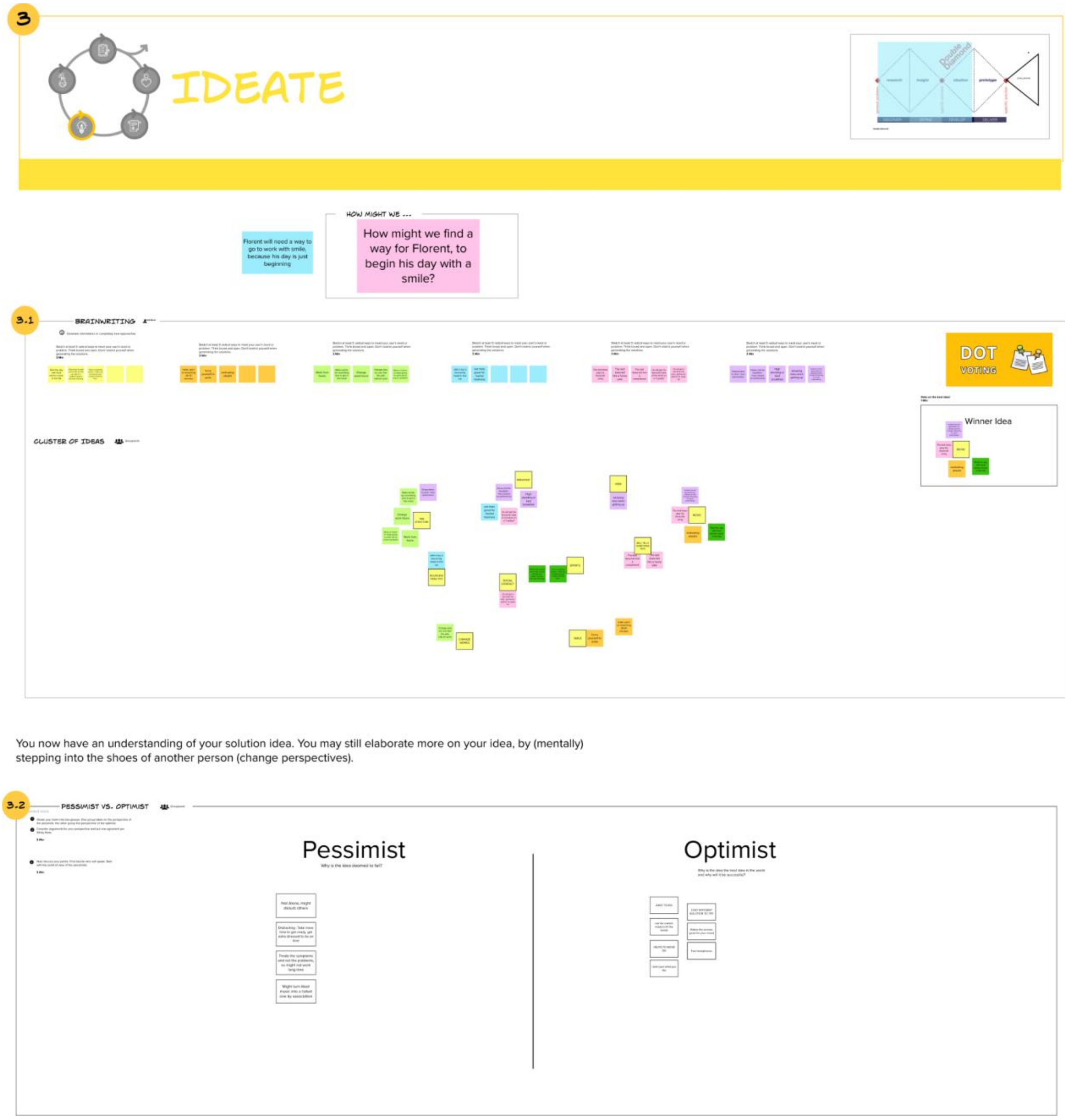

Figure 8: “Ideate” exercises (details not relevant)

We ended the training with a feedback session to understand potential improvement points. All given feedback was positive. In particular, the general experience of the training was positively mentioned. Also, participants said, they wish to directly follow up with practical ideas.

In conclusion, the given format seems to be fitting for teaching maker spaces to develop in a more human-centered way. The wish to follow up with practical ideas and our impression during the workshop of the ways to prototype in maker spaces let us come to the conclusion that (in contrast to the focus group findings mentioned above) a dedicated training on human-centered prototyping would be useful for makers as well.

3.1.2 Human-Centered Prototyping

Maker spaces are mainly about prototyping, but very focused on 3D prototypes and rather high-fidelity prototypes. There is a lack of understanding for earlier steps of low- and medium-fidelity prototypes as well as prototyping for services and digital products. The Human-Centered Prototyper training was designed to address these issues.

The training aims to teach how to design, test and improve a low and medium fidelity prototype quickly and with simple tools. This involves the prototypical development of services and business models, digital products and haptic products.

Participants are informed about different approaches, their objectives and methods that they can use in prototyping and that they will be confronted with in practice. These are the design thinking, service design, lean startup, human centered design and product design approach. Thus, the acquired competence consists primarily in the planning, creation and further development of low and medium prototyping of products and services.

The training session took place as a three-day online training over MS Teams. We used Miro[5] as a virtual whiteboard. Three persons from the ecosystems of the German and French cMDFs participated. Table 3 shows the agenda of the training.

Table 3: Agenda of the Human-Centered Prototyping training

Description
Introduction to Human Centered Prototyping ● Importance of human centeredness for prototyping ● Known disciplines and approaches in the context of prototyping ● Overview of methods and tools in prototyping ● Overarching principles for the development of good prototypes

Creation of human-centered services and business models
● Methods to develop a seamless service experience
    ○ Storyboard, user journey mapping, customer journey mapping, service design blueprint
● Methods to design a business model
    ○ Value Proposition Canvas, Business Model Canvas

Testing of human-centered services ● Methods to test a service and develop it further based on the test results   ○ Desktop walkthrough

Creation of human centered digital products
● Approaches to visually and quickly design prototypes
● Methods to develop step-by-step prototypes
    ○ Wireframe, page flow (as a paper prototype)
● Methods to test prototypes
    ○ Wizard-Of-Oz, Thinking aloud

Best Practices and Challenges

In contrast to the Design Thinking for Makers training, the Human-Centered Prototyping training is too extensive to report every step in detail, so Figure 9 and Figure 10 are meant to give an overall impression of the Miro session and one exemplary exercise.

[5] https://miro.com

Figure 9: Overview of the Miro session on Human-Centered Prototyping

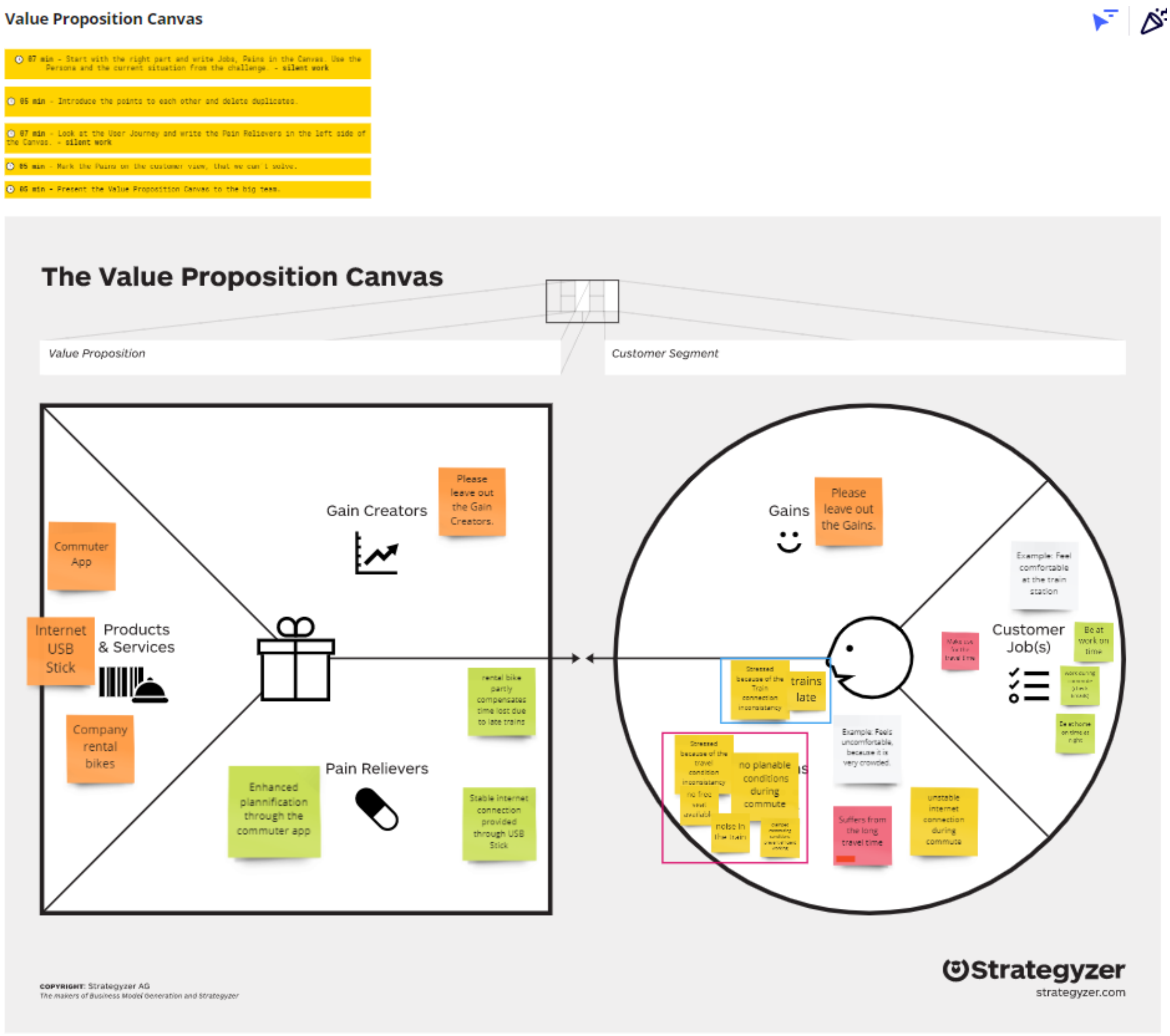

Figure 10: Value Proposition Canvas as exemplary detail of the Miro session on Human-Centered Prototyping

Evaluation

We collected feedback in three different ways. First of all, we introduced feedback sessions after every main block of the training in which we asked the participants to create sticky notes according to the categories:

- What was new to you?
- What was surprising for you?
- What did you miss?
- What do you see critically?

This way, the participants had to reflect and verbalize about the most recent part of the training. Figure 11 shows one of those boards.

Figure 11: Reflection session after the service and business model block on Miro

Similar to the reflection session after each block, we added a reflection session at the very end of the training. There, the participants were asked to verbalize their overall impression of the training (in contrast to just the block before, described in the previous paragraph). The trigger questions were a little different, namely:

- Who would you recommend this training to?
- Would you do an exam after the training to get a certification?
- Is there a maximum duration that you would accept for a training?
- Do you have any concrete suggestions for improvement that you would like to share with us?
- What do you think about this training being remote?

- Can you use what you have learned in your professional practice?
- Did the training meet your expectations? Did you find the name “Human-Centered Prototyping” appropriate?

Higher level trigger questions were added as “Five Finger Feedback”:

- What did you like?
- What did you find remarkable?
- What did you not like so much?
- How did you feel during the training?
- What did you miss?

Figure 12 gives a high-level impression about this session.

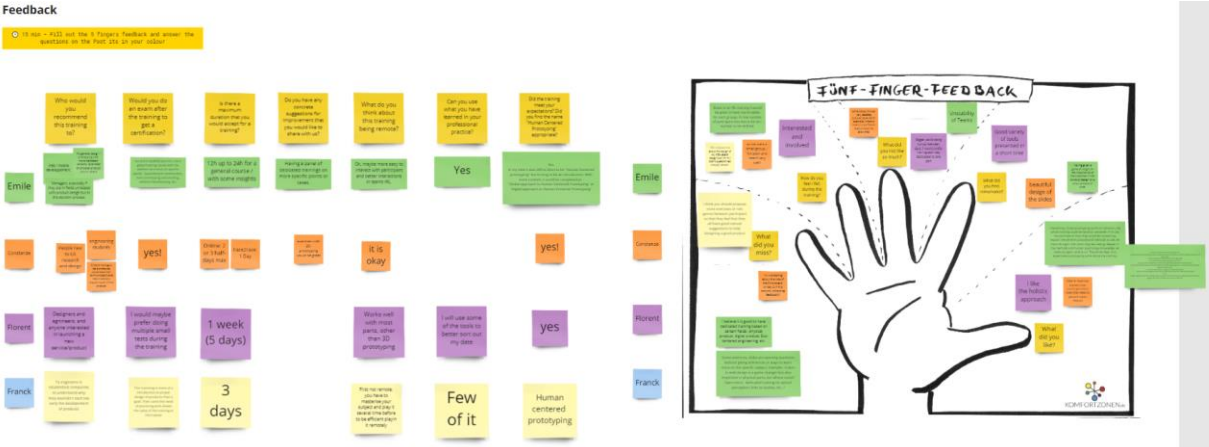

Figure 12: Retrospective exercise (details explained in the text)

Finally, we used the observation method for evaluating the training. First of all, we conducted the training with two trainers who alternated with each session. The trainer who was passive at a particular session, observed and took notes. Furthermore, a third iPRODUCE member took part as participant and also observed and documented insights from the participant perspective.

As a summarized conclusion on high-level: In general, all participants perceived the training as very useful and relevant for the job in the maker scene. The suggestions for improvement mainly revolved around higher-level and detailed process representations of prototyping and its embedding in the design thinking process; a continuous example as well as practical examples regarding 3D printing. Going deeper, we identified the problem that people usually just think of 3D prototypes (in contrast with digital or service prototypes) under the term prototyping. As a consequence, we will not divide the different types of prototypes so much in further iterations; we will set up the training by explaining prototyping as a process that consists of several steps instead. Furthermore, the use of a continuous, practical example would give the participants additional guidance. One concrete idea for a practical 3D prototyping exercise is to let the participants create a shape in TinkerCAD, to download the resulting model file for viewing it on their computer and to order it on imaterialize[6] so that the participants have a nice physical takeaway after the training.

[6] https://i.materialise.com/en

3.2. Additive Manufacturing Training Material for professionals and SMEs' personnel

3.2.1. Training Material for Additive Manufacturing

ProM Facility (the prototyping lab owned by Trentino Sviluppo and hosted in its Business Innovation Centre of Rovereto, named "Polo Meccatronica") has more than 4 years' experience in supporting industry, professionals and SMEs in prototyping activities. Moreover, it also supports students - mainly from the University - with hands-on sessions of training and coaching on prototyping technologies.

Figure 13: ProM Facility was inaugurated in June 2017

On the basis of their competences and long-lasting experience on the field, the experts of ProM (PhDs, technicians, professionals with master's degree) have developed training materials on advanced additive and subtractive manufacturing metallic machines as well as training materials on additive manufacturing, training methodologies, lessons learnt in the daily work with final clients.

In particular, the training material has been created for three main target technical profiles. The modules, that are compliant with EWF Qualification System[7] are customised for the following three profiles:

- Product Engineer (with a focus on the design, characterization and acceptability of the product)
- Process Engineer (with a focus on the optimization, monitoring and qualification of the process)
- Manager (with a focus on the implementation of AM technologies into the company, the supervision of AM adoption and the overview of market trends and opportunities).

The materials are based on the follow up of a previous project, named LILIAM and funded by EIT KIC Raw Materials where teaching materials and methodologies were developed for technicians, designers, engineers willing to learn more on additive manufacturing.

[7] European Federation for Welding, Joining and Cutting

The trainee should be able to understand the functioning principles of all major Additive Manufacturing process categories, for metals and non-metallic materials, their pros and cons, applicative fields, technology drivers and workflows. As well as market trends and a full picture of major innovation trends.

Topics developed concern:

- Overview of 7 main categories of AM processes, their basic working principles, applications, pros and cons
- Metal additive manufacturing
    - Powder bed fusion (laser and EB)
    - Direct energy deposition (laser, EB, arc)
    - Binder jetting
    - Extrusion
- Non-metal additive manufacturing
    - Material extrusion
    - Material jetting
    - Vat photopolymerization
    - Power bed
- Workflow for various AM processes
- Overview of applications, pros and cons
- Market trends, main developers, foresight

3.2.2. Training experience

One training session took place as a three-day physical training in the ProM Facility. Nine people - SMEs managers and technicians - from the Italian cMDF ecosystem participated.

Figure 14: Theoretical sessions in the classroom

Classroom sessions were performed for the theory (Figure 14), whilst hands-on sessions were run using the ProM Facility machines (Figure 15).

Figure 15: Hands-on session using an additive laser machine.

The topics specifically covered in the training are reported in the following:

Day I

- ProM Facility Structure presentation and iPRODUCE short introduction
- Introduction to additive polymer technologies
- FDM In-Depth Analysis
- Care / toolpaths / filling
- File Types for AM
- Sla/DLP In-Depth Analysis
- Casting of material
- Multi-jet fusion
- HP (Hewlett Packard) technology explanation on board the machine
- Magic for HP

- Nesting
- TPU printing
- Examples of Products objects
- FormLab SW Samples
- SLA/DLP Machine vision in the laboratory
- Mechanical characteristics of polymeric materials
- Post processing techniques

Day II

- TPU Job Removal
- Introduction to Metal 3D Printing
- Magics and supports
- Economic considerations
- Design for Additive Fusion360
- Visit to SLM printers
- Dust management
- Machine preparation and printing
- AM Applications
- Customization, Rapid prototyping, Spare Parts, Maintenance
- Tooling, Production, Art, Design, architecture Performance improvements.
- Post processing in metal Additive Manufacturing
- Ntop (Network top)

Day III

- JOB SLM Removal
- Reverse engineering / 3D scanning / X tomography
- Reverse engineering / 3D scanning / X tomography
- Introduction to DED Technology
- NX and hybrid manufacturing
- Reference regulations reference about Additive Manufacturing
- DMG MORI LASERTEC Machine
- Final test and corrections

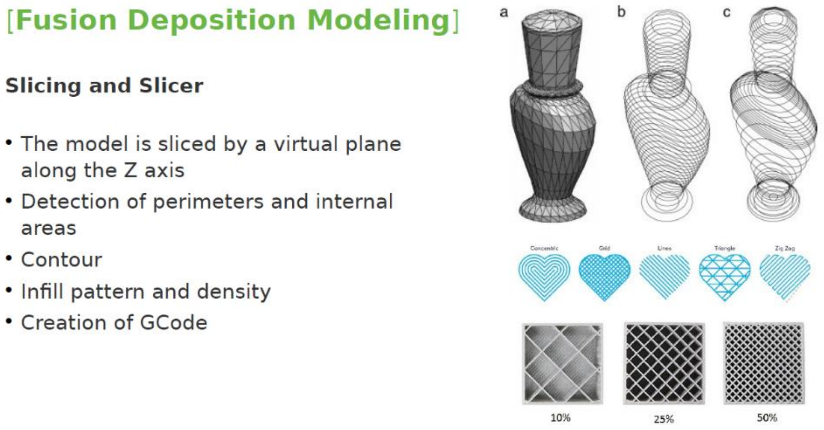

Figure 16: Example of training material on fusion technology

3.2.3. Training Evaluation

A customer satisfaction questionnaire was created and administered to the training participants. It included three evaluation sections, containing specific questions. In the following the evaluation sections and the questions are reported:

The training experience as a whole

- Q1.1 Were the topics covered important for your work?
- Q1.2 Were the topics treated with the right level of detail?
- Q1.3 Was the duration of the course appropriate?
- Q1.4 Was the time devoted to the discussion with the participants sufficient?
- Q1.5 Were the objectives of the course clear and were they achieved?

Training materials evaluation:

- Q2.1 Was the teaching material clear and legible?
- Q2.2 Was the teaching material complete and adequate for the learning objectives?

Trainers and trainer methodology evaluation

- Q3.1 Did the teacher speak clearly and competently?
- Q3.2 Did the teacher adequately answer the questions and encourage the attendance of those present?
- Q3.3 Did the teacher use the time efficiently?

Each question was to be answered by choosing one of the following standardised responses:

- I fully agree (High score)
- I partially agree (Medium score)
- I don't agree (Low score)
- I don't know

The participants were also asked to suggest other topics of their interest, in order to evaluate the possibility of extending the current topics with new ones.

3.2.4. Evaluation Results

In the graph of Figure 17, the evaluation results of the course are reported. Furthermore, the participants suggested new training modules on industry 4.0, process sustainability, industry 4.0.

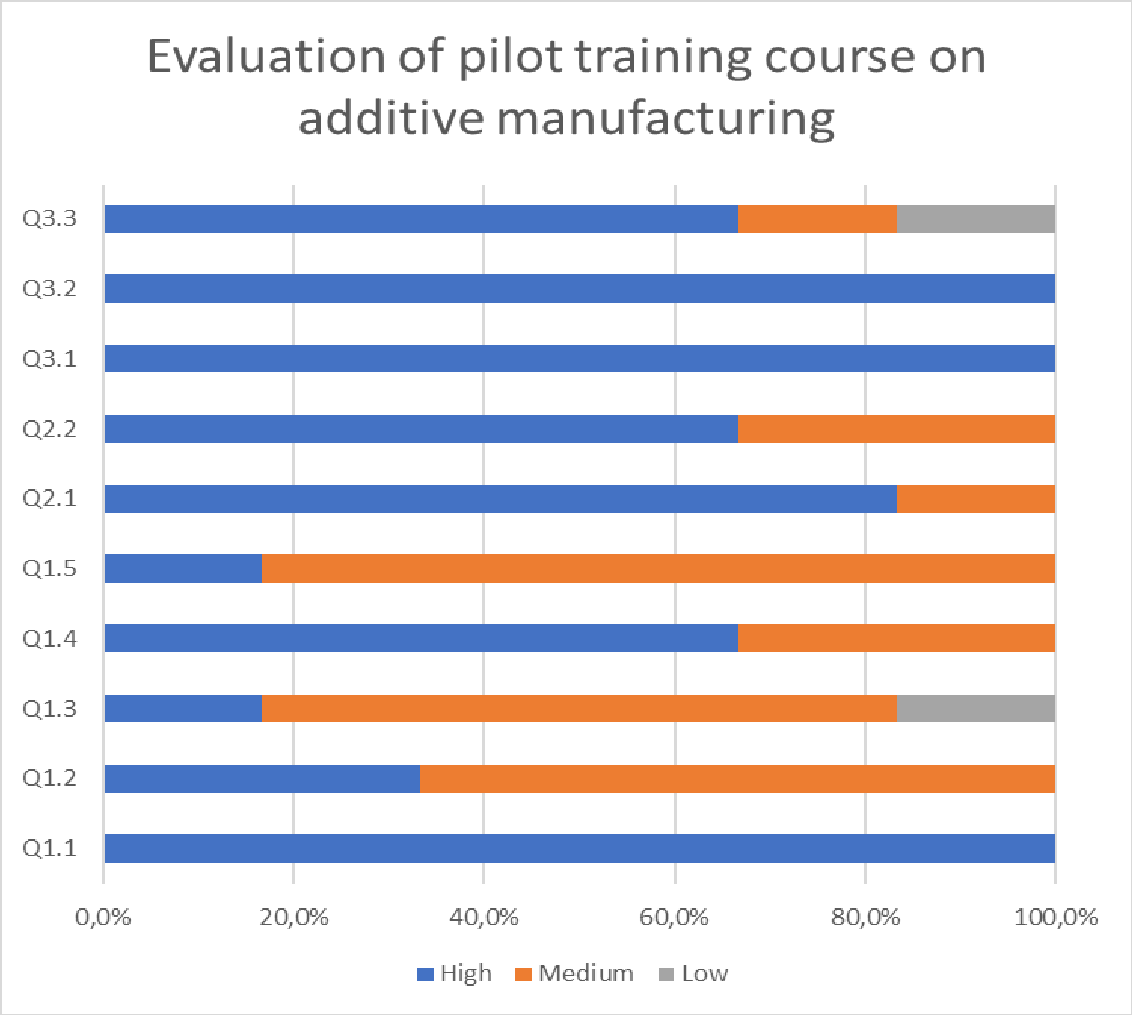

Figure 17: Course evaluation by participants

3.2.5. Lessons Learnt

Despite the persistence of the pandemic, Trentino Sviluppo organized a face-to-face course in its ProM Facility. This decision is due to the conviction that training in the use of machines must be carried out in person, in order to provide an effective approach for the participants of the course.

Of course, the tools currently developed in iPRODUCE (f.i. digital twin, etc.) could change this constraint and make the virtual experience effective also for hands-on sessions.

The theoretical lessons could be realized fully online, remotely, and iPRODUCE tools will be very useful.

Furthermore, they could also help Trentino Sviluppo to overcome the slightly weaker points that emerged from the evaluation questionnaire. In particular, a more appropriate duration of the course, as underlined in the answers to question Q1.3 and more focus on the course objectives as underlined in the answers to question Q1.5.

3.3. FFF 3D-printing training material for new users in FabLabs and Maker Spaces

FabLabs and Maker Spaces are of interest to people who want to develop a project as they offer access to skills, advice and machines.

Pain point #7 reveals that users need to have a basic skill set (e.g., handling CAD program) to get access to machinery.

In the current as-is situation, a new FabLab user is welcomed in person by a member of the FabLab in charge of transmitting knowledge and training in the use of the machines. For these members, it means repeating the same training to each new user, which has a low-added value in comparison with supporting the FabLab users in their projects.

However, FabLabs need to welcome new members to develop their activities. They need to facilitate access to their machines and their methods while reducing repetitive work with low-added value.

For this purpose, Open Edge worked with BetaFactory to develop specific training material for Fused Filament Fabrication (FFF) 3D-printing for new FabLab users. It consists of a 2-part training course:

- Online asynchronous learning that the user can follow at home (regardless of the FabLab's opening hours)
- Validation of the training in the FabLab with the FabManager or a dedicated FabLab member (reduction of repetitive work with low-added value)

The framework of the online training program is defined, but not implemented yet. It is made of 6 modules and each module must be validated before using a FFF 3D-printer in the FabLab:

- Module 1 – CNC machines in general
- Module 2 – Basic usage and safety
- Module 3 – Zoom on Fused Filament Fabrication
- Module 4 – Modelling with Fusion 360 (introduction)
- Module 5 – Slicing with Cura (introduction)
- Module 6 – Using a 3D-printer

General challenges:

- The validation of the modules 4, 5 and 6 requires the validation of a dedicated FabLab member: how can this time be reduced to a minimum?
- The creation of the training content is time consuming: how can this time be reduced to a minimum? could the users record their own videos according to a framework and share them?
- Should the FabLab rules and regulations be integrated into the training material?
- How to ensure that no one cheats on online validation?
- Which platform to use for online validation?
    - The platform must include corrections / feedbacks
    - The platform must allow for updates

Performance indicators:

- Time spent by a dedicated FabLab member with a new user
- Difficulties encountered during the practical application in the FabLab
- Number of machines used by one person
- Ease of use of FFF 3D-printers

A response must be made to the general challenges before implementing the training content into a platform. Then a plan should be developed for testing the training material with participants.

4. Digital Fablab Kit

The Digital Fablab Kit is a software platform including the Process Automation Tool and the Training Support Tool. The Process Automation Tool helps modelling FabLab processes whereas the Training Support Tool aims at supporting training processes within maker spaces. There is a landing page for the Digital Fablab Kit which is accessible under: *https://iproduce-tools.iti.gr/main/fablab*

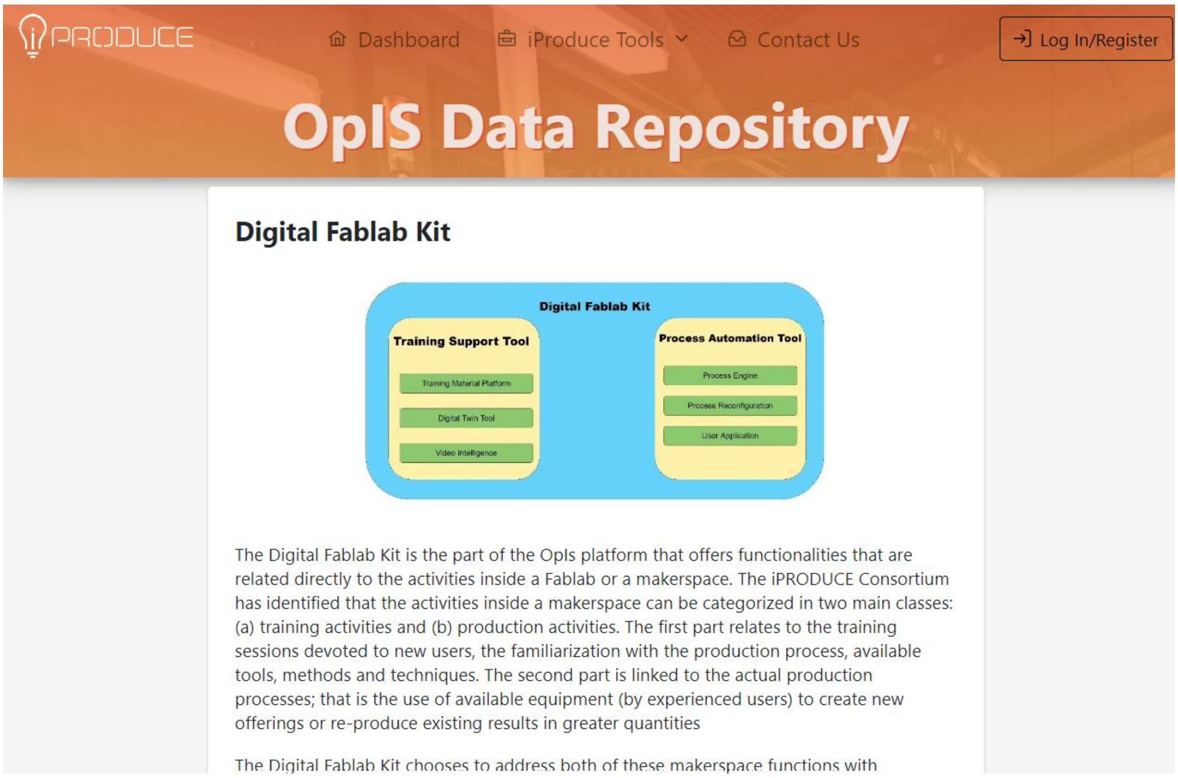

Figure 18: Digital Fablab Kit landing page

4.1. Process Automation Tool

The Process Automation Tool intends to automate the design and prototyping process of new products within the Spanish cMDF. It is an extension of the Manufacturing Process Management System (MPMS) tool developed by ED and is based on the use of the Camunda engine with a Spring-Boot application written in Java. The Process Automation tool is configured for the process model defined for the specific Use Case and the relevant functionalities (file upload, user authorization, creation/ compilation of document, project management features) have been added as part of this software extension.

The Spanish cMDF has been selected to drive the development of the tool because the corresponding Use Cases assume a structured interaction among different actors. This characteristic enables the modelling of the process in a Business Process Management (BPM) framework on which the Process Automation Tool is based to provide the orchestration of the different entities.

The Use Case is on the development of a new product-line of furniture (intelligent bed headboard), which implicates three actors: (a) AIDIME the engineering manager, responsible for the coordination of the effort and its support in terms of covering the engineering aspects (Quality Assurance) of the end product, (b) VLC the designer and prototype developer and (c) LAGRAMA the 'client', which in this case is a furniture production factory, interested to develop a new line of product. The interaction among the actors aims to cover mainly the steps of:

a. Reaching a clear definition of the user requirements
b. Agreeing on the technical specifications of the product
c. Developing a prototype

The Process Automation tool is employed in this interaction to:

- Act as the single source of truth for the collection of the necessary information
- Derive the documentation describing each product in a formal way (documented in a 'Design Brief'), from the information exchanged as the users interact along the way
- Function as a project management tool, that is each actor is assigned specific tasks, who are called to carry out within predefined timeframes, alerts are generated towards the engineering manager when these deadlines are violated
- Enable the coordination/ monitoring of a number of parallel activities (investigation of ideas/ production of prototypes)

The Process Automation tool, although configured for the Spanish cMDF Use Case, intends to serve the needs of similar production processes where (a) the process/ interaction can be structured in a format compatible with BPM and (b) multiple parallel processes need to be executed.

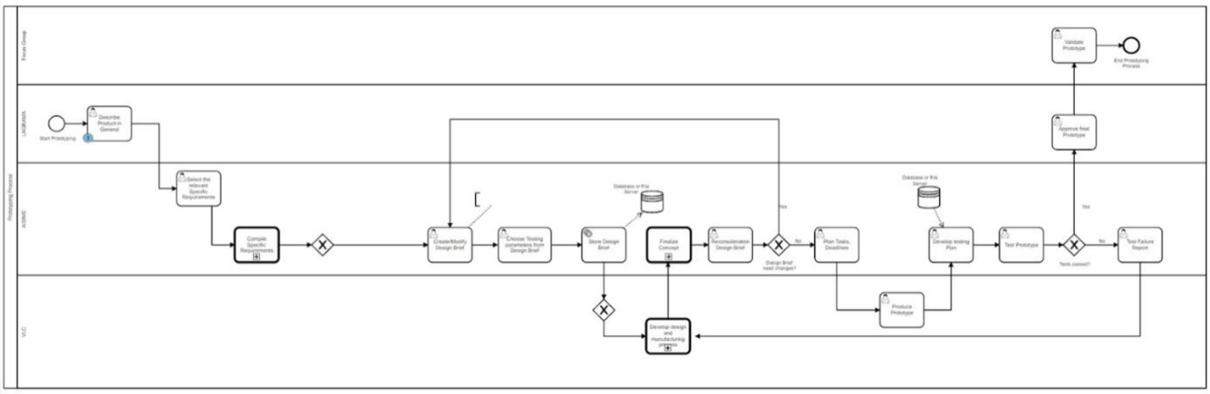

Figure 19: Production process for the Spanish cMDF

The main flow of the production process is modelled in the BPM diagram of Figure 19, where three main phases can be seen: (a) the agreement of the user specifications, (b) the definition of the technical specification of the product ending in the derivation of the Design Brief and (c) the scheduling of the production of the prototype. Several parts of this interaction require the involvement of different actors in an iterative ('conversational') way, an activity modelled as a sub-process (not visible in this diagram). The Process Automation tool facilitates the interaction among the actors by showing predefined forms or templates containing only the information relevant at a particular phase of the production process. It enables, this way, the onboarding of persons less experienced with the structure of the process and minimizes the loss (or dispersion) of information along the way. The screens/ information collected from the users is given in the following screenshots.

The first phase of the production process ends with the derivation of the Design Brief. The Sections composing the Design Brief (Figure 20) are individually addressed by the involved stakeholders in dedicated subprocesses. These subprocesses contain a ‘looping’ structure. This means that the implicated actors all work on a specific section of the Design Brief by iteratively making contributions, which at the end of each cycle are evaluated by the Engineering Manager. Once approved, the specific process is considered complete.

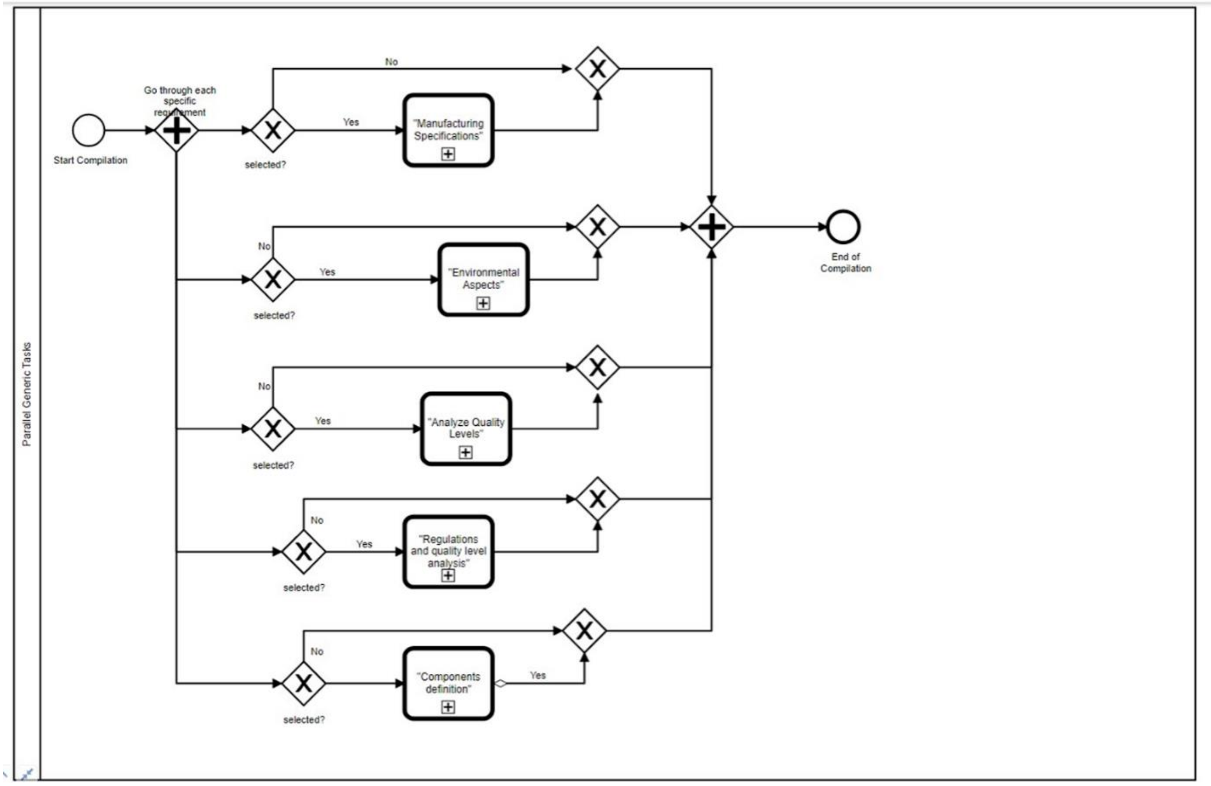

Figure 20: Sections (optional) composing the Design Brief

In each of the production stages, the system presents the relevant form to the actor. This form contains (a) the relevant fields to be filled-out by the actor and (b) the relevant information collected from the previous stages. The content of these forms has been curated to match the specific user-needs at each step of the production process. By aggregating the necessary information at each step of the process actors are supported in their decision making, since they are not required to handle / collect the necessary material from any number of external sources. The process automation tool functions as a single source for the management of the collected material in any form (files, messages & material collected through the forms) and from all actors. Examples of these forms from some parts of the production process are given in the following.

The Process Automation tool provides user-authentication and user access control to the relevant functionalities. In Figure 21 the user Joan Gau (1) (‘client’ under the organization LAGRAMA) fills in the section with the user requirements (2), with the option to upload files, which is made available to the rest of the actors at subsequent steps (3).

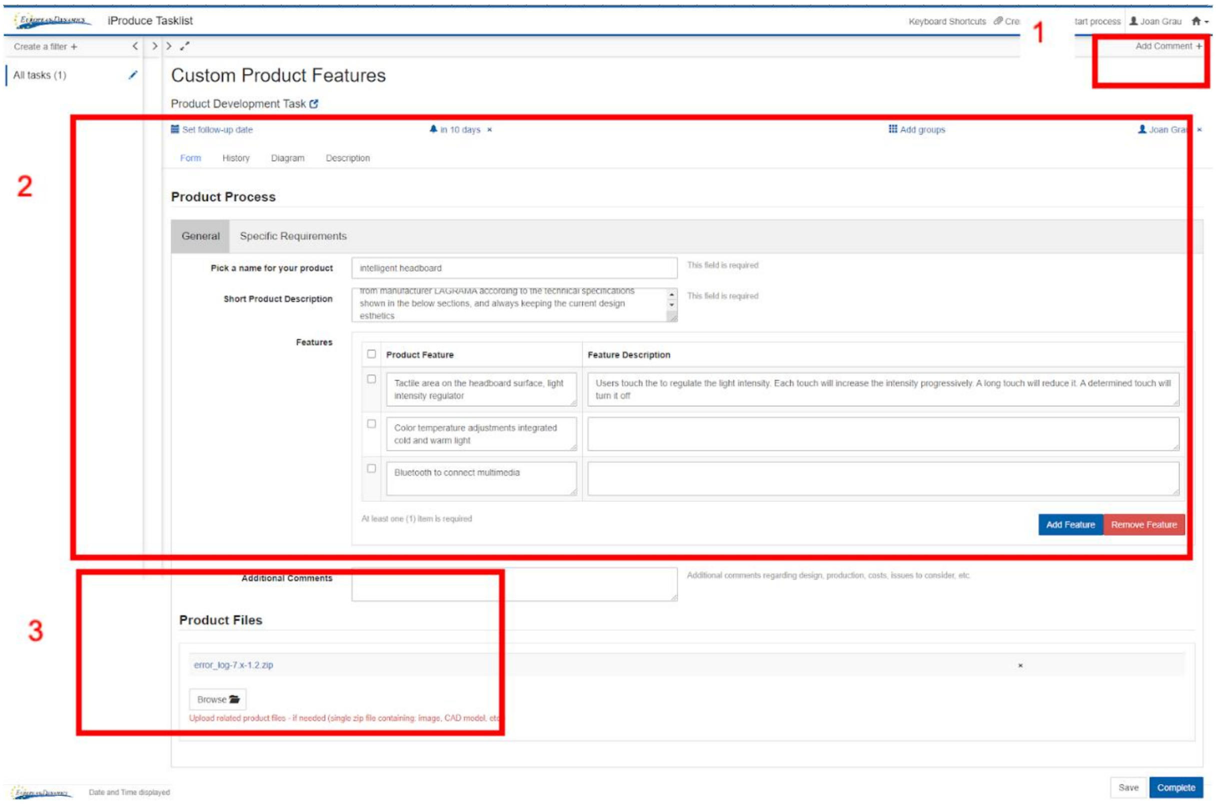

Figure 21: Description of User Requirements

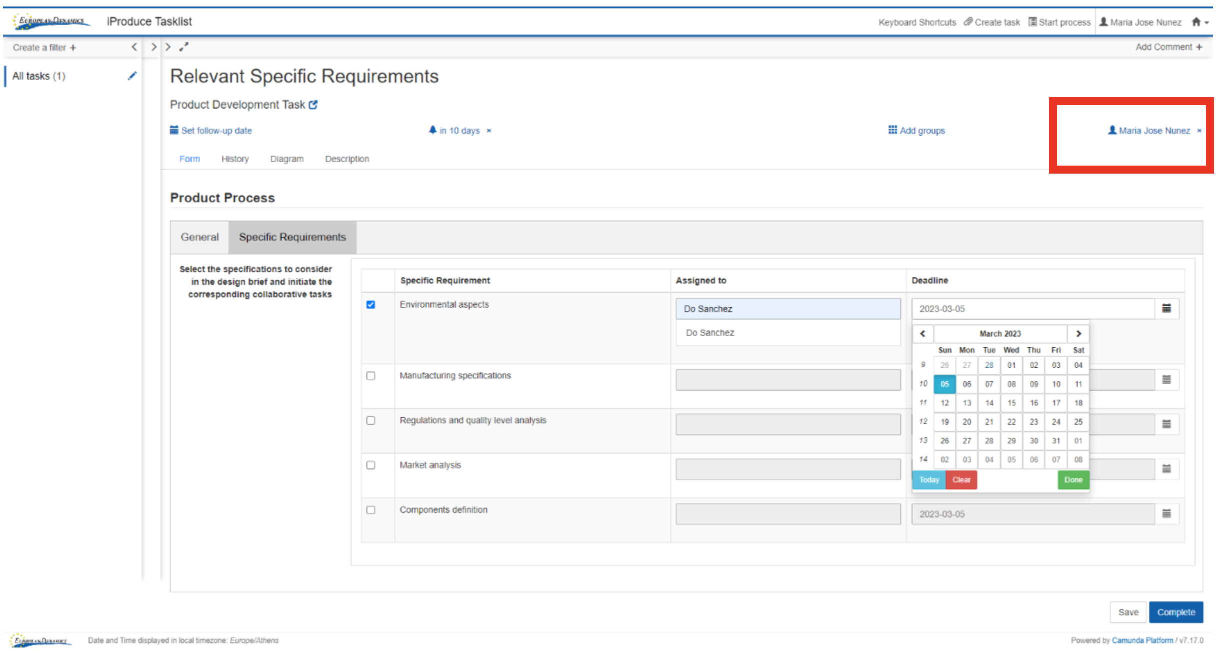

Figure 22: Project Setup by Engineering Manager

The petition for a new product, is received by the Engineering Manager, who is responsible to assign the collection of the technical specification to the appropriate personnel within the team. The project is set, once deadlines are defined for each section of the specifications document. This project setup information is visible by all relevant actors but can only be modified by the Engineering Manager herself (Maria Jose in the example of Figure 22).

Figure 23 and Figure 24 show that for each assigned task, users have access from within the system to the information relevant for the completion of their own task, including the way the project is set.

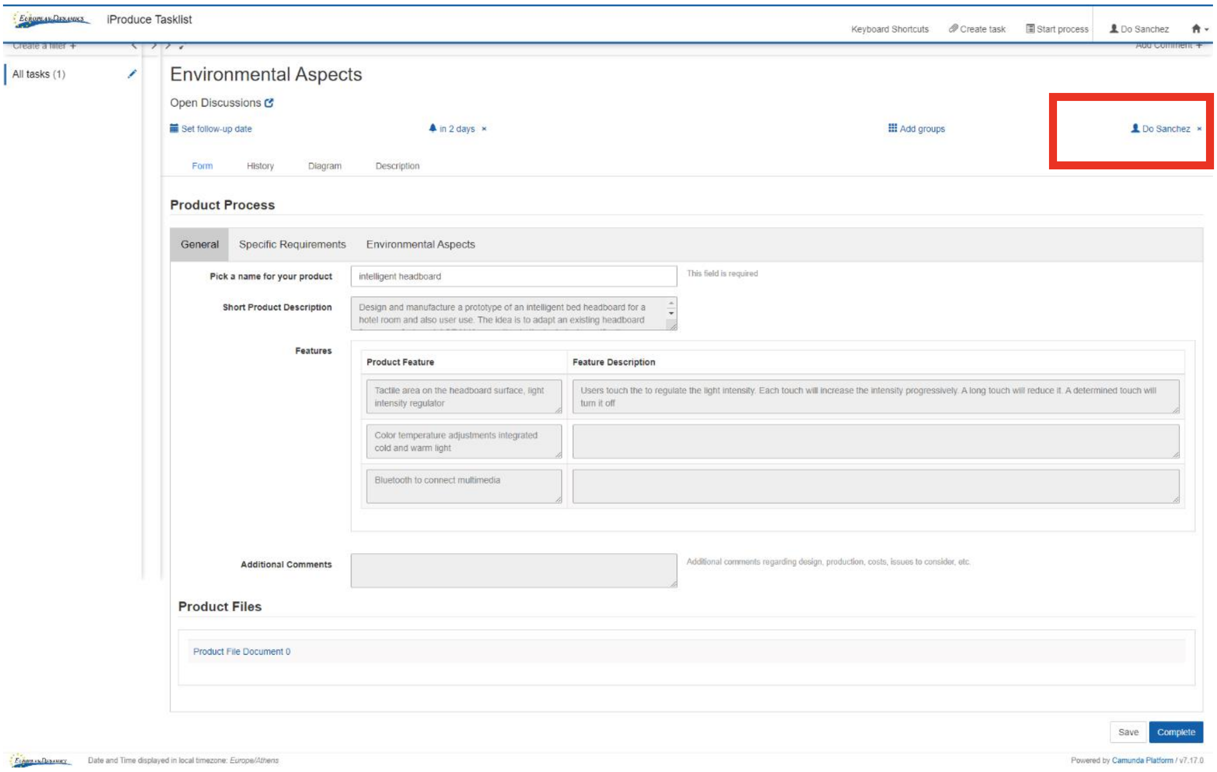

Figure 23: Assigned users have access to previously uploaded info

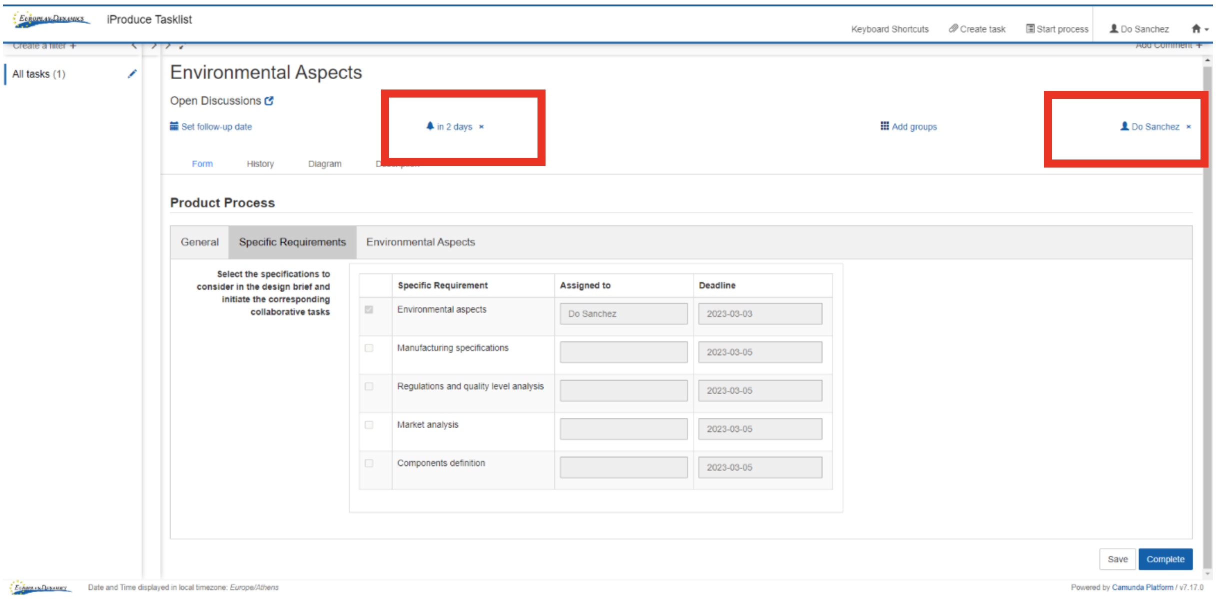

Figure 24: Assigned users have access to the project scheduling

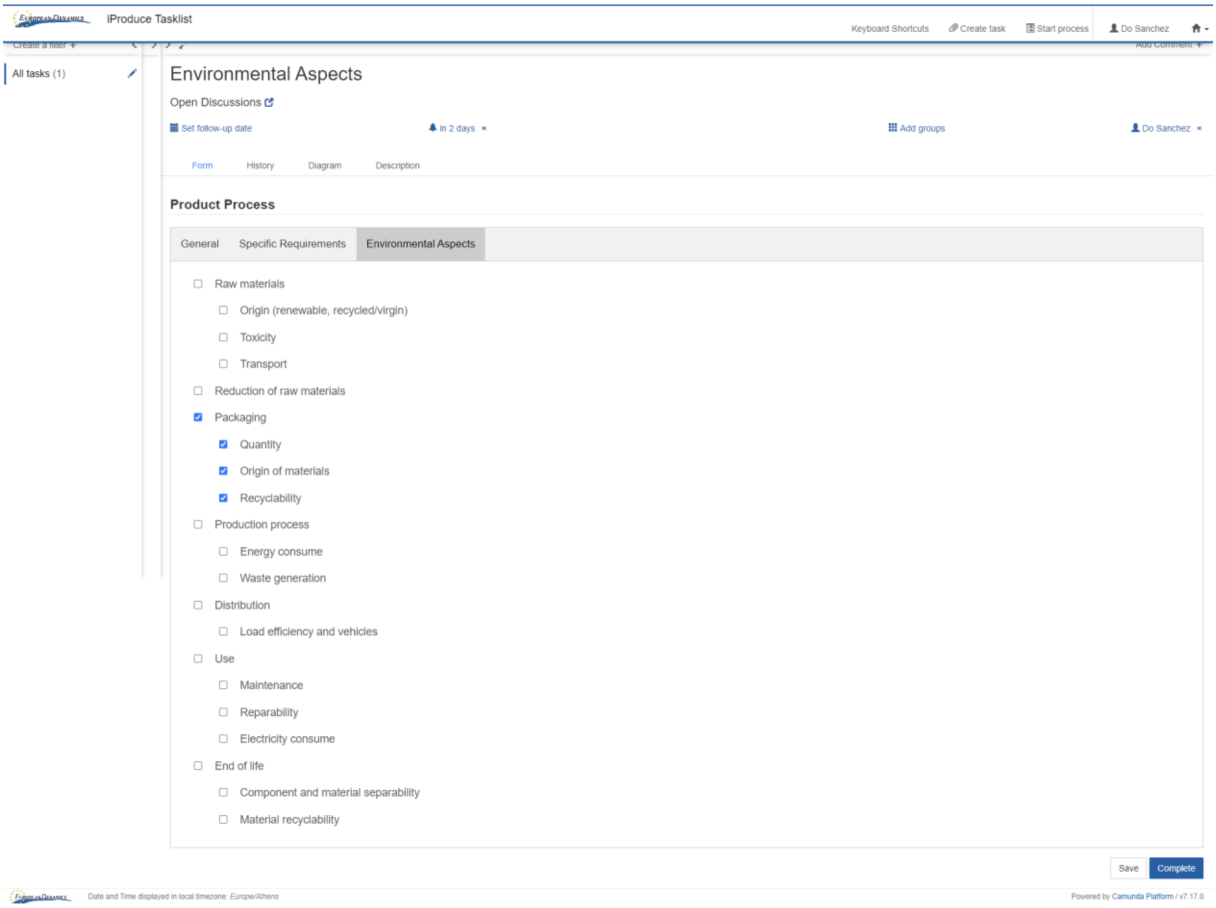

Figure 25: Definition of engineering requirements

The above examples provide a representation of the user interaction with the tool. The application is deployed in the servers of European Dynamics and is accessible via the link *http://spanish-iproduce.eurodyn.com* (user authentication is required). It has been developed in close collaboration with the end-users, so that their usual way of working is captured in the BPM model and that the relevant functionalities are directed towards the facilitation of their interaction.

4.2. Training Support Tool

The Training Support Tool is a software, which bundles the subcomponents cMDF Training View, cMDF Training Flow, Video Intelligence and Digital Twin Development Kit. All subcomponents are integrated so that the user can navigate from one component to the other. A plan is laid out, how the Training Support Tool will be applied at OpenEdge.

4.2.1. cMDF Training View

The cMDF Training View is a software able to navigate the bundle that is the output of the cMDF Training Flow. It has the capability of navigating the procedure step by step, following sequences, loops, conditions included in the procedure and, in doing this, it delivers the content which has been previously managed and included as resource by the cMDF Training Flow. The content delivered could depend on the capabilities of the platform (for example, the user will be exposed to video, sound, images, 3D models etc.). Furthermore, the user has the opportunity to choose the best content that fits its own needs among the contents that can be deployed and delivered in the platform he/she is actually using. Key features of the cMDF Training View are: a) high scalability on physical android devices; b) large number of presentation modes (e.g. in Augmented Reality, Virtual Reality, Text only, Hybrid, etc.).

The cMDF Training View allows to provide these services for all main types of procedures required by the project (Training) and for the various situations in which these procedures and information content may be of added value (standard and / or planned activities, management of emergency situations). The services of these groups make innovative instruments available to the end user which support the implementation of training procedures. Following an approach both “on the job” (based on Augmented Reality capabilities) and in “simulated environment” (totally based on Virtual Reality), this tool guides the users in their activity by presenting the step-by-step procedures interactively, by providing guidance on tools, materials and components involved and to use.

In this model, the AR content is one of several content types that can be made available in the cMDF Training View; it can be triggered in the following way:

- Frame Marker based; i.e., by means of the recognition of a high contrast, fiducial markers that provide the anchor to which the AR content is bound.

Services

- Support users in conduction specific training procedures.
- Support users by providing them advanced information and content.

Dependencies

- cMDF Training Flow
- Video Intelligence
- Digital Twin Development Tool
- OpIS data repository
- Training material management system
- Hardware Devices Capabilities & Performances (android devices)

Inputs

- Training Procedure (output of the cMDF Training Flow).

Outputs provided

- Audio/Visual information shown by android devices

Type of exposed APIs

The cMDF training view is a stand-alone mobile App. It will use an authentication method in order for a user to get access to the content. The content will also be retrieved from the OpIS data repository through the API. Furthermore, the application will be integrated with the outcome of the Video Intelligence tool. So, at each step of the training procedure, there is the possibility to be available the output of the video intelligence.

User Flow

The user has to install the apk in his/her android device. Once the installation completes, the user has to log in through the cMDF training view application using his iPRODUCE credentials. The registration to the platform will be provided by the marketplace. The image on Figure 26 is the initial interface of the application.

Figure 26: cMDF Training View

Once the user opens the application, he/she is available to see and download all the training procedures that are enrolled. For example, in the image on Figure 27, the user can see two training procedures.

Figure 27: Choose a training procedure

After that, the user selects the training procedure that he/she would like to be trained in. The application downloads the training procedure to the android device. So, the user has the availability to surf through the steps of the training and check the available media content of the corresponding step as well as the available video output from the video intelligence component.

Also, the application gives the possibility to the user to use the camera of the android device in order to project to the environment the 3D model (AR). The animation of the 3D model gives the user the experience to understand the training procedure with an interactive method. The image on Figure 28, presents a step of the training procedure. The bar with the images below shows the available content of this step (the images are highlighted in orange).

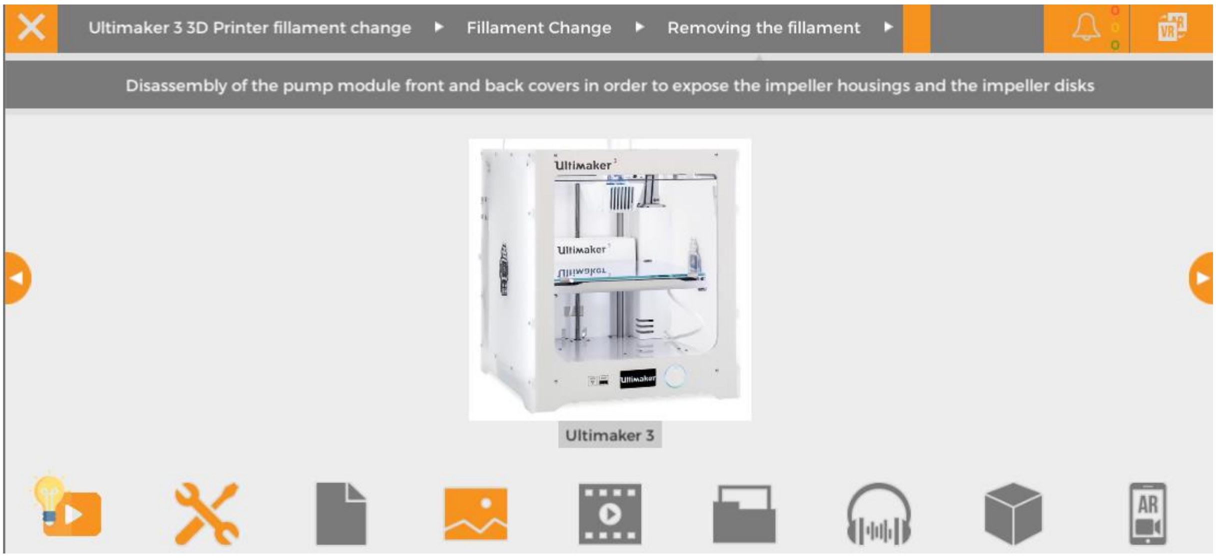

Figure 28: A step of the training procedure

The bar contents from left to right are:

- Video Intelligence content.
- Text description.
- Document files (.pdf, .doc, .docx, .txt, .srv).
- Image (.jpg, .jpeg, .bmp, .png)
- Video (.MPEG, .mp4, .3gp)
- Files
- Audio (.mp3, .wav)
- 3D Models (.3ds, .fbx, .lwo, .obj, .stl, .off, .prefab, .objz), available for VR and AR projection.

4.2.2. cMDF Training Flow

The cMDF Training Flow allows to convert original Training Procedures, often described with different formalisms, in a new format, called AR OP (Augmented Reality Operating Procedure) ready to be used by the cMDF Training View developed to support training environments. The cMDF Training Flow provides functionalities designed to manually describe a new AR OP by a dedicated approach. This tool supports the technical actor who is in charge of the new AR OP creation, by providing him power wizards, resources and inventory management, node-based UI to describe structure and properties of each operation, step, action and relationship, etc.

Services

- Storage of AR OP in OpIS Data Repository ready to use with cMDF Training View.
- Augmented Reality Operating Procedure creation.

Dependencies

- OpIS Data Repository.
- cMDF Training View.

Inputs needed

- Original Operating Procedures (e.g. specific use-cases) and all related contents (e.g. images, 3D models, videos, etc…).

Outputs provided

- Augmented Reality Operating Procedure, ready to be used by cMDF Training View.

User Flow

The Resource Module allows the creation of a resource repository that can be used by any procedure. It allows the resource definition, supporting as main resources: texts, images, videos, 3D models, 3D animations, audio clips, documents and AR Targets.

The Operative Procedure Module allows the definition of a procedure in terms of several possible steps, namely:

1. **Operations;**
2. **Steps;**
3. **Actions;**

and the **Relationships** connecting them.
This kind of logical organizations contributes to two different purposes:

1. To provide a logical grouping related to different abstraction layers, useful to easily design and maintain the procedures;
2. To keep at the minimum the number of actions at the bottom layer, in order to make the handling of the procedure.

A complete procedure definition is implemented as a graph enabling the procedure execution according to a well-defined navigation model, as shown in Figure 29.

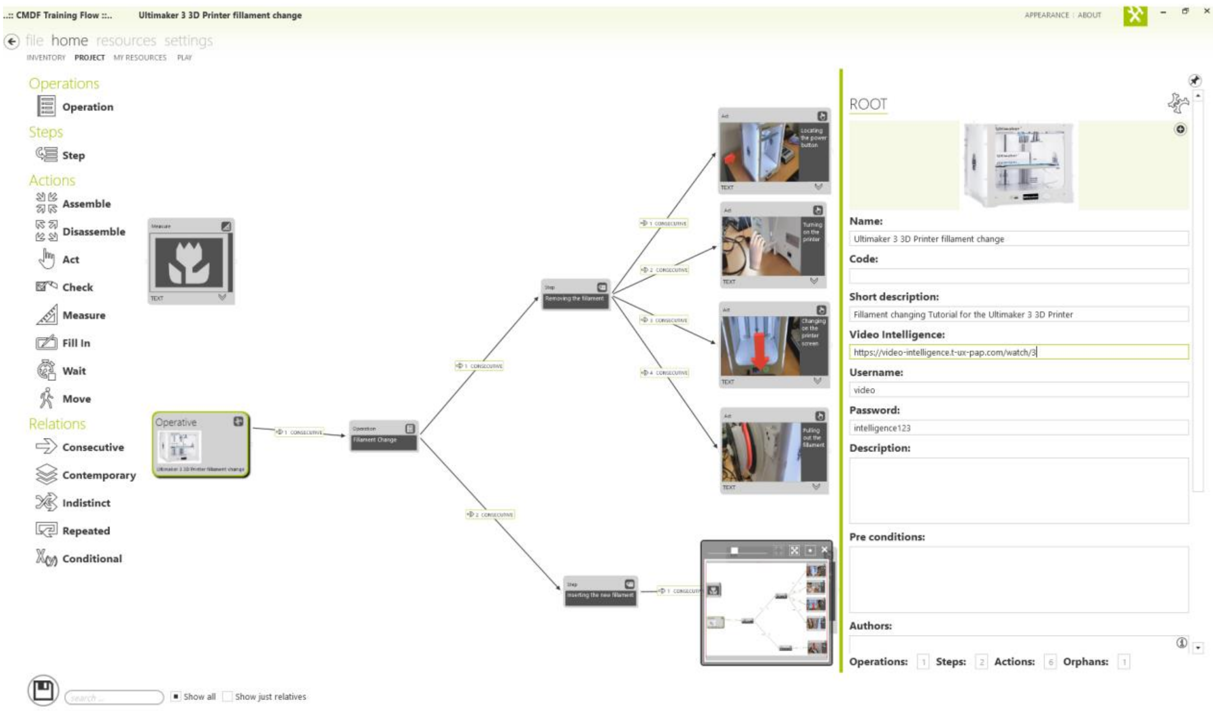

Figure 29: Create a training procedure

Various text fields are included in the user interface to facilitate the input of the metadata that accompanies a specific training scenario. In particular, the **Video Intelligence** field is used in conjunction with the **Username** and **Password** fields to achieve integration of the cMDF tool with the Video Intelligence platform, which provides annotated training videos. The link in the Video Intelligence field points to a relevant annotated video. The username and the password are credentials needed to get access to the protected materials on the Video Intelligence server.

Besides supporting the training definition, the cMDF Training Flow makes available an inventory allowing the definition of all the elements required to execute the training. In fact, in order to better specify the types of objects that are involved in a specific action, the Editor Tool allows to define the list of objects required from its execution by getting them from the inventory already filled by means of elements such: **Components, Equipment, Tools**.

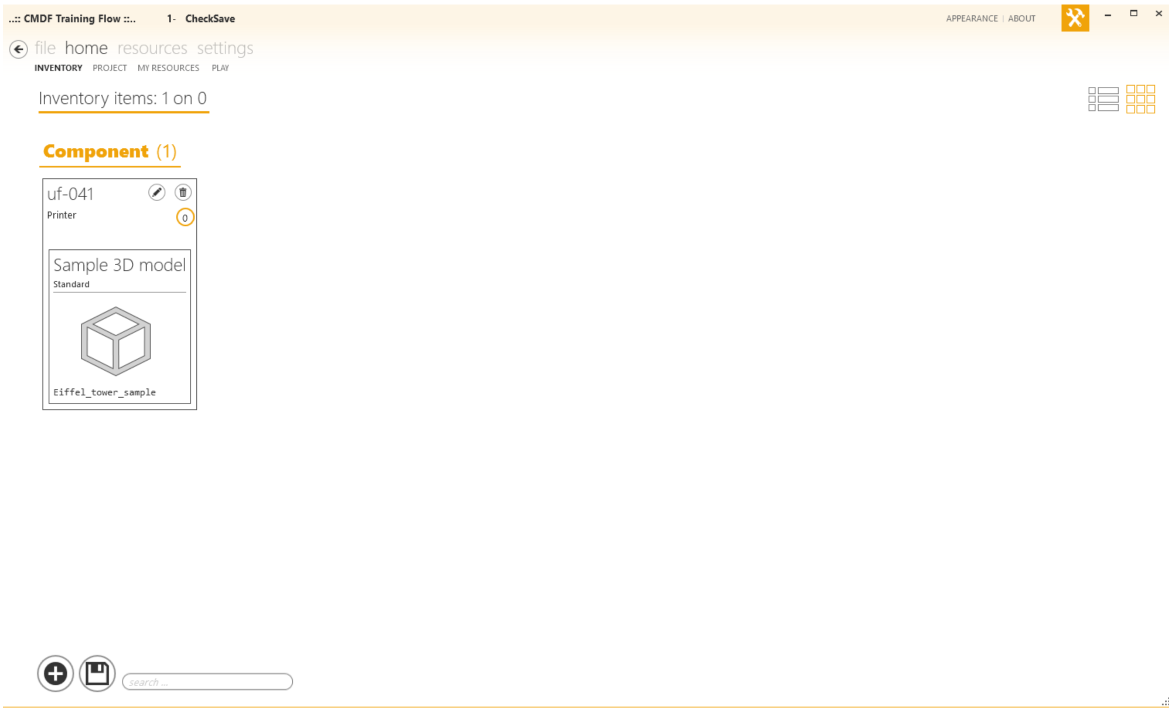

Figure 30: Inventory

As a further step, the cMDF Training Flow allows to refine each element in the procedure (operation, phase, action, relationship) in terms of its own base properties. About them, the level of detail provided for an action is the most important descriptive feature, called **Descriptive Layer**.

The Descriptive Layer provides several contents making it possible to describe how an action has to be performed. The image below shows the resources page, where these contents could possibly be added as media content at each action from the Descriptive Layer.

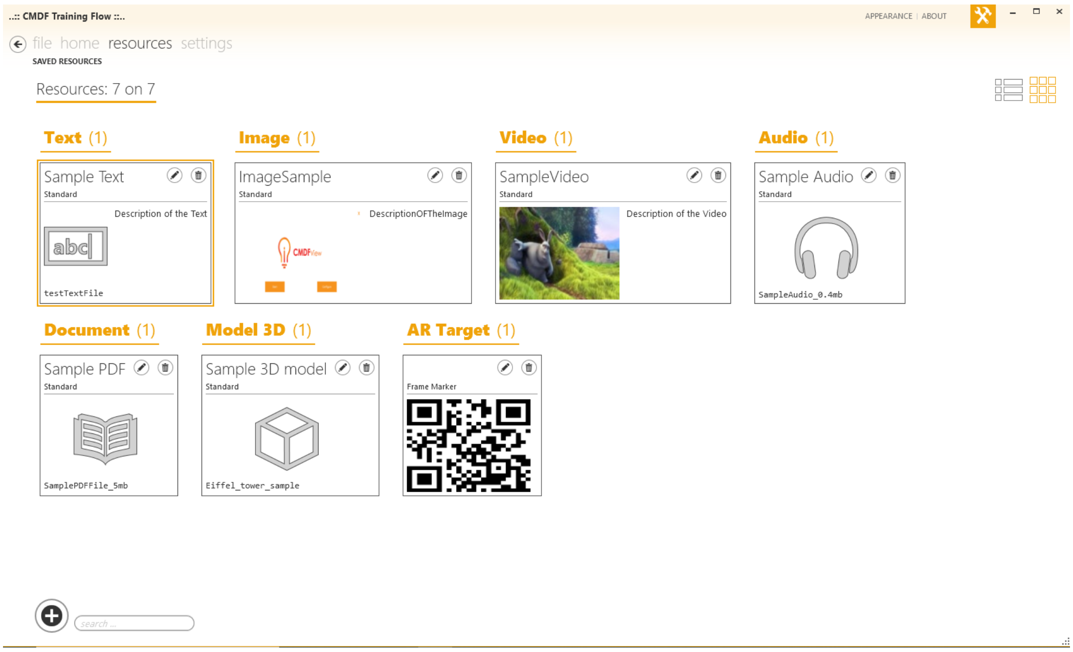

Figure 31: Available media content

The formats supported as resources in the cMDF Training Flow are listed in the following table:

Table 4: Content types

Content type	Import Format	Export Format
AR OP	Proprietary, XML-Based	Proprietary, XML-Based
Audio	MPEG Layer 3 (.mp3), Microsoft Wave (.wav)	
Video	MPEG-4 Part 14 (.mp4), 3GPP (.3gp)	
Image	Jpg, Bmp, Png	
3D Model	Autodesk FBX (.fbx), Collada (.dae), Alias Wavefront (.obj/.mtl), 3D Studio (.3ds)	
3D Animation	Autodesk FBX (.fbx), Collada (.dae)	
Document	PDF, TXT, DOC	

Finally, a service (Package to Bundle Tool) running in the server, which transforms the Standard Training Procedure, as internally represented as a project by the cMDF Training Flow in a bundle that could be opened and parsed by the cMDF Training View. In doing so, the Package to Bundle process gathers all the resources included in the procedure and reworks them performing all the possible optimizations applicable for the intended destination platform where the Presentation Tool has to be run.

The cMDF Training View is a Unity application, so the Package to Bundle transforms the procedure into an Asset Bundle. i.e., a data unit that can be understood, in fact, from Unity.

Should the current procedure use resources for augmented reality, the Package to Bundle tool allows the import of Vuforia datasets that will be optimized and embodied into the final Asset Bundle. The Package to Bundle Tool is a Unity project to which the required parameters must be passed in order to get successful Asset Bundle creation; for that reason, the installation of Unity Editor is a must to have in place (server) the transformation occurs.

In the current iteration of the deliverable, the Package to Bundle is a tool transparent to the user; it is used directly by the Creation Tool when the export as Package Bundle is requested by the user. Currently, the possible target platforms are Android and Windows.

The **cMDF Training View** and **cMDF Training Flow** are both deployed and integrated via the central OpIS Dashboard page under the **Digital Fablab Kit/Training Support Tool/cMDF Training Platform** menu options.

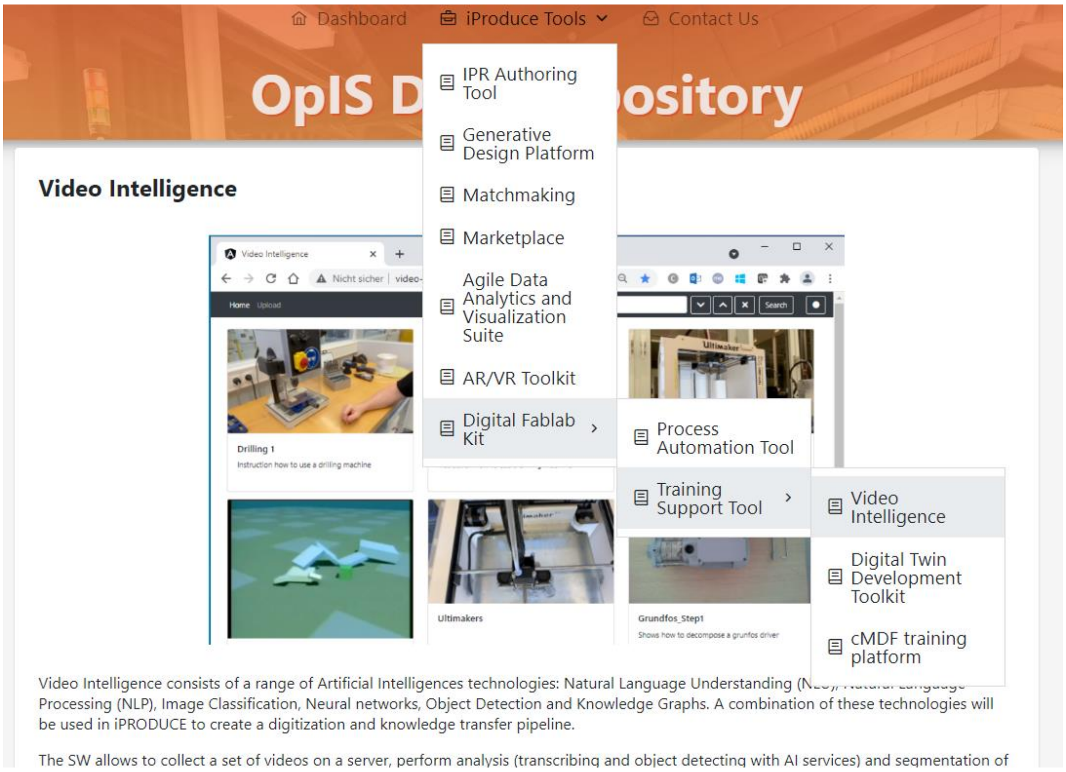

Figure 32: Digital Fablab Kit / cMDF Training Platform Menu Options

In addition, they are distributed in the form of an .apk installation file for android devices and a zip file that bundles the required executable respectively. Users can download the files via the appropriate buttons inside the OpIS Dashboard page.

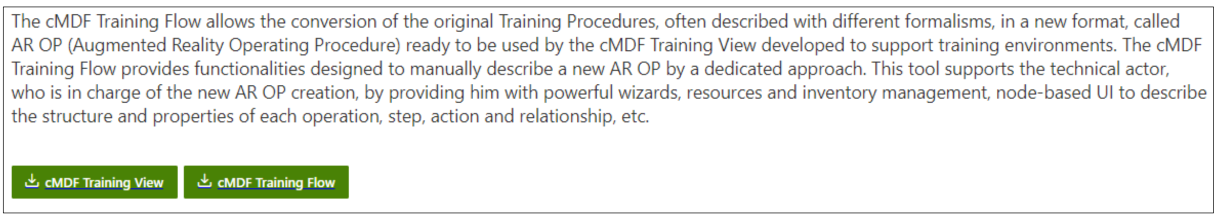

Figure 33: cMDF Training View - cMDF Training Flow download buttons

4.2.3. Video Intelligence

Video Intelligence allows to collect a set of videos on a server, perform analysis (transcribing and object detecting with AI services) and segmentation of video recordings, and process textual search requests through the video. The search is performed over the contents of audio tracks as well as over the objects detected within the video.

The software consists of a range of Artificial Intelligence technologies: Natural Language Understanding (NLU), Natural Language Processing (NLP), Image Classification, Neural networks, Object Detection and Knowledge Graphs. A combination of these technologies will be used in iPRODUCE to create a digitization and knowledge transfer pipeline.

The main usage of the video intelligence is for knowledge exchange among makers and consumers. This tool can also be effectively used for (remote) training for makers and other equipment, in particular if safety requirements shall be addressed for specific potentially hazardous machines.

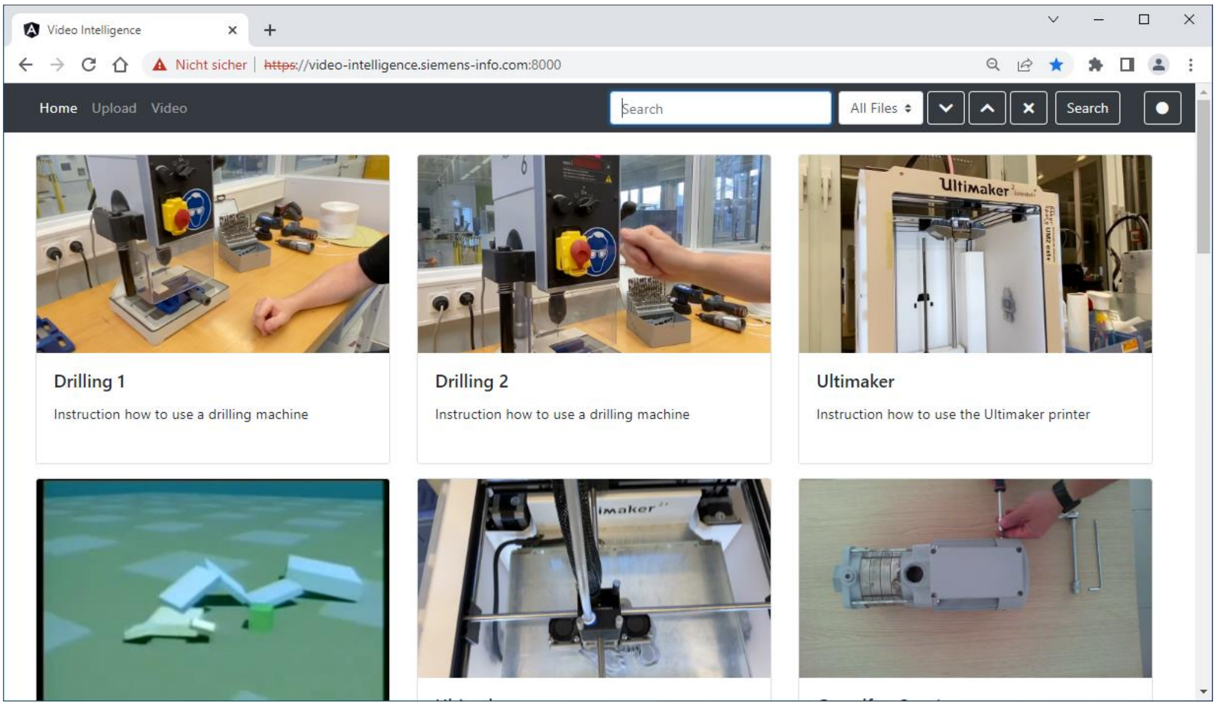

Figure 34: Homepage of the Video Intelligence

The access to the Video Intelligence platform is password protected. All iPRODUCE partners can access the platform following the instructions provided in the iPRODUCE area on Google Drive. The document with the instructions [Video Intelligence access](#) is located in the folder [IPRODUCE>WP3>T3.4>Videointelligence](#).

The following user interfaces have been implemented in the front-end:

- Video Intelligence Home page (https://video-intelligence.t-ux-pap.com/ Figure 34) collecting all results of videos processed
- UI for uploading a new video (https://video-intelligence.t-ux-pap.com/upload Figure 35, menu item “Upload”)

- UI for video processing (https://video-intelligence.t-ux-pap.com/video Figure 36, menu item "Video")
- UI with the processed results:accessible when clicking on the video from the "Home" page or on "Watch Video" from the "Video" page (e.g.,https://video-intelligence.t-ux-pap.com/watch/1 Figure 37 together with the search results for this video)
- API documentation (https://video-intelligence.t-ux-pap.com/api/swagger)

On the Home page, all videos available on the Video Intelligence platform can be browsed, and their short descriptions can be viewed.

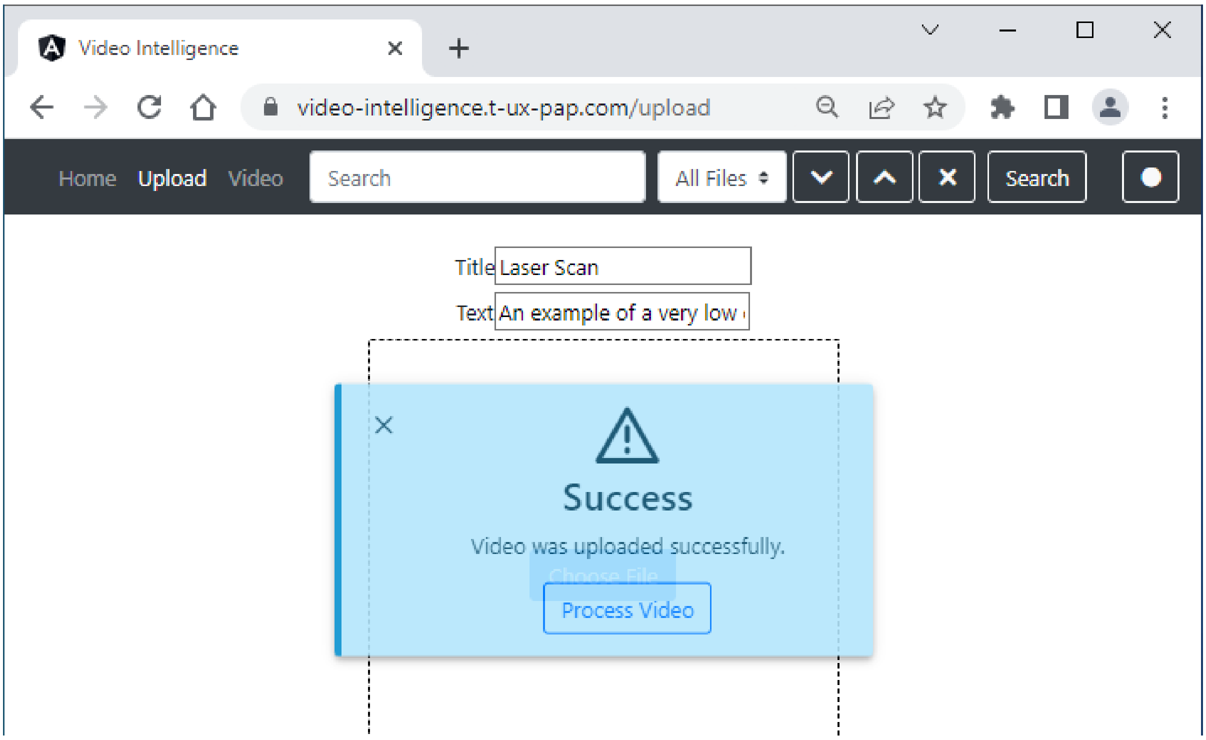

Figure 35: Uploading a new video

On the "Upload" site a title of the new video together with its short description must be specified as they should appear on the home page. After that the corresponding video can be selected from the user's local drive. It can take several seconds until the video is completely uploaded to the platform, depending on the size of the selected video. Currently only videos in the **.mp4 format** can be accepted by the Video Intelligence platform. The size of the videos is limited for the **free demo version** by the provider of Video Intelligence (SAG) to the file size of **50 MB**. After the .mp4 file is successfully uploaded, the user is invited to start video processing.

Video processing can be invoked for all uploaded video files later through the "Video" site from the home page or other locations within the Video Intelligence platform.

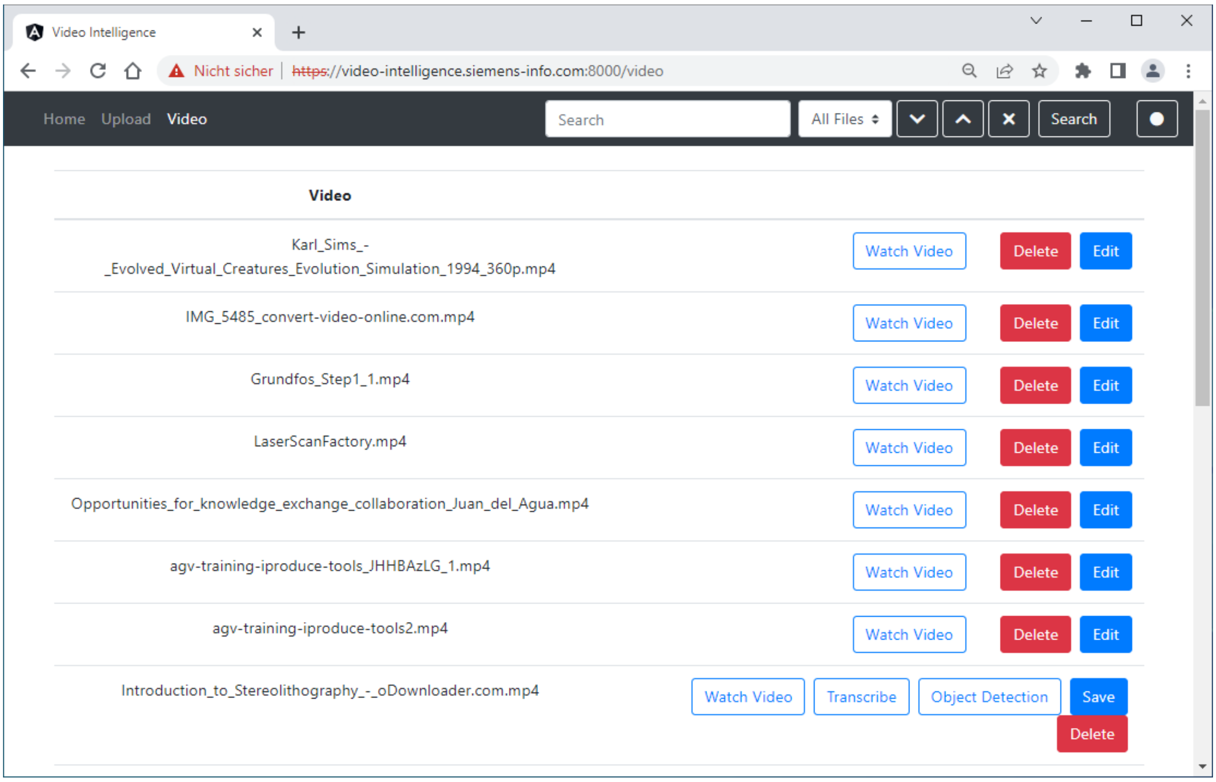

Figure 36: Processing videos after uploading

Video processing site “Video” lists all videos uploaded to the Video Intelligence platform by users either manually, as described above, or automatically from other SW components over API. If the processing of a video is complete and stored to the platform, this video can be watched on the platform, edited or deleted from the platform. More management possibilities are available for newly uploaded video files. In addition to “Watch Video”, “Edit” (to update the title and short description), and “Delete” there are following options for newly added videos:

- “Transcribe” starts to generate textual subtitles out of the audio track of this video. This can take from several seconds to several minutes depending on the size of the video file. This operation results in “Error” if the video does not contain an audio track, but it does not prevent other operations and storage on the platform (in this case without subtitles).
- “Object Detection” (also known as Labelling) starts to recognize objects within video frames at different time stamps. This can also take from several seconds to several minutes depending on the size of the video file. This operation does not depend on the audio track and can be performed for any video file.
- “Save” can perform the storage of the processed results only after “Transcribe” and/or “Object Detection” run and produce at least results with objects detected. After the results are saved to the platform, they cannot be changed, i.e., the processing cannot be rerun.

The main result of video processing is illustrated in the Figure 37 below, also including the illustration of the search results within the current video:

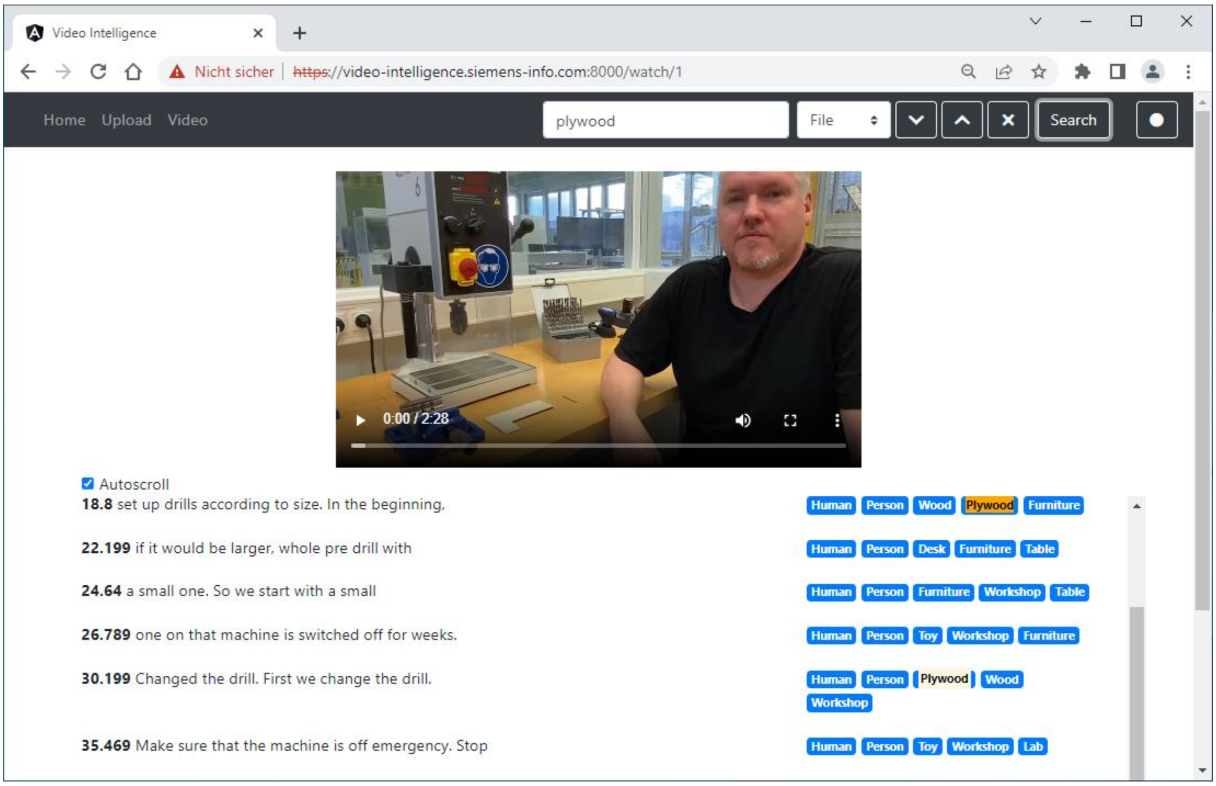

Figure 37: Searching through the results of transcribing and object detection

The complete results of the video processing contain:

- Video itself to be watched or downloaded
- Textual subtitle (only if the video contains an audio track with English speech)
- Time stamps, corresponding to the phrases from the subtitle or selected accidentally in case of absence of the audio track
- List of objects detected within the video track to the specified time stamps

Having these results, a user can jump easily to a corresponding location in the video when clicking the phrase or object. Within each video, a user can search for a keyword and jump to the point in the video, where this keyword was spoken or appear as a detected object on the video.

While the video is playing, the user observes the currently said phrase via auto-scrolling the text. In case this disturbs watching the video, “Autoscroll” check-box can be unchecked to prevent auto-scrolling and staying on the top of the site.

Such webpage for each video also allows to download the current video as an .mp4 file on the local drive.

A user can search for a keyword through all uploaded and processed videos. To do this, the option “All Files” should be selected near to the search text-field in the main menu. The result of such global search will list all videos, where this keyword was found either within the transcript text or within the objects detected.

Video Intelligence – Architecture

Video Intelligence can be integrated into the iPRODUCE Training tool kit. But it can also be used as a stand-alone component. Any user of the tool Video Intelligence can upload his/her short video instructions to AWS (Amazon Web Services) The backend API is interconnected via REST API and the JSON format. The figure below visualizes the top-level architecture of the Video Intelligence.

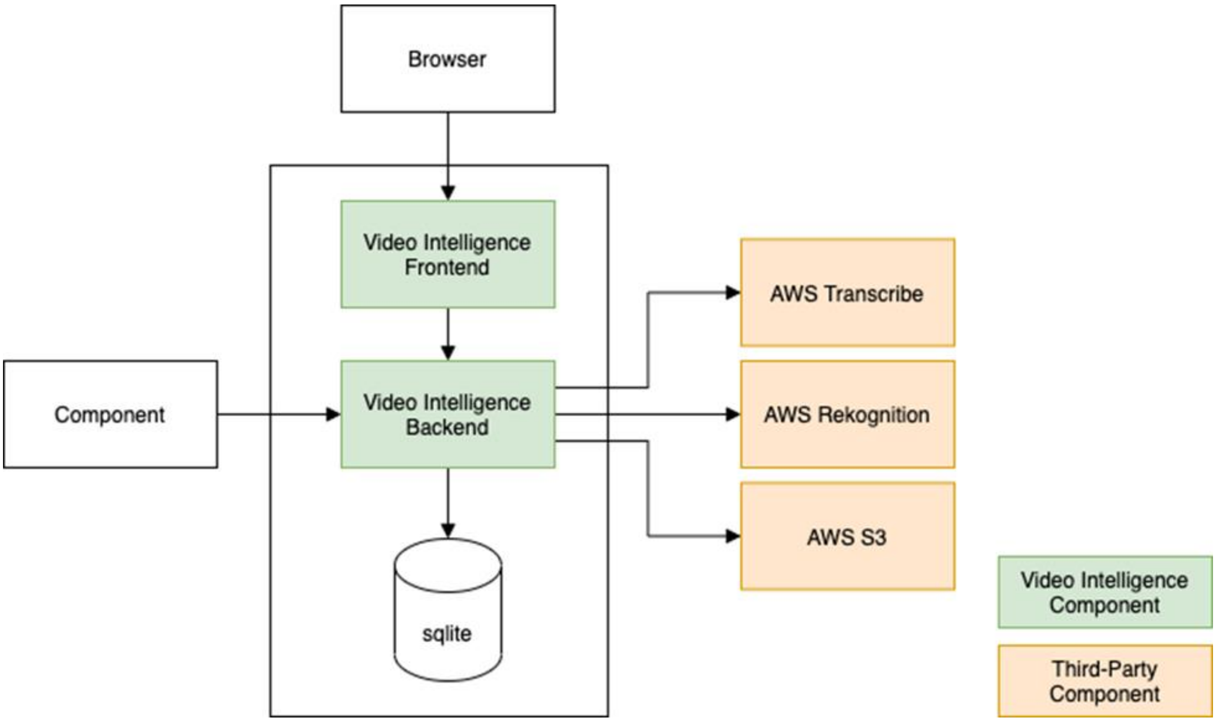

Figure 38: Architecture of the Video Intelligence

As stated previously and visualized on the architecture diagram, Video intelligence can be accessed over an internet **Browser** or any other software **Component.**

The main components of the Video Intelligence are the following:

- Video Intelligence Frontend written in Angular
- Video Intelligence Backend: REST API for the frontend and other components, written in Python and Flask
- SQLite: a Database used by the Video Intelligence

The implementation of the Video Intelligence Backend exploits the following 3rd party components from Amazon Web Services (AWS):

- AWS Transcribe: Transcribing videos to generate subtitles with time stamps
- AWS Recognition: Object detection in the video tracks
- AWS S3: Storage of videos, objects and subtitles

For the integration of the Video Intelligence into the iPRODUCE Training toolkit, a REST API has been developed, documented, and published under https://video-intelligence.t-ux-pap.com/api/swagger. The available commands of this API are shown in the figures below.

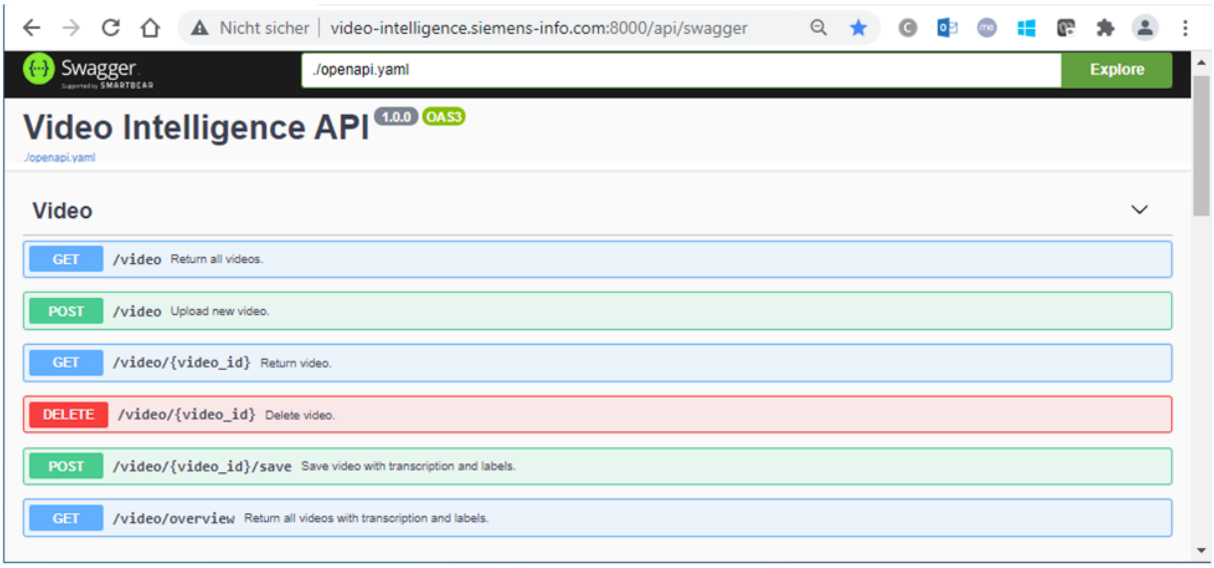

Figure 39: Video Intelligence API: Access to the videos

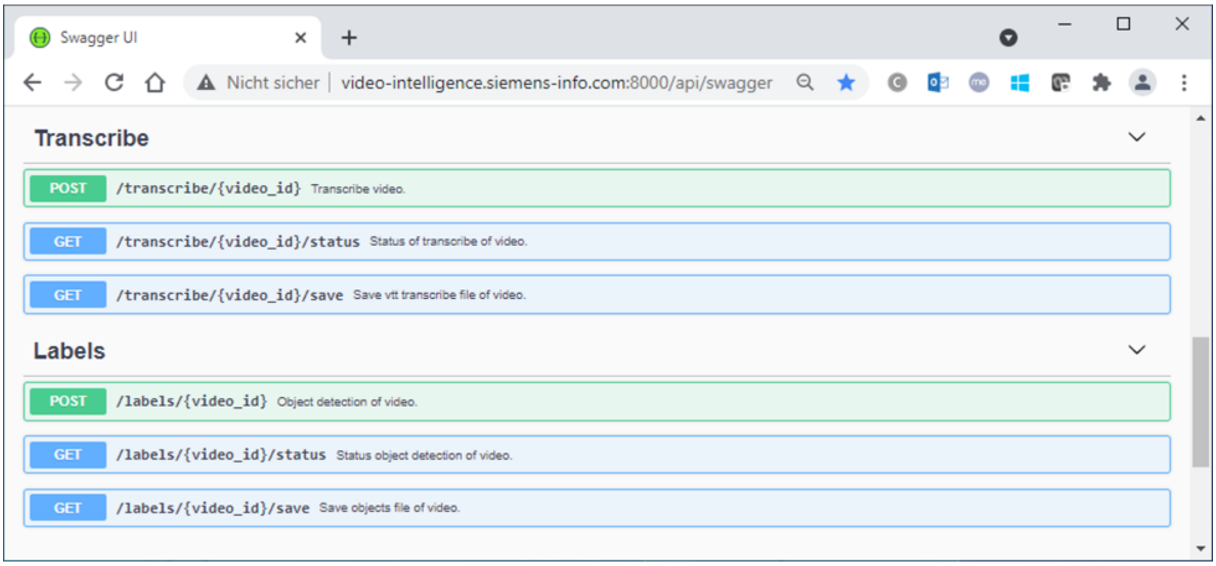

Figure 40: Video Intelligence API: Processing videos – transcription & object detection

The tool limitations are the following:

- Hosting Infrastructure: only limited size of the videos can be processed on the free demo version of the platform
- Language support: currently only English is supported
- User management & notifications not implemented
- Security Level provisioning not covered

4.2.4. Digital Twin Development Kit

Purpose

The Digital Twin Development Tool Kit is designed to facilitate the development of digital models, also known as digital twins of physical entities. These digital twins possess the capability to replicate the physical behavior of their corresponding entities within a digital environment. These digital twins can be stored and shared for the purpose of learning, Training and experimentation. The toolkit does not require the user to have a physical model in order to create a digital twin, however, in the context of the iPRODUCE use case, it is likely that a physical model will be utilized.

The digital twins created through the use of this tool can be utilized by OpIS users to develop, design, and deliver learning and training materials utilizing advanced digital technologies. Moreover, digital twins developed by the tool kit let you visualize and predict how a product will appear and operate, even before physically manufacturing it.

The utilization of a digital twin enables the simulation of activities on a small scale, allowing for the learning and experimentation to take place without the wastage of resources or damage to equipment. Furthermore, digital twins can execute synthetic scenarios as a part of training and support learning activities. They learn about behaviour in a playful manner which helps foster familiarity with the machine.

The kit which helps those interested in developing a digital twin model can be found at [iproduce-digital-twin-kit]() (GitHub project). A ZIP file is included in this GitHub repo. Prior to commencing activities with this project, it is recommended that the ZIP file be extracted and the word document be read in full. The word document contains instructions on how to run the digital twin project and how to access the documentation for developing a digital twin.

Screen Shots

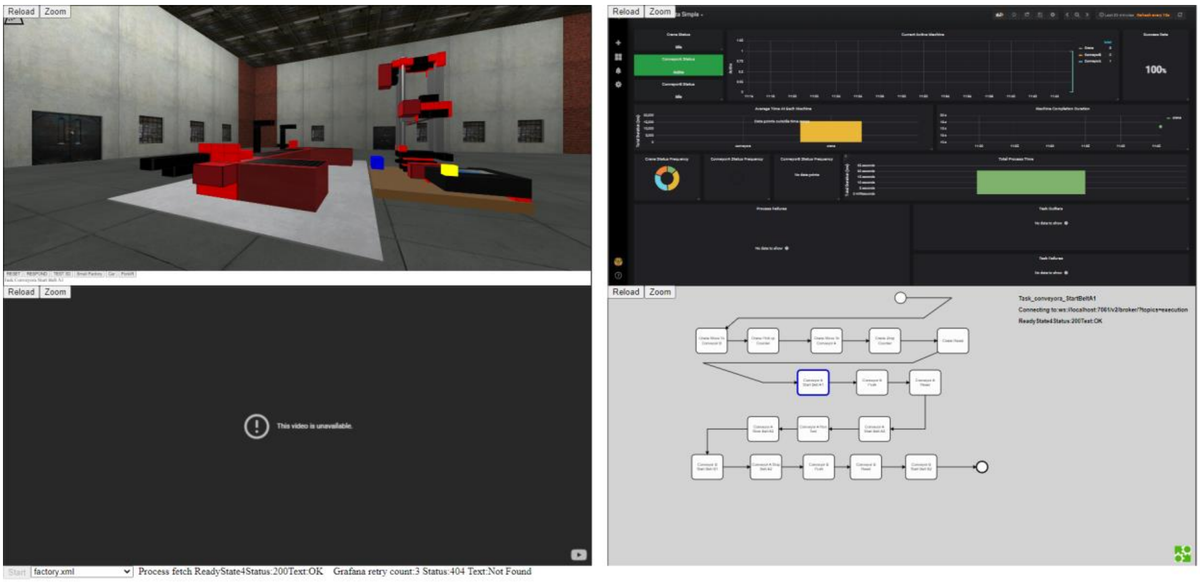

Figure 41: Digital Twin screens

The Digital Twin Development Toolkit is composed of four main components that is visible to the user

- The 3D Model View, which provides a visual representation of the digital twin in a 3D world.
- The Grafana Dashboard, which allows for the monitoring and analysis of data related to the digital twin.
- Live video feed of the corresponding physical machine, allowing for the real-time comparison and correlation of the digital twin with its physical counterpart
- The BPMN Sequencer, which enables the automation and control of processes within the digital twin

Interaction Diagram

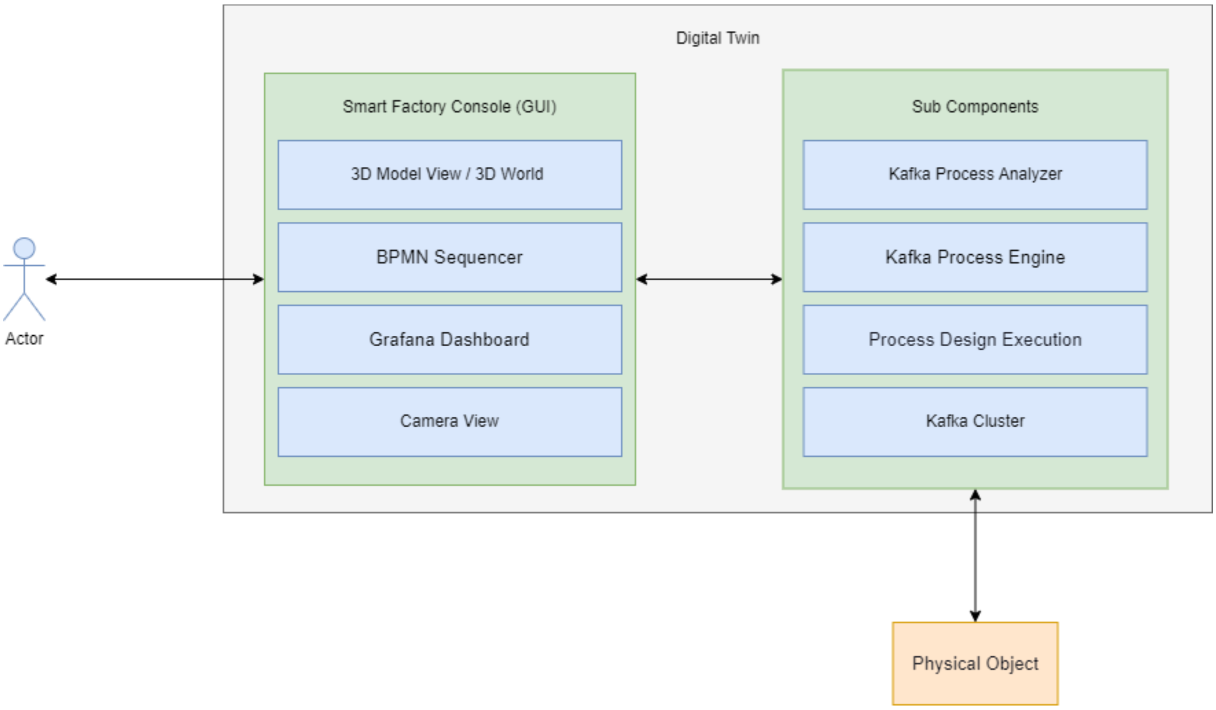

Figure 42: User interaction with the digital twin

The above diagram shows the interaction of the user with the digital twin.

The first component of the Digital Twin Development tool kit is the 3D world or the representation of the 3D model. This feature provides the capability to design and import custom 3D models (Using three js). Within this component, a comprehensive 360-degree view of the 3D model or 3D world can be obtained, enabling the manipulation of the view through rotation, zooming in and out, and the ability to observe the 3D model from various angles. Also this component can be used by the end user to test animations for the selected 3D model. The 3D model can be developed using the three js editor and then imported into the digital twin development toolkit.

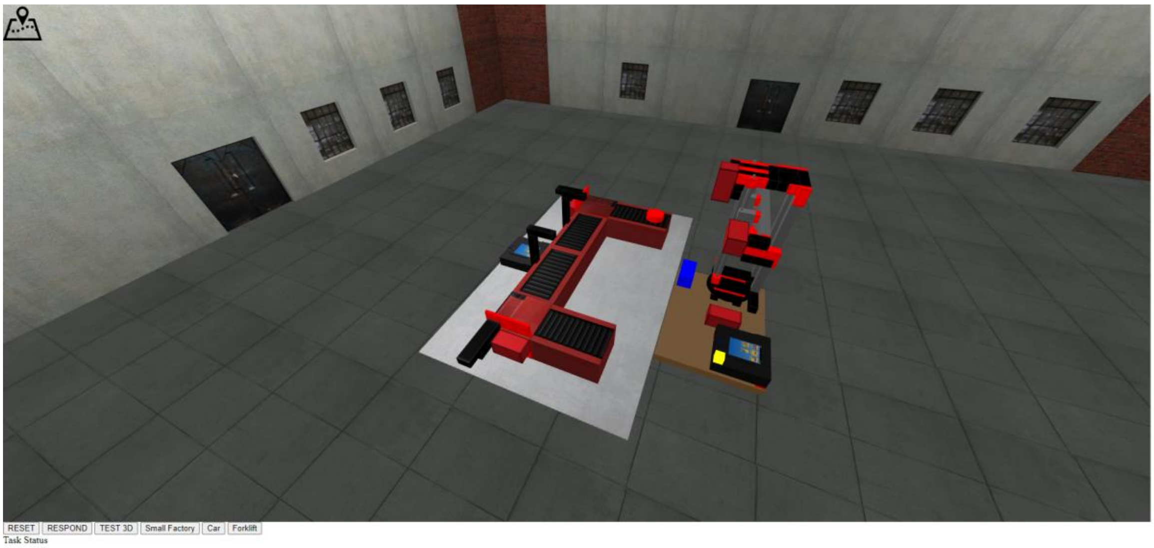

Figure 43: Web3D component

The next component of the Digital Twin Development tool kit is a Business Process Modeling Notation (BPMN) viewer, which is a graphical representation tool that illustrates the various steps involved in a process and it highlights the current stage of the active process. BPMN enables the automation and control of processes within the digital twin. By utilizing BPMN, the arrangement and sequence of processes required for implementation can be effectively organized and managed.

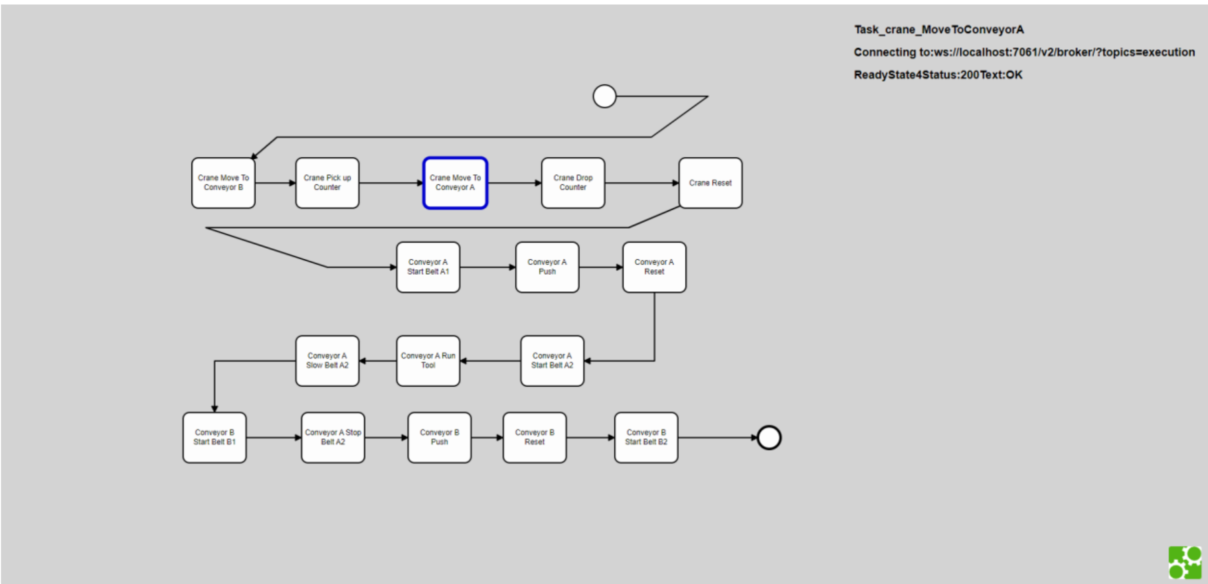

Figure 44: BPMN Viewer

The next component of the Digital Twin Development tool kit is a Grafana dashboard, which serves as a visualization and analytics tool utilized to display all analytics pertaining to the selected 3D model. This includes but not limited to, the identification of currently active machines within the process, the calculation of average time per task, and the detection of any failures within the system.

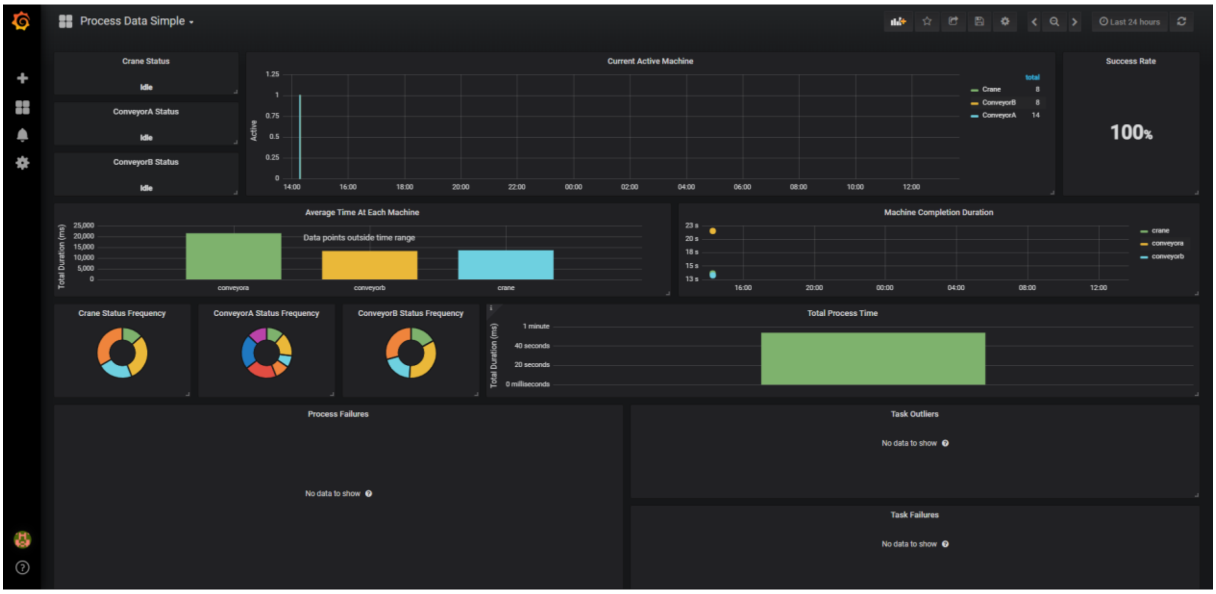

Figure 45: Analytics Dashboard

The last component provides a live video feed of the physical machine corresponding to the digital twin, enabling real-time comparison and correlation between the two. End user can set up a web camera/mobile phone camera to record the physical machine and the video feed can be streamed to any platform, such as YouTube or a dedicated video streaming service. The link to the stream can be added to the digital twin. When the end user interacts with the digital twin, the live video feed of the corresponding physical machine will be displayed in the panel, allowing for easy comparison and analysis. But this feature is optional, and the end user may not always have a physical machine to connect to the digital twin.

https://www.youtube.com/watch?v=4gp7DhKD-EI

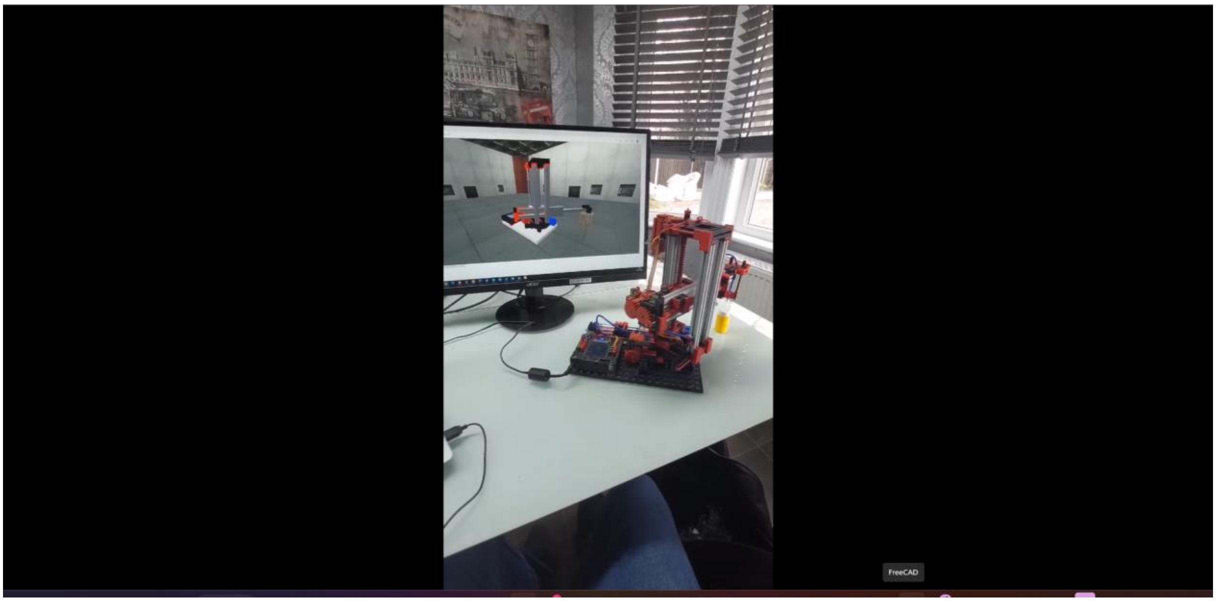

Figure 46: Live Video Feed

Architecture - High Level Conceptual

Below you will see two diagrams relating to the architecture of the digital twin kit. The first one is a less detailed higher-level diagram, more conceptual. It is intended to show a higher-level view with a focus on the parts the user interacts with, and those elements they do not . The second diagram is a detailed and technically accurate depiction of the implementation, along with all the fine details which make up the implementation.

The diagram below is a conceptual high-level view of the main entities of the digital twin (DT) kit. Here you can see.

- Red - Physical Entity which is controlled by the system
- Grey - Represent items not visible which contribute to the operation of the kit
- Orange - Visible elements which the user interacts with

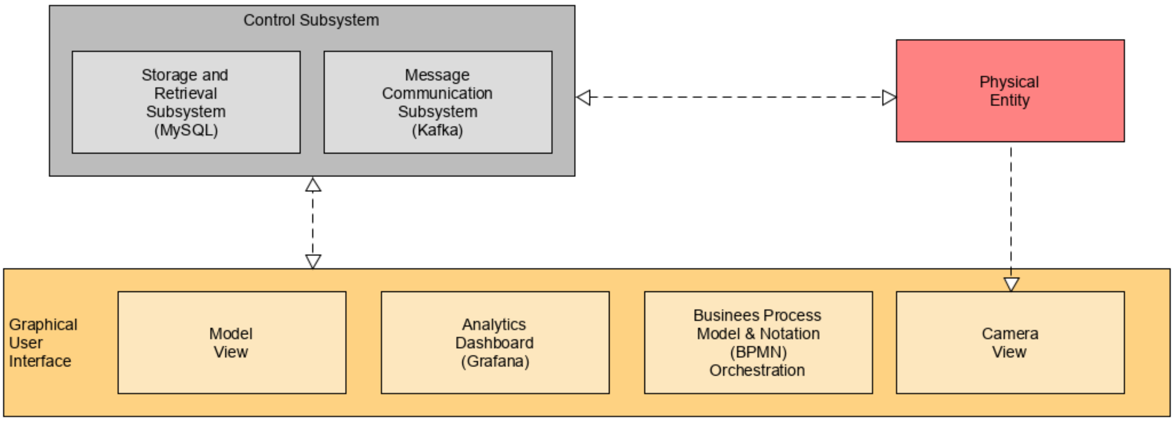

Figure 47: Higher-level, conceptual Digital Twin Kit architecture

In more detail the above diagram breaks down as follows

- Orange
  - Model View - the area where the 3D model is; displayed, animated and the user viewpoint can be changed
  - Analytics dashboard - is where the data which controls and animates the model is shown in a visual/statistical form
  - BPMN - The overview and control system which orchestrates the animation of the 3D model
  - Camera View - Is an optional feature where a web camera can be connected so the 3D model animation can be seen at the same time as the physical model is moving. The two move at the same time in synchronisation.
- Red
  - Physical Entity - this is the physical item which is being modelled
- Grey
  - Storage and retrieval sub system - this is the “conceptual” component which allows the data to be retrieved which in turn is used to animate the 3D and Physical models.
  - Message Communication Subsystem - this is like the road system or nervous system, it is the conduit used to pass messages between components.

In terms of the iPRODUCE use case for training, the synchronization of the 3D model is more than likely not a feature which will be required.

Architecture - Detailed Implementation Level

The diagram below is a technical and more detailed architectural diagram which becomes understood when looking at the detailed instructions found in the iproduce-digital-twin-kit[8] project on GitHub.

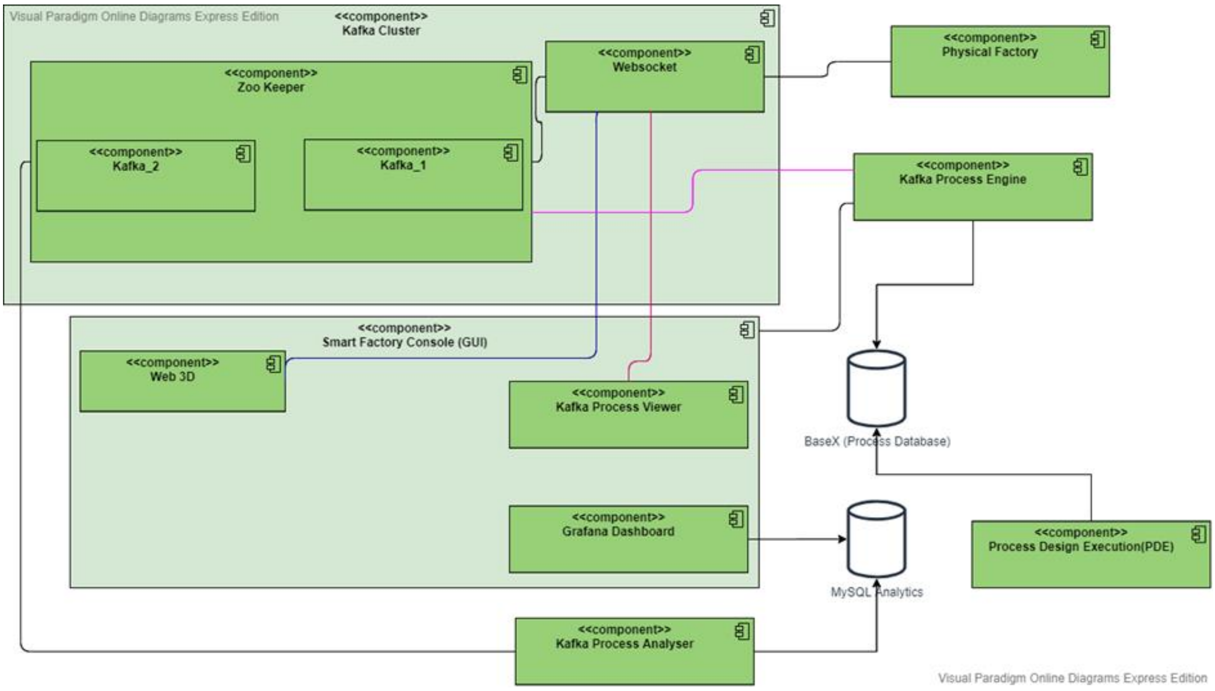

Figure 48: Technical architecture diagram of the Digital Twin Kit

The diagram immediately above, relates to the higher-level diagram which precedes it, as follows.

- Grey (high level diagram)
  - Kafka cluster and its contents
  - Kafka process engine
  - Process design execution
  - Kafka process analyser
- Orange (high level diagram)
  - Smart factory console and its contents
- Red (high level diagram)
  - Physical factory

Now we describe in detail each of the components in the low-level detail diagram

- ZooKeeper
  - ZooKeeper is a centralized service for maintaining configuration information, naming, providing distributed synchronization, and providing group services. Kafka uses Zookeeper to do leadership election of Kafka Broker and Topic Partition pairs used as messaging channels. Zookeeper sends the topology changes to Kafka, so each node

[8] https://github.com/information-catalyst/iproduce-digital-twin-kit

in the cluster knows when a new broker joined, a Broker died, a topic was removed or a topic was added, etc. Zookeeper provides an in-sync view of Kafka.

- Kafka_1, Kafka_2
    - Kafka is used as an event/messaging system to communicate between various components in the Digital Twin ecosystem
- WebSocket
    - The WebSocket is used to allow remote/web connections to connect to the Zookeeper/Kafka system.
- Web3D
    - This component is the Three.js web-based animated 3D model that provides the means to design and develop Digital Twins. The application consumes data from the Kafka topic using the WebSocket and, based on the type of message, animates the 3D model.
- Kafka Process Viewer
    - The Kafka Process Viewer provides a panel (Iframe) on the main GUI web page of the Digital Twin tool. FIt knows this by listening to the Kafka messages via the WebSocket.
- Grafana Dashboard
    - The data from the Kafka Process Analyser in the MySQL database is displayed on a live dashboard to display various pieces of information (Ex: Overall Equipment Effectiveness (OEE) statistics, currently active machines in the process, Average time per task, Any delays/failures in the system)
- Kafka Process Analyser
    - The Kafka Process Analyser listens to both Kafka topics to see when a new process begins and when the tasks are started and completed. This information is input into a MySQL database along with the duration of each task by calculating the time difference. The average times of each task are also taken into account so that if a task takes longer than average, an alert will be input into the database, which will then be displayed on the Grafana Dashboard.
- Kafka Process Engine
    - The Kafka Process Engine is used as the orchestration for the process. The Engine listens for message events on Kafka on two separate topics. One topic is when a new process starts, and the other is the individual tasks starting and finishing. When a new process message is received, it loads the process from the BaseX database, sorts the tasks into chronological order; then sends a start task for the first task via Kafka. The Web 3D receives this message and does the relevant task. Once the task is completed, it sends a completed message back to the Engine, which then, once received sends a start task for the next task, so the cycle repeats until the process is finished.
- Process Design Execution (PDE)
    - The PDE is used to design the BPMN process. The processes are used to model the behaviour of physical objects or assets modelled as Digital Twins. The behaviour of physical assets is modelled as a set of activities/tasks that are interlinked in a process. Once designed, the processes are then stored in the BaseX database.
- Physical Factory
    - this is the physical item that is being modelled

3D Printer Digital Twin Example

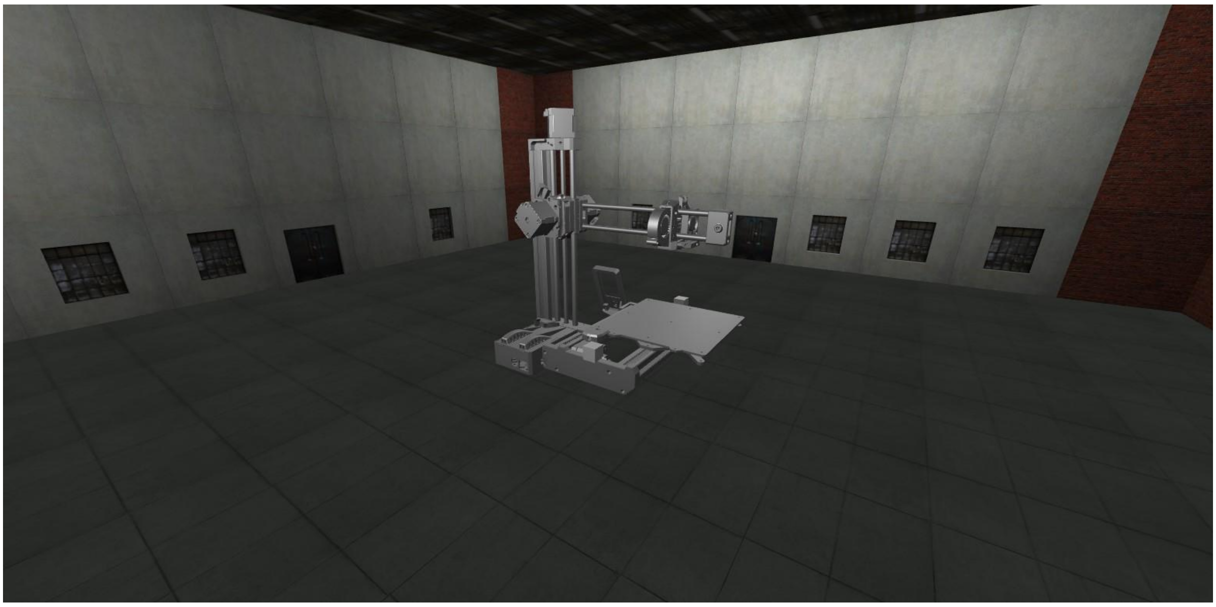

Figure 49: 3D printer digital tiwn

Using the digital twin development tool kit, a digital twin of a 3D printer was created. The 3D printer digital twin comprises a 3D Model View and a BPMN Sequencer. With the use of the 3D Model View feature, the 3D printer is displayed in a three-dimensional landscape, and the BPMN Sequencer facilitates the automation and control of processes within the 3D printer digital twin.

The 3D model for the 3D printer was acquired from GrabCAD, a public source. The model was then customized and organized into separate groups before being imported into the digital twin development tool kit with the help of OpenEdge. Each component of the 3D printer was then animated using three.js, the JavaScript library used for creating and displaying 3D graphics in the digital twin development toolkit.

By utilizing the 3D Model View, a complete 360-degree perspective of the digital twin was acquired, facilitating the manipulation of the view by rotating, zooming in and out, and enabling observation of the digital twin from diverse angles.

The BPMN Sequencer was used to change the workflow of the 3D printer digital twin and arrange the order of the process. This graphical representation tool illustrated the different steps involved in the 3D printing process and highlighted the current stage of the active process.

Using the digital twin development tool kit, a simulation of the 3D printer was created. Users can interact with the 3D printer and observe how it works in a virtual environment. They can see how the components and printer head move across the build platform and change the order of the process using BPMN. The combination of the 3D Model View and BPMN Sequencer allows for the visualization and control of processes within the 3D printer digital twin, providing a comprehensive and interactive experience for the user.

4.2.5. Tools Integration

Figure 50 shows the high-level view of the Training Support Tools components' integration.

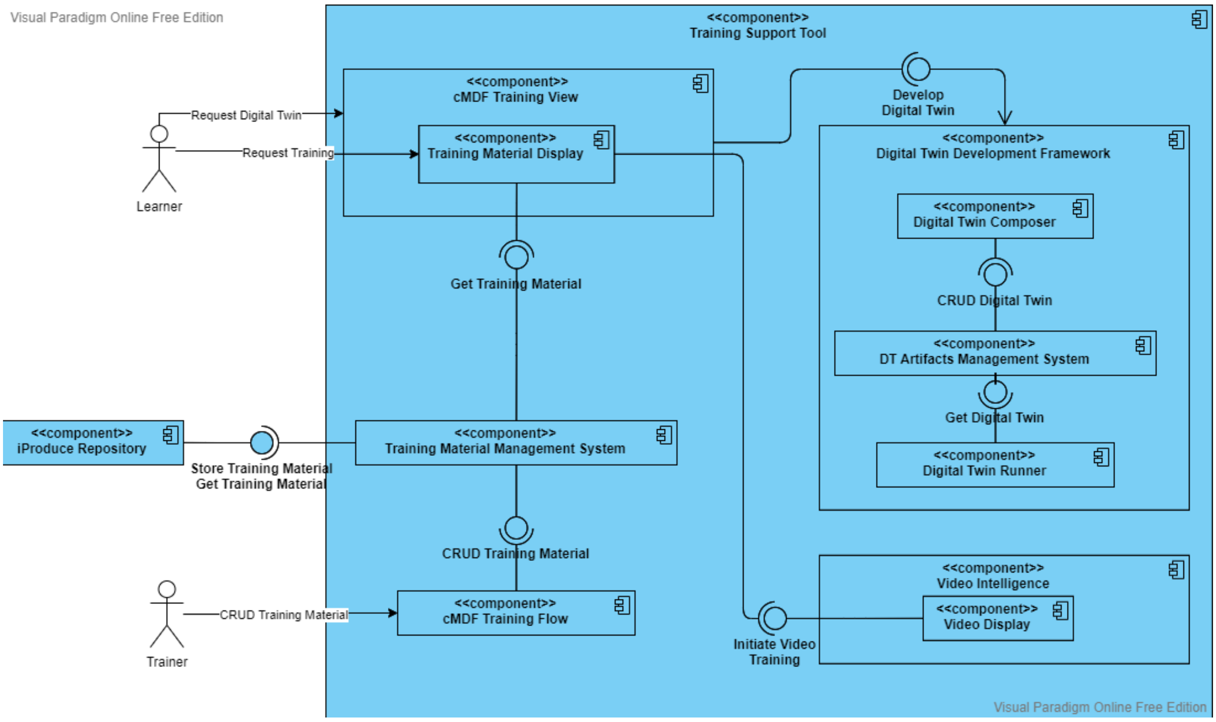

Figure 50: Component diagram Training Support Tool

There are two types of user groups who interact with the system. Firstly, trainers create, update or delete (CRUD) training material. Secondly learners request training supported through digital training material.

Trainers interact with the cMDF Training Flow component which is the interface to the Training Material Management System. This uses the iPRODUCE repository for storing training material.

The starting point for learners is always the cMDF Training View. This can by default be used to consume training material in the augmented reality view of the Training Material Display. If other than augmented reality training material is requested, then the cMDF Training View forwards the user to either the Digital Twin Development Framework for exploring machines through the use of digital twins, or video content is consumed by a forward to the Video Intelligence.

4.2.6. Landing Page for the Training Support Tool

The purpose of the landing page is to serve as an entry point to the Training Support Tool and provide a look and feel of an integrated tool to the end-user. It includes a diagram (Figure 51) giving an overview of the existing tools and how they are interconnected. This helps to understand how the individual tools are actually connected and how the data flows between the tools and the backend components.

The explanation on the landing page distinguishes two different types of users: content creators, and trainees or learners. Content creators are usually experts in a field, FabLab personnel involved in providing instructions (including obligatory safety instructions) or individuals capable of explaining how to work with a particular device or machine in the workshop. The learners or trainees are usually the

FabLab visitors/customers who are trying to understand how to use a machine or device in the FabLab or how something can be done. Suitable description for each particular user group of the functionality which the Training Support Tool provides is included in the landing page. Those descriptions include references to the individual tools or explanations how a tool can be accessed when it is running on a mobile device.

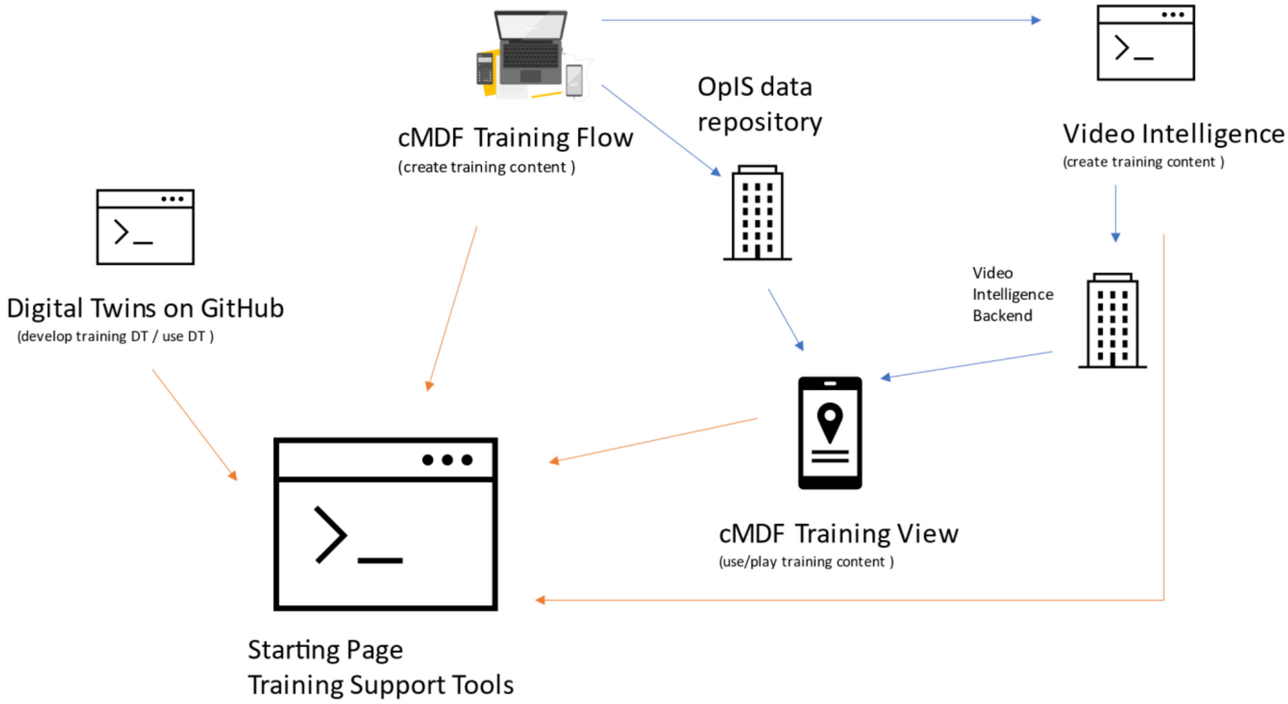

Figure 51: Integrated View of the Training Support Tool

The following is a copy of the explanation provided on the Training Support Tool landing page:

> The Training Support Tool is composed of several interconnected tools which are providing training and instructional material for the FabLabs visitors. With the help of some of the tools new training and instructional materials can be easily created by the FabLab staff itself.
>
> **Creating training content and instructional materials**
> The Training Support Tool provides possibilities for creation of different types of learning materials and training instructions.
>
> For example, the *cMDF Training Flow* can be used to create a training procedure for disassembling and assembling a device, for operating a

machine or for conducting a faulty analysis. The training procedure can also help a new member of a makerspace to get familiar with an unknown machine and/or provide the obligatory safety instructions.

The *Video Intelligence* tool can parse existing instructional videos to annotate them and create an index of the terms in the audio stream and of the object found in the video. The annotated videos are helping to get better orientation in sophisticated instructional videos and to quickly locate a subsection later on, when the trainee needs to repeat only the subsection because of doubts or uncertainty. The integration between the components of the Training Support Tool allows for use of annotated *Video Intelligence* materials within a training procedure created in the *cMDF Training Flow*.

The *Digital Twin Framework* is a toolset letting advanced users (programming skills required) to create a digital twin of a device, machine, or a production line. The digital twin can be used by novices to get familiar with a new device without the risk of breaking it.

Accessing the existing training content and instructional materials
To see what learning materials and training instructions are there available, one should download the *cMDF Training View* and install it on an Android device (mobile phone or a tablet), visit the *Video Intelligence* server or check for new *Digital Twins* on GitHub.

The Training Support Tool landing page is located under the menu “iProduce Tools / Digital Fablab Kit”.

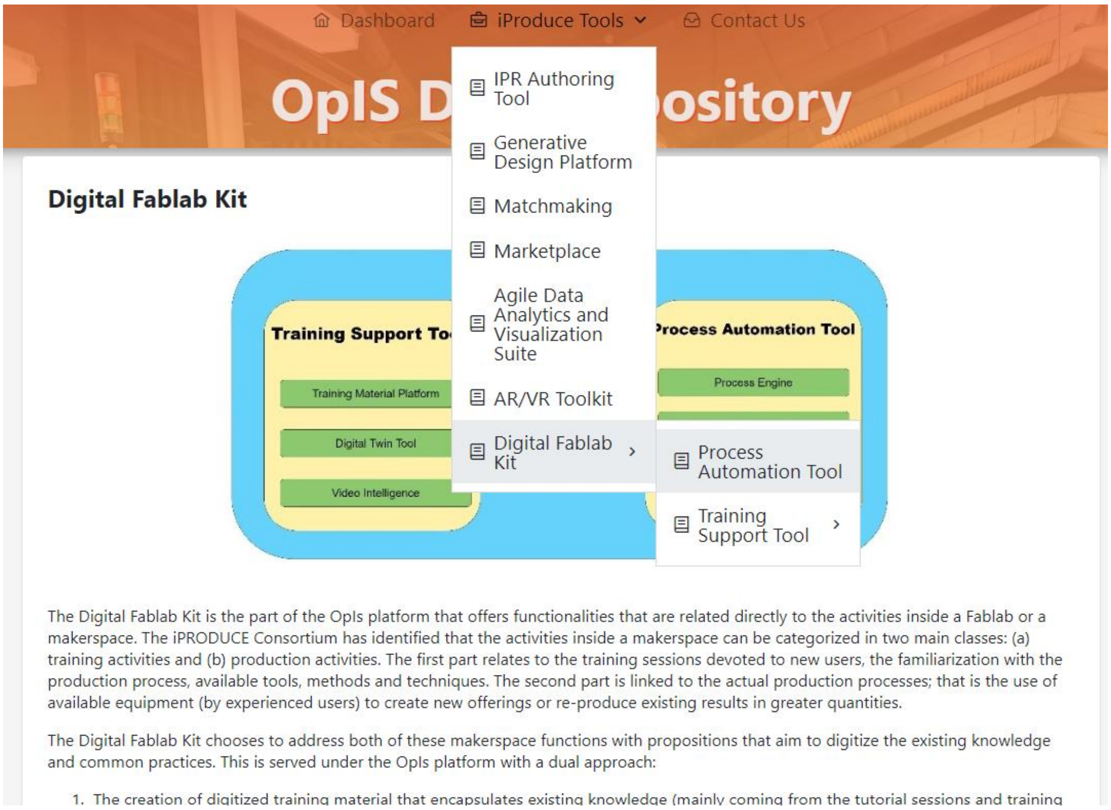

Figure 52: Access to Training Support Tool landing page

4.2.7. Roadmap for applying Training Support Tool

As current state, the Training Support Tool is ready to be applied in FabLabs. This section describes the plans to apply the tool at the Open Edge Fablab.

As a FabLab and training centre in additive manufacturing, Open Edge can draw on its community of users to apply the Training Support Tools.

cMDF Training Flow / View

Open Edge is working with the CERTH team on the cMDF Training Flow / View to create and update training material focusing on FFF 3D-printers manual bed-levelling.

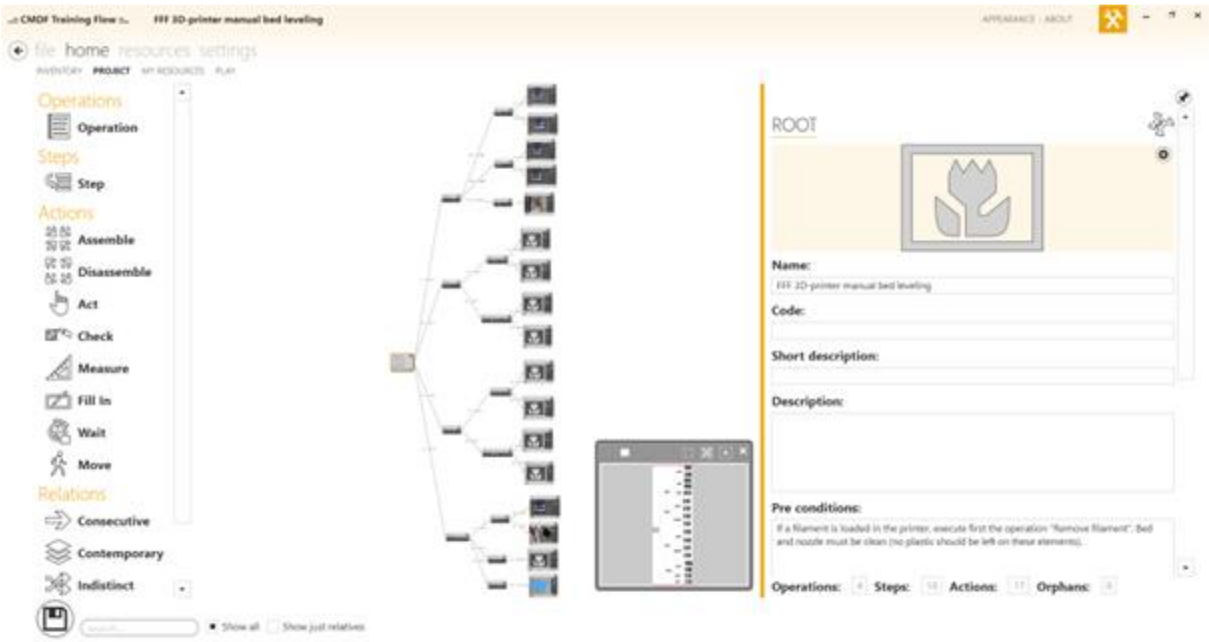

Figure 53: FFF 3D-printers manual bed-leveling procedure in the cMDF training flow

The procedure is based on videos, images, text descriptions and an animated 3D-model.

Once the training material is validated by CERTH and Open Edge, it will be tested through the cMDF training view by members of the Open Edge FabLab according to the following criteria:

Table 5: Structure of testing the Training Support Tool at Open Edge

C1	**Procedure**
C1.1	operator performs the calibration steps in the correct order
C1.2	operator uses the appropriate tools at each step
C1.3	procedure is valid for different models of 3D printers with manual calibration

C2	**Procedure results**
C2.1	operator can identify the state of the calibration (good or bad)
C2.2	distance between the nozzle and the bed is constant at all points on the printing surface
C2.3	distance between the nozzle and the bed is less than 0.1 mm when the elements are at printing T°
C2.4	extrusion lines stick properly to the bed

C2.5	extrusion lines of the first layer of the object merge
C2.6	extruder stepper motor spins continuously without skipping steps

To evaluate the procedure and the tool, the following protocol will be followed:

Context:

- Participants: Open Edge FabLab members
- Material: non calibrated FFF 3D-printer, smartphone (Android)
- Tools: precision shim (0.1 mm) or a piece of paper (80 grams)

Steps:

- Each participant follows the bed-levelling procedure on the cMDF training view
- At each step of the procedure, the fabmanager notes the supports that were used (text, pictures, videos, documents, etc.)
- The fabmanager indicates the time spent performing the whole procedure
- The fabmanager evaluate each criterion of the procedure and of the procedure results
- Each participant explains the positive and negative points of the procedure and the tool

This protocol aims to evaluate the quality of the digitisation of the learning of a key step in the calibration of a FFF 3D printer. If the quality is good enough, then the digitised bed-levelling procedure can be implemented in other FabLabs or maker spaces. If not, the procedure and / or the tool will be improved.

Results of the cMDF Training Flow / View test

Context:

- Participants: 4 experimented Open Edge FabLab members (no new inexperienced member since the implementation of the tool); they all learned how to calibrate a 3D-printer at the FabLab, with explanations, demonstrations and corrections from the fabmanager
- Material: non calibrated FFF 3D-printers (models: Alchimies HD, Velleman Vertex); computer (a technical problem made it impossible to use a smartphone)
- Tools: precision shim (0.1 mm)

Organization of the session:

- Participant 1 (P1) and 2 (P2) are working on an Alchimies HD 3D-printer model (M1).
- Participant 3 (P3) and 4 (P4) are working on a Velleman Vertex 3D-printer model (M2).

Evaluation:

+ : criteria is validated
- : criteria is not validated
~ : criteria is partially validated

	Machine (3D-printer)	***M1***		***M2***	
	Participant	***P1***	***P2***	***P3***	***P4***
C1	**Procedure**				
C1.1	operator performs the calibration steps in the correct order	+	+	+	+
C1.2	operator uses the appropriate tools at each step	+	+	+	+
C1.3	procedure is valid for different models of 3D printers with manual calibration	+	+	+	+

	Machine (3D-printer)	***M1***		***M2***	
	Participant	***P1***	***P2***	***P3***	***P4***
C2	**Procedure results**				
C2.1	operator can identify the state of the calibration (good or bad)	+	+	+	+
C2.2	distance between the nozzle and the bed is constant at all points on the printing surface	+	+	+	+
C2.3	distance between the nozzle and the bed is less than 0.1 mm when the elements are at printing T°	+	+	+	+
C2.4	extrusion lines stick properly to the bed	+	+	+	+
C2.5	extrusion lines of the first layer of the object merge	+	+	+	+

C2.6	extruder stepper motor spins continuously without skipping steps	+	+	+	+

Observations:

The participants were all experienced 3D-printer users. They had to follow the procedure as if they were performing the calibration steps for the first time, but they were necessarily influenced by their experience, which may partly explain why the result of the procedure was validated for each participant.

The cMDF training view was “simulated” on a computer so it was not possible to test the smartphone interface, but from the cMDF training flow the transition between the different steps was easy.

When they started to use the cMDF training view, participants were watching all the media available at each stage (discovery of the tool). After several steps, participants tended to focus mainly on the videos and the animation and less on the pictures and texts.

Participants’ opinion:

+	-
It’s convenient to have access to different media, depending on the users’ preferences.	It is easier / quicker to navigate through a standard video to find a specific passage.
The step-by-step procedure eliminates the need to pause or rewind a video; the user just needs to restart the corresponding piece of video.	The aesthetics of the smartphone interface (seen on a demo video) could be more contemporary.

Conclusions / recommendations:

According to the criteria, the procedure and the procedure results are both validated. The cMDF training flow enabled to formalize the procedure; the cMDF training view enabled the participants to apply the procedure.

The diversity of media in the procedure is appreciated, but participants tend to focus on moving visuals (videos, 3D animated models). For the person designing the procedure on the cMDF training flow, it is recommended to work mainly on these moving visuals.

5. Conclusions

This deliverable reported about diverse activities that are all aiming at improving FabLab-internal processes. This involves improving training processes and supporting the interaction of users engaged in a co-creation/co-production activity.

The user research turned out that pain points with regards to training processes in FabLabs are mainly around asynchronous information exchange, predefined settings / best practices exchange, reference files up to date, safety instructions & access control, repetitive starting and closing instructions, understanding the mode of operation, user pre-selection, administrative support for participant management and project documentation. Basic functionalities and concrete feature requirements for the Training Support Tool subcomponents were derived from these pain points.

Two training concepts have been set up and tested, which teach makers how to get from idea to prototype in a more human-centered way. Two training sessions are defined: The Design Thinking Introduction for Makers and the Human-Centered Prototyper. Both trainings were positively evaluated by the participants. Several indicators have been found where the Human-Centered Prototyper training can be improved. Based on this feedback, a next iteration with a follow-up evaluation is planned in iPRODUCE. Furthermore, the training material for additive manufacturing was evaluated to be useful for a physical training. The iPRODUCE tools can help convert this into an online version. Finally, the framework for teaching FFF 3D-printing can help replace the repetitive manual task to explain this to new FabLab guests by FabLab members. The training has to be implemented in the next step.

The Process Automation Tool derived the user needs by analysing directly the existing co-production practice of professionals affiliated with larger scale production - as opposed to one-of-a-kind products made by hobbyists. These production processes are characterized by the need to execute multiple production processes in parallel and usually have clearly delineated actor responsibilities. These characteristics bring a structured approach in the co-creation process, which is now orchestrated by digital means. The implementation of the Process Automation tool in the Spanish cMDF reveals the Tool's value proposition and indicates some possibilities for extension. Other ways for co-design and co-creation will be explored with the other cMDFs in the upcoming period to investigate different roles of the Process Automation tool in the co-creation process.

The Training Support Tool is a software framework which bundles the subcomponents cMDF Training View, cMDF Training Flow, Video Intelligence and Digital Twin Development Kit. Despite the intensive integration efforts, all subcomponents are remaining loosely coupled and the integrated look and feel is achieved through the Training Support Tool landing page. The landing page visualizes (Figure 51) how the subcomponents are interconnected and how data is exchanged between them. The aim of the Training Support Tool is to provide training and instructional materials to FabLabs visitors and to provide FabLab staff with power toolset for easy creation of the need training materials and instructions. The cMDF Training Flow is an authoring tool, that helps the FabLabs staff to create and manage sophisticated training material including augmented reality, text, images, and video. The cMDF Training View is the tool used by the FabLabs visitors to access and play the training instructions and materials. The Video Intelligence is a dedicated tool that can index videos using speech-to-text conversion, natural language processing and artificial intelligence. Indexed instructional videos are much more useful for training purposes because the knowledge in the video content is externalized and this helps to search and locate described concepts and procedures easier. Available indexed training videos from the Video Intelligence server can be included in the training procedures created by the cMDF Training Flow. These indexed videos are then available to the FabLab visitors within the cMDF Training View in the context of training procedures. The Digital Twin Development Kit enables FabLab personnel witch programming skills to develop digital models/twins of physical entities, such as sophisticated machines or devices (3D printers, CNC cutters). It helps users to learn about machine behaviour in a playful manner without the risk of damaging the actual machine.

The Training Support Tool was applied at OpenEdge. Further, it was tests by other cMDFs . Feedback from the tests was used to improve the technology and fix bugs.

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