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Ar/vr foR aErOspace pfb-Lb operAtors

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Report on Validation Needs Analysis

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1. Foreword

PR1 provides the foundation for the work which will be conducted in the AREOLA project. Since is the introduction of Additive Manufacturing (AM) over three decades ago, industry has struggled with the shortage of skilled additive manufacturing professionals. This problem is particularly acute in the rapidly adopted area of metal PBF-LB (Powder Bed Fusion Laser Beam) where there is a shortage of both operators and engineers. The covid-19 pandemic has exposed the problem of relying solely on face-to-face training. To tackle this issue, education must continuously improve and evolve to take advantage of new digitally enabled training tools. The aim of the AREOLA project is to help to address the shortage of PBF-LB operators through the use of AR and VR technologies, particularly to undertake aspects of practical training.

The need for improved AM training has already been in the AM Skills Strategy Roadmap in 2021, developed in the Erasmus+ SAM (Sector Skills Strategy in AM Sector) project, where the "competition for skilled AM workers and lack of knowledge of AM from existing workers/students" as well as the "shortage of training centers, specially at Vocational Education and Training (VET) level, capable of delivering AM training", were identified as gap drivers to address in the AM sector. In terms of training offer, although there are a number of courses available from universities focused on AM (from example from Cranfield University in the UK), however these are primarily at master's level (level 7 in the European Qualifications Framework). As they are aimed at a relatively high academic level and thus may be inaccessible for many workers that could potentially be "skilled up". In this sense, a higher number of qualifications for lower EQF levels is deemed to be necessary in the AM education system, preferably qualifications recognized at a European/international level. On the other hand, highly complex, diverse and knowledge-intensive production processes, such as AM, will demand a high level of specialization of skills and knowledge which is still not being addressed by the great majority of AM education centers. Moreover, according to the studies performed in SAM project, training providers deliver their training at customer's premises or at the training center itself. Another significant proportion of training courses are offered online. In summary, it can be concluded that individual providers use several ways to offer training (at company site/education center or as mixture of presential and online-training, e.g. blended learning).

AREOLA can be seen as a logical development which addresses some of the concerns raised in the SAM project, specifically in addressing the need to undertake practical training in a more flexible, accessible, efficient and scalable approach. In this way, the project will help to support the large number of employees who have so far been neglected by traditional learning opportunities and whose potential for upskilling would be lost as a result. Machine operators of metal PBF-LB systems fall precisely into this target group.

2. PR1 Presentation

2.1 General Information

For the detailed internal analysis, the content of the existing vocational training profile for metal AM PBF-LB operators (defined in the International AM qualification system – IAMQS - developed under the SAM project) was first analyzed by desk research with regard to its composition and feasibility for the implementation of Augmented Reality or/and Virtual Reality. In the following, the abbreviations "AR" and "VR" are also used for the terms "Augmented Reality" and "Virtual Reality". In addition, the abbreviation "XR", which stands for the collective term "Extended Reality" and includes the technologies AR and VR will be used.

This first step is carried out in section 2.2.1 by means of a blended learning and AR/VR screening. In detail, this implies that every single learning unit (“Competence Unit” or “CU”) of the training profile was examined regarding its potential for blended learning or AR/VR support.

For the second step of the analysis within PR1 (Project Result 1), an evaluation matrix was designed that allows individual use cases, within the previously identified learning content, to be analyzed in more detail. Eventually, each of these use cases has been evaluated and classified based on a collection of criteria. The resulting evaluation score allows a pragmatic assessment of how suitable the individual use case is for revision with XR tools. PR3 will make use of this template to finalize the analysis of potential use cases to enable the selection of the scenarios to be addressed using XR enhanced training.

2.2 Task 1: Internal Analysis and Desk Research

2.2.1 Blended Learning / Extended Reality Screening

A major part of the desk research is represented by the analysis of the existing training profile for the metal AM PBF-LB Operator, every single competence unit was reviewed taking into account four perspectives: training, didactics, XR and finally norms, as shown in Figure 1.

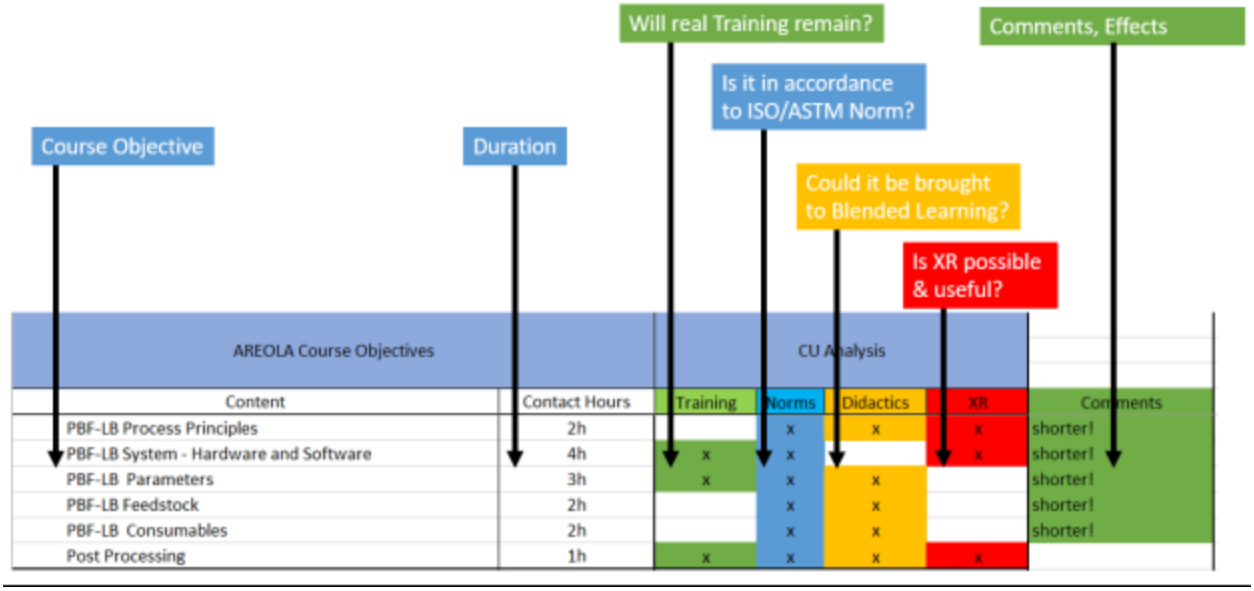

Figure 1: BL/XR Screening

The columns under the first headline “AREOLA Course Objectives” are directly deducted from the content of the training profile. “Content” specifies the single learning packages stated in the profile, whereas “Contact Hours” represents the time that trainer and learner physically spend together for processing the specific content.

The second heading (“CU Analysis”) summarizes the desk research. Here, each learning content was assessed with respect to the following approaches which could be implemented, namely:

- Training (physical face-to-face training)
- Didactics (learning concepts such as eLearning)
- XR (extended reality content)

In addition, the conformity of the respective learning content with the ISO/ASTM 52942 “Additive manufacturing - Qualification principles - Qualifying Machine Operators of Laser Metal Powder Bed Fusion Machines and Equipment used in Aerospace Applications” standard was cross-checked, as far as possible based on the data available. This guideline represents the base of education in AM for Aerospace. It provides worldwide standardization of the certification of machine operators in PBF-LB in the aerospace industry. Manufacturers, suppliers, and customers should be able to trust the given level of training, if certification is received.

To ensure that the standard does not lose its validity for our modules, the activities that are digitally expanded or replaced must be carefully selected. So, the following investigations and research were carried out conscientiously in order to avoid a possible compromise of the acceptance of the certificate.

2.2.2 XR Evaluation Matrix

The screening for the utilization of BL and XR in section 2.1.1 showed great potential for the application of XR within the learning path. Next, for the analysis the potential of possible use cases within PR3 a XR evaluation matrix was developed. Therefore, many different criteria were collected and clustered in order to allow a proper evaluation of every single possible use case.

Screenshots of the full version of the matrix are attached within Appendix 2 of this report. The version shown below includes the full complement of criteria and associated questions without actually evaluating use cases.

The following explanations will give a detailed overview of the overall structure, as well as of every single criterion defined within the matrix.

The matrix is composed of five sections, each of which in turn contains a collection of questions and criteria. The five sections are defined as follows:

Knock-Out Criteria

In order to successfully transform theoretical analog content into XR content, some things have to be considered as basic requirements. If these basic requirements cannot be fulfilled, this makes the implementation of this specific use case impossible.

The section “Knock-Out Criteria” summarizes these criteria and thereby enables, as a very first evaluation step, a filtering of all theoretically possible use cases, without considering other criteria. Some of the most important criteria in this section are, for example, the availability and accessibility of proper 3D/CAD data. If suitable 3D data material cannot be accessed, or if IP rights deny access, this makes the development of XR content much more difficult and expensive. If a heavily simplified reverse engineering of 3D data is also not possible, this often prevents the development of XR content.

Use Case Classification

This section refers, quite pragmatically, to the characteristics of the respective use case. Due to the ability of XR to use 3D animations, practical content of an application or training (e.g., manual steps) is often much better suited for the implementation as XR content than theoretical content (e.g., software training). The number of steps and the additional tools or equipment required also play a role.

Business Case

The "business case" cluster goes one step further and no longer just evaluates whether use cases are generally technically possible, but, as the name suggests, includes business aspects and impacts. These relate both to the hardware for which the content is tailored (through taking into consideration the installed base, as well as sales forecasts), as well as factors such as time savings, how frequently tasks are executed, or whether XR content might save time when performing tasks.

Risk Assessment

XR training content offers the possibility of safely depicting potentially dangerous content. This applies both to the people to be trained and to the hardware used. This section is trying to pin down and evaluate these risks.

XR Related

This last section of the evaluation includes criteria related to XR development. These are based less on hard facts, such as in the "Business Case" section, and more on experience.

2.2.3 Conclusion

In conclusion, the analysis of the vocational training profile for metal AM PBF-LB operators conducted as part of the desk research holds great potential for the digitization of content using XR technologies. It is striking that above all competence units with a focus on training content to be carried out manually, such as machine maintenance, prove to be suitable for transformation. This is clearly demonstrated by a look at "CU 21: Maintenance of PBF-LB Systems". However, other content should not be neglected. According to desk research, it may also be worthwhile to include topics such as health and safety (H&S) or the training of machine software. At first glance, these areas do not appear to be suitable for implementation with XR technologies, but it is also possible to find ways to supplement these contents with XR and thus enrich them.

In summary, the profile consists of 10 Competence Units, which in turn consist of a total of 43 individual learning units (training sessions ranging from 1-5 hours). The blended learning / extended reality screening has shown that only about 58% of these units are well suited for classic face-to-face training. Around 72%, on the other hand, are ideally suited for the use of didactic learning technologies such as eLearning. Just under 42% of the content is suitable for the use of XR learning technologies, which perfectly reflects the great potential already mentioned.

It should be noted that this analysis was conducted at the very beginning of the project. It cannot be ruled out that the percentage distribution will change slightly as the project proceeds and experience increases. Furthermore, this first step of the analysis can only be understood as a rough approximation. A more precise analysis of individual applications will only be made possible by the XR Evaluation Matrix created in the following and applied in PR3.

The creation of the XR Evaluation Matrix based on the desk research is therefore seen as a necessary tool in the final evaluation of individual use cases. Especially when based on the large potential identified in the BL/XR screening. Ideally, the results of the evaluated applications coincide with the previously considered learning units of the Competence Units. However, deviations, as already indicated, cannot be ruled out.

2.3 Task 2: Development of Interview Guideline

For Task 2, an interview guideline was developed as methodological approach to engage aerospace partners. One of the objectives of this interview was to compare the results of the internal evaluation of possible use cases with expert opinions from the aerospace industry and training providers. This approach allowed an objective insight into the results of the internal

evaluation and reveals possible unconsidered demands of the aerospace industry and training providers.

The full version of the interview guideline is attached within the Appendix 3 of this report.

In general, the following questions represent the core of the research:

- What sort of AM training is in use/needed?
- What is the format of the training implemented at your organization? (e.g.: in house training; outsourced; blended; e-learning; face to face)
- How do you undertake practical training (internal or machine OEMs)?
- Have you considered/used of AR/VR tools for training and what was the experience?
- Could AR/VR tools be used to replace face-to-face training, or it is a supplement to support conventional training routes?
- How did/is Covid19 affecting training at your organization?

2.4 Task 3: Analysis of Interview Results

2.4.1 Presentation of Results

The following pages provide an insight and summary of the interview results. Semi-structured interview form was used to gather data from the participants. The interview protocol was developed by project result leader and finalized with expert opinions from other partners. The final protocol includes eleven questions to be addressing, the nature of the AM training is in use/needed, the format of the training implemented at your organization, the way of undertaking practical training, experience of AR/VR, view about using AR/VR in the training and Covid-19 effects on training.

Every consortium member conducted at least one interview with aerospace sector stakeholders (OEMs or tier 1 suppliers) or training providers. Interviews were conducted through video calls and face-to-face meetings, lasted for approximately 30 minutes. A total of twenty interviews were conducted by the consortium, considering the nature of the qualitative data, twenty interviews are quite sufficient to draw conclusions about the needs of the aerospace industry and training providers. To conclude the result, the most relevant and significant answers from all the interviews are given in a paraphrased version.

It is important to mention that all the interview results will be provided in an anonymous way. Nevertheless, the following table gives an overview of the interviews conducted:

#	Industry Sector/Role	Country
1	Aircraft Manufacturer	USA

2	Aerospace Supplier	Germany
3	Aircraft Manufacturer	Germany
4	Space Enterprise	Germany
5	Aerospace Supplier	Spain
6	Aerospace Supplier	Spain
7	Aerospace Supplier	Turkey
8	Research Institute	Germany
9	Aerospace Supplier	Spain
10	Aerospace Supplier	Germany
11	Aerospace Supplier	Germany
12	Aerospace Supplier	Great Britain
13	Aerospace Supplier	Great Britain
14	Aerospace Supplier	Great Britain
15	Vocational Education and Training Center	Portugal
16	Vocational Education and Training Center	Portugal
17	Vocational Education and Training Center	Spain
18	Vocational Education and Training Center	Turkey
19	Vocational Education and Training Center	Italy
20	Vocational Education and Training Center	Ireland

The responds of the participants were transcribed on the questionnaire form right after the interviews. Then the gathered data were analyzed through descriptive analysis method and reported under categories.

Implementation of AM training in Aerospace Industry and at Training Providers

For most of the aerospace organizations and training providers that was talked to, it seems to be essentially important that their machine operators are being trained by the open education methods, either on their own site or at the OEMs facilities. This highlights the importance of the face-to-face training offered by the vast majority of OEMs and also speaks for its quality.

Some interviews comments are given below:

Question	Industry Stakeholder	Training Provider
Do you provide or intend to provide training for additive manufacturing?	Yes, we are providing technical trainings. Yes, for our machine Operators it is a basic requirement to receive training from the machine provider, even if there is high fluctuation.	Yes Yes, for designer to design or in general topic. Designer, operator and we are willing to do for engineers also.
What sort of AM training are you delivering?	General training on AM, to better understand the technology in order to use it in the future -Training on Postprocessing: machining of AM parts They need training in design engineering for AM, calculations, optimization and simulation of components	PBF-LB; introductory level PBF-LB trainings for students, and internal people as small groups We have polymer, metal AM, FDM, SLS, Stratasys 400-mc, SLM PBF machines and have trainings in these fields.
How do you undertake practical training (internal or machine OEMs)?	For us it is especially interesting to receive a first training session done face-to-face by the OEM within our own facilities. For any other colleagues involved in the AM process, the people who initially received the OEM training can educate others. Two lead operators are being trained by the machine OEM, these lead operators train the additional staff in-house. No particular training material is used, training is based on the	the powder bed machine training is in house. In house At the moment we are going to implement blended learning, so some modules will be online, i.e. theoretical. These are both undertaking at home. We are developing our learning elements. We want to deliver the

	operating procedures defined in the machine manual. All machine operators take the basic machine operation training. Due to the low number of AM staff the face-to-face training becomes quite expensive, therefore also remote trainings have been used, especially during Covid times. The practical training is conducted on site on our own machines. All our machine operators have gone through the in-person machine operation training. As far as we can imagine we would continue doing that for new colleagues. We want to make sure all the proper techniques and safety precautions are taken. For smaller procedures we would do that internally. For our machine Operators it is a basic requirement to receive training from the machine provider, even if there is high fluctuation. It is not only about operating the machine, but also the background knowledge that´s important for our operators. New colleagues typically run with experienced colleagues for a couple of weeks before they are being sent to EOS. We consider the on-site training even more efficient when the operators have already acquired some amount of pre-knowledge. They are then more open for additional information.	theoretical parts first and then reinforce it with a practical session, so the trainings will be more integrated.

According to the results, both aerospace industries and vocational training providers have additive manufacturing (AM) training and deliver it at different levels. In the case of industry training is undertaken internally, externally or through the AM machine OEM. However, training providers often provide training internally, even though the AM machine OEM.

Awareness about AR/VR Tools in AM Training

In order to explain the knowledge of industries and training providers about AR/VR, some questions were asked to participants.

As shown in Figure 2, 57% of the respondents have knowledge about AR/VR and 43% have some knowledge about AR/VR. However, all respondents have an idea of what AR/VR is.

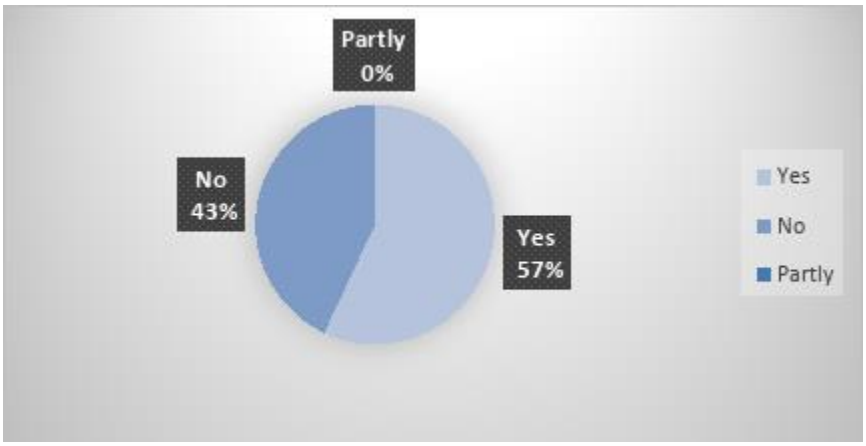

Figure 2: Having knowledge about AR/VR

When we asked to the participants' view about AR/VR can support the training or not, almost all participants reported that AR/VR can be used as a supporter in training (see Figure 3).

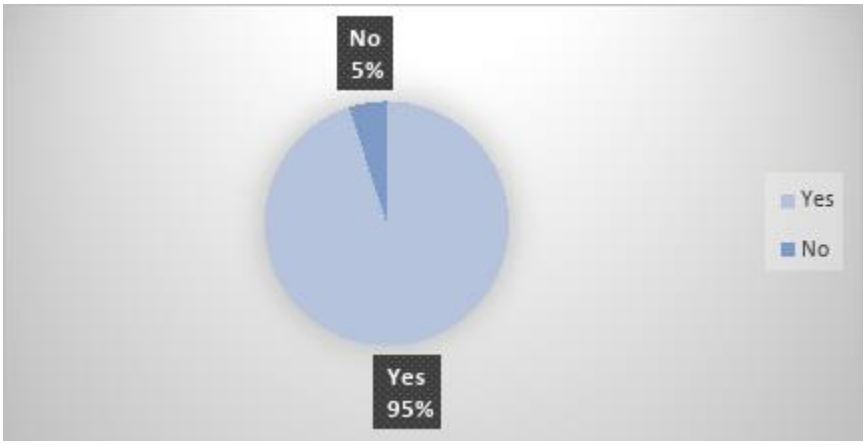

Figure 3: AR/VR as training supporter

The participants were asked about they have already used AR/VR tools to conduct training (Figure 4), most of the participants answered the question “yes”.

Note: it should be noted that AR/VR was generally used for management training none of the organizations consulted are using AR/VR for practical AM training.

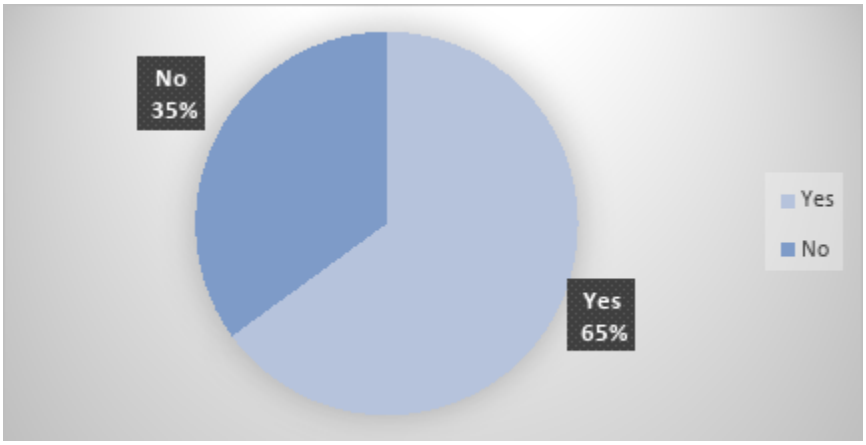

Figure 4: Usage of AR/VR in training

Both graphs above provide a clear picture of the application of AR/VR technologies within Aerospace training. The graphs show that all of the interviewed aerospace organizations and training providers are aware of AR/VR technologies. At least in each group of interviewees, there are participants who are familiar with the technology. Only individual interviewees were not familiar with the technology or were unsure of the distinction between AR and VR. Within each group of interviewees, it was agreed that the technologies are suitable for use in the training sector although 65% of the industry stakeholders and training providers integrating AR/VR tools in the training.

The following paraphrased quotes provide a better insight into the current role of AR/VR in the training of aerospace companies:

Question	Industry Stakeholder	Training Provider
Have you used AR/VR tools to conduct training?	We have not used it ourselves, but I know there is something going on with this technology within our company. Our company is testing AR technology already in the field of assembly. We could imagine the same setup for maintenance procedures on an AM machine. Our experience with AR/VR comes from the implementation of such tools to provide training	Yes, we are considering to using AR/VR tools. We should start from training purposes so sometimes for companies that don't have the facilities available for company. They are far from the training centre or actually when you want

	for arc welding. From the interviewed perspective, AR/VR can be used as a substitute in an initial stage of the training. Above a certain level it is more difficult to implement as it starts to lose its usefulness. At least for arc welding the experience is good, AR/VR can be used as a complementary tool for the practical training delivery. We´ve mostly been using AR/VR tools in management training. We´ve been using AR/VR for a manufacturing challenge we once did for the rapid supply of ventilators for Covid patients. After that, more MS HoloLens's have been purchased to support inter-site communication where travel has been restricted. We´ve established three use cases: Training, Remote Assist, Quality Assurance. Although the level of use is relatively low (internal "audit" of use will be undertaken) in some cases the use of AR/VR tools have proven to be very helpful, for example avoiding key technical experts traveling around the world to visit different sites.	to save materials and resources AR/VR tools are very effective. Yes, a virtual reality welding tool is used. This tool can't completely replace the real experience. However, it allows for the simulation of very complicated scenarios that can't be easily replicated in real life such as welding in different positions.

Views on using AR/VR in Training

Participants were asked what they think about the negative (limitations) and positive (benefits) aspects of using AR/VR tools in training in order to get more detailed information about the use of AR/VR tools in the aerospace industry and the training provider. Some quotes from the participants are as follows:

Questions	Industry Stakeholder	Training Provider
Do you foresee limitations to the use of AR/VR tools for practical training?	For training our operators, we have imposed even stricter rules on ourselves internally than the standard specifies. The XR content would therefore also have to comply with our stricter rules. This could be the case for other companies as well, which might be a challenge for the creation of XR content. Basic information could nevertheless be transferred via XR technologies.	Requires highly qualified trainers to provide the training. There are a lot of variables that come into play when talking about PBF-LB and providing a simulation that will accurately replicate what

	After some time, every machine will become unique as more and more maintenance is done on them. Standard trainings could not match with the actual state of the machine. Basic training should be close enough though.	happens in real life may prove to be very difficult.
	To put yourself in the XR environment could be more complicated than the task you actually got to do.	These tools are expensive. It is difficult to create complex scenarios within them.
	Headsets are often not the best solution. Min. 1 hr - hassle of setting up the unit (this may change if used more often). Max. 4 hrs – uncomfortable to wear for long periods.	The lack of real sensation. It's not yet 100% representative of the reality and still need to developed.
	Limitation if displays are to be made, for example, in narrow inaccessible zones of a machine, etc., where the operator also does not have good access (design limitations according to type of activity).	Sometimes students do not want to wear the glasses, because the glasses have effects. Some scientific studies pointed the effects of head dizziness, nausea and so on.
	If you have only been trained virtually, you don´t have any sensation or feeling on forces that you need to unlock or open something. When you get back to reality you fear to be too forceful on something.	If you do not have glasses for each student, they have to wait for each other which wastes time.
	With VR, there are basically no concerns, but the haptics are missing, which means that the weight, for example, when filling or decanting powder cannot be recreated. This would probably be the biggest difficulty.	If a software does not have good quality and resolution, these contents will have a side effect on users.
	Cost of the glasses, depending on the tasks this can be a limitation.	
	For riskier tasks it is even more important to have hands on the machine (but the AR/VR can be a first introduction).	

	Some employees seem reluctant to embrace new approaches. Ideally there is someone available to iron out IT issues. Users need to be familiarised with the equipment before training starts. AR/VR is not as effective as face-to-face classes where people need to work together. To get the most out of this approach all attendees need to be comfortable/relaxed. Some workers struggle with the AR/VR devices – particularly older workers and those without computer gaming experience. Complexity for the subject of short series. Because a digital model would have to be developed for each case of need and it might not pay off.	

Participants' opinions on the negative side or foreseen limitations of AR/VR use were quite parallel. In general, participants stated that some limitations in the use of AR/VR due to expenses of AR/VR goggles, inadequate for complex issues, resistance from the personnel to be trained, and lack of a sense of reality.

On the other hand, benefits, and positive sides of using AR/VR were explained by participants as follows:

Question	Industry Stakeholder	Training Provider
What are the benefits you see in using AR/VR tools for training?	We were able to do some dry runs on a powder free filter, but we could imagine doing this in a virtual environment to get even closer to real doing without having the machines running. XR could help to address several senses at the same time, which increases the learning success.	it's really useful for machine demonstration, so it's really helpful for attendees. For instance, cleaning the bed and how that would look if they can't be on site. I think that would be very useful. You can use and also to avoid limiting the risks that

	Possible applications: RFS, dealing with hazardous substances, HSE. For sure in the area of filter change or for setting up the machine. We have machine setup described paper-based or as an PDF. Digital tools could make things easier, also when we talk about documentation and quality assurance but as well about worker safety. So, there are two areas of application. One is the initial training and the other one is digital support during the execution of the tasks. Filter change was the scariest part of the training, with the rest of it we felt quite comfortable. If you could find a way of teaching the filter change without exposing someone to the risk, then it should be done.	can always happen during the training when you are facing this welding and the and the inspection processes, you can actually perform these by either augmented reality or virtual reality. You can save resources and you've got much more availability and flexibility to perform the process whatever you want. These machines are safety for dangerous tasks. They provide visual inputs to students. You can make a prototype or in real life can avoid waste of materials steal or titanium.

Most of the participants revealed that AR/VR tools are useful to protect trainers from hazardous chemicals or tasks, to avoid material waste, to introduce a new task to trainers, and to feel inside of a real-life experience.

Role of AR/VR in Training

Covid-19 has undeniably had a serious impact on education processes. Both industry stakeholders and training providers mentioned how Covid-19 has affected delivering training:

Question	Industry Stakeholder	Training Provider
How did /is Covid-19 change the way you undertake training?	Following all the safety protocols, we were able to conduct the training on-site at the EOS training center. One training took place within Covid. We were able to execute the training on-site though, following all the safety	During the Covid-19, they delivered only the theoretical training. Nobody thought about online training before but today almost all students want to

	protocols. For some training we asked for online training/MS Teams sessions. Covid absolutely changed the way we undertake training. There is no face-to-face personal training anymore, and there's some barriers that remote training cannot address, like personal interaction and level of attention of participants during the whole session. Covid-19 was very disruptive for training – eventually on-line (TEAMS) and social media platforms were adopted for training. We are also evaluating new on-line training platforms such as EDX and Udacity.	have online trainings. It has some positive and negative consequences. Positive side; people can attend any training from anywhere without wasting time going to training centres. But imagine you're at home and you have some responsibilities with you (children, cook etc.), so in this condition the efficiency of the training decreases this is one of the negative sides of online learning. We moved all trainings to the online platform. We provided the software used in the training to the students with laptops. But when we were able to do the lessons face-to-face, our trainings became 100% hands-on and face-to-face.

Covid-19 particularly negatively affected practical training because both sectors and training providers did not have enough training materials for it. During Covid-19, training was mostly focused on theoretical training, practical training gaps were closed when face-to-face trainings could be implemented.

The proliferation of technologies and integrating technology into education can support training but according to most of the participants, AR/VR tools cannot totally replace face-to-face training.

Question	Industry Stakeholder	Training Provider
Could AR/VR tools be used to replace face-to-face training, or it is a supplement to support conventional training routes? What could be the role of AR/VR tools in training?	When you initially buy your first machine, face-to-face training is necessary. But if you have a first specialist and you get additional associates you could teach them virtually and the experienced person could follow up with hands-on training to reduce the time spent with hands on training. I don´t think you will be able to eliminate hands on training entirely, it should be a combination.	I cannot say for AR, because wearing the glasses for a long time is not possible and it is not affordable provide a glass to each student. However, I can say VR could be replaced 100% with conventional training.

	Not as a replacement. It may be used to reduce face to face training duration.	It cannot be given totally virtually. I estimate that up to 80% of the training could be undertaken virtually.
	We cannot stress this enough, but we envisage AR/VR tools as supplement to conventional training routes. There is no way we would ever substitute the first contact in person with the technology provider, if possible, in our own facilities. For us it would be a supportive tool for that, or even for secondary training session which require less level of immersion.	We can use AR/VR in some particular topics; however, it is not possible to totally replace with conventional training. But if you want to practical training and you should wait for this, AR-VR will be good solution.
	It could partially replace the pre-specialty. It would be a complementary tool. Very interesting to reduce the staff that is giving training to new operators.	
	Flexibility of the scenarios that can be displayed at any time, especially for activities that occur infrequently, for example, on machines that are only serviced 2-3 times a year.	

2.4.2 Conclusion

The results of the interviews with industry and training providers, the current use of AR/VR in training, and the participants' views on the topic, have confirmed the necessity of the AREOLA project.

Suitable Subjects for AR/VR

AR/VR is a valid approach to have existing trained and experienced operators educating new colleagues, perhaps located elsewhere. AR/VR can be used to reinforced/refresh training conducted previously face-to-face. Here, learning content optimized by AR/VR technologies could be a suitable alternative for conveying knowledge to new colleagues in a reliable and correct manner. Especially, AR/VR tools would be efficient to train new colleagues or to introduce a new machine or task to trainers. For instance, in an industry stakeholder, new colleagues run with experienced colleagues for some time in the regular daily routine, and then sends them to OEM face-to-face training with the prior knowledge they have already acquired. Likewise with AR/VR

training, the effort required by experienced colleagues to train new machine operators can be significantly reduced without reducing the quality of the training.

From a practical point of view, the use of AR/VR tools is appropriate for training in aerospace sector and will contribute to practical training. In particular, when used in health and safety issues, in introductory level subjects, in applications where high-cost materials are used, it can help to reduce work accidents, prevent damage to machinery and conserve resources. To illustrate, typically, face-to-face operator training begins with a thorough introduction to health and safety issues, including personal protective equipment. During face-to-face training, attention is continuously paid to these issues, and they are also mentioned when handling the real machine. Nevertheless, there seems to be additional demand from the training in aerospace field interviewed for continued training in the area of health & safety, which could possibly be satisfied with the help of digital content. Another example, when practicing changing filters, trainees can come into contact with metal condensate and the activity is often only possible with Personal Protective Equipment (PPE). AR/VR tools offer operators the opportunity to carry out training without coming into contact with hazardous substances. In addition, the operation of the plant is not disturbed.

The innovative approaches of AR/VR technologies, when used as a supplement to traditional education, can support education in many ways, making it a more efficient process. For example, thanks to AR/VR technologies, trainees have the opportunity to repeat trainings at any time. Especially in e-learning processes, it makes practical training more useful because it provides trainees real life experiences through simulations the environment. Moreover, training might become accessible, and less expensive through AR/VR tools. Trainees do not have to travel any training centre.

AR/VR vs. Conventional Training

AR/VR tools are certainly resources to improve the quality and efficiency of education. However, due to some limitations, AR/VR tools cannot fully replace face-to-face education. When developing AR/VR content, deviating from the standard is indeed a challenge that should not be underestimated, as even small changes to the content can result in major changes to the 3D data, for example. Within the framework of the AREOLA project, it will therefore be particularly important to identify standardized processes that are equally relevant for all organizations. Another significant limitation is the lack of haptic (touch) sensing and feedback during training with AR/VR. Especially for new machine operators, it is important to get a good feel for the forces that certain activities require. The selection of suitable content to be digitized goes hand in hand with its complexity and the resulting use of AR/VR devices (especially headsets). On the one hand, the setup of the AR/VR content must not further complicate and unnecessarily prolong the actual learning content. Moreover, a coherent learning unit should not exceed a certain length of time to avoid the discomfort of wearing headsets for example, over a protracted period.

Even if regulations/ standing (such as ISO/ASTM 52942) allow entire training to be undertaken virtually the aerospace companies do not wish to switch to 100% digital training. Indeed, most respondents believe that conventional training should never be completely replaced by digital

content. AR/VR is mostly seen as a useful complementary approach. In the AREOLA project, the right content such as highly hazardous situation and time-consuming job must be found for transformation in order to find the most effective combination of on-site training and digital training.

3. Conclusion

In order to be able to carry out a final evaluation of PR1, we take another look at both parts of the analysis, the desk research carried out first ("Blended Learning & Extended Reality Screening") and the subsequent analysis of the industry and the training providers, both of which were collected through interviews. Two clear trends emerged from the desk research. First, that the vocational training profile for metal AM PBF-LB operators is very well suited for the extensive use of extended reality (XR) technologies and secondly, that at first glance, practical “hands-on” activities such as maintenance work is particularly suitable.

In PR3, these first rough results are checked again in detail with the "XR Evaluation Matrix" developed in PR1 and compared with the interview results before they finally go into production.

If we compare the results of this initial theoretical analysis with the developments and ideas in the market, we find clear overlaps. One example of this is the process of handling the filter system of PBF-LB systems, which has been mentioned several times. From the point of view of the industry and training providers, these steps, usually during the setup process or maintenance, are not adequately trained for various reasons. This may be due to safety reasons or simply a lack of time to repeatedly perform critical and/or complex operations. Apart from overlaps in the obviously suitable processes such as manual maintenance processes, training content such as health and safety was also mentioned by companies from the aerospace sector. For this particular training content, XR tools could serve primarily to improve clarity and engagement.

Basically, the use of digital technologies such as augmented reality or virtual reality could revolutionize the training of this content and thereby significantly boost efficiency and effectiveness.

4. Appendix

Appendix 1: Blended Learning / Extended Reality Screening

AREOLA Course Objectives		CU Analysis				
Content	Contact Hours	Training	Norms	Didactics	XR	Comments
CU00: Additive Manufacturing Process Overview	3,5h					
Directed Energy Deposition	0,5h			x		shorter!
Powder Bed Fusion	0,5h		x	x		as review to TR
Vat photopolymerization	0,5h			x		shorter!
Material Jetting	0,5h			x		shorter!
Binder Jetting	0,5h			x		shorter!
Material Extrusion	0,5h			x		shorter!
Sheet Lamination	0,5h			x		shorter!
CU15: PBF-LB Process	14h					
PBF-LB Process Principles	2h		x	x	x	shorter!
PBF-LB System - Hardware and Software	4h	x	x		x	shorter!
PBF-LB Parameters	3h	x	x	x		shorter!
PBF-LB Feedstock	2h		x	x		shorter!
PBF-LB Consumables	2h		x	x		shorter!
Post Processing	1h	x	x	x	x	
CU16: Quality Assurance (QA) in PBF-LB	7h					
General QA Principles	2,5h	x	x	x		shorter!
AM Machine QA	1,5h	x	x	x		
AM Parts QA	1h	x	x	x		
Visual Inspection Overview	2h	x	x		x	
CU17: Health, Safety and Environment (HSE) in PBF-LB	3,5h					
Health, Safety and Environment	3,5h	x	x	x	x	everywhere
CU18: Hardware, software and build file set-up for PBF-LB	14h					
PBF-LB machine set-up requirements	4h	x	x		x	shorter!
Pre-build check list - APS/pAPS	3h	x	x	x		APS/pAPS?
Consumables, feedstock and substrate	3h	x	x	x		shorter!
Build Files	1h		x	x		
Work Documentation	2h	x	x	x		shorter!
Practical implementation of HSE procedures (while fit and set up the machine)	1h	x	x	x	x	everywhere
CU19: Monitoring and managing the manufacturing of the PBF-LB par	3,5h					
Machine functionalities	2h	x	x		x	=> for practice
HSE Procedures	0,5h	x	x		x	Content?
Documentation	1h	x	x	x		into APS?
CU20: Post Processing of PBF-LB parts	7h					
Post-build cycle operations	3h	x	x		x	shorter!
Manual tools and methords for post-processing operations	4h	x	x	x		shorter!
CU21: Maintenance of PBF-LB systems	7h					
General maintenance aspects	2h	x	x		x	
Optical elements	0,5h	x	x		x	
Parts maintenance	1,5h		x		x	
Gas supply system	0,5h		x			Content?
Auxiliary elements maintenance	1,5h	x	x	x	x	=> more
Application driven material change	1h		x	x	x	
CU48: Powder Handling	7h					
Overview of Powder Manufacturing Processes	1h		x			Content?
Chemical Composition and Physical Properties	2h		x	x		
Particle Size Distribution	0,5h		x	x		
Powder Storage, handling, ageing and documentation	1,5h	x	x	x	x	=> more
Powder reusability	1h		x	x		shorter!
HSE Procedures	1h	x	x	x	x	shorter!
CU49: Laser Beam and Characterisation	7h					
Laser Beam parameters and conditions	2h	x		x		standard: optional
Measurement Equipment	5h	x			x	standard: optional
Total	74h					

Appendix 2: XR Evaluation Matrix

Criteria
K.O.
CAD model of involved equipment available?
Is there IP critical content involved?
Are there any impediments by standardization?
Are 3rd party products involved? (e.g. lifting truck, tools)
If 3rd party products are involved, can we access their CAD models?
If not, can we substitute 3rd party products? (e.g. simple CAD mock-ups or include videos)
Are there ongoing developments that might make this use case obsolete soon?
Classification of Use Case
How many steps are included in this task? (<5 give 0 points, ≥5 give 10 points)
Does the use case predominantly include manually handled tasks? (y = 10 points (e.g. mechanical parts/hardware), partly = 5 points, no = 0 points (e.g. GUI/software))
Business Case
What´s the installed base of the machine? (<5 give 2p, <25 give 4p, <50 give 6p, <100 give 8p, <500 give 10p)
What will the installed base of the machine be in 1 year? (<5 give 2p, <25 give 4p, <50 give 6p, <100 give 8p, <500 give 10p)
What will the installed base of the machine be in 3 years? (<5 give 2p, <25 give 4p, <50 give 6p, <100 give 8p, <500 give 10p)
Frequency of task performed? (Please give an answer: job-to-job, daily, weekly, monthly, anually)
Can travelling be reduced or even completely avoided by applying XR for training the use case? (completely = 10 points, partly = 5 points, no = 0 points)
How much time can be saved through XR? (<30% = 3p; <60% = 6p; >60% = 10p)
Does XR speed up the learning curve on the machine? (y = 10 points, n = 0 points)
Risk Assessment
Process could be interrupted
Quality of parts could be negatively influences
Equipment could be damaged
Risk for human health and life
Sum

Appendix 3: Interview Guideline

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Proposed questions

Q1 – Do you provide or intend to provide training for additive manufacturing to your staff?
Q2 – What sort of AM training are you delivering?
Q3 – How do you undertake practical training (internal or machine OEMs)?
Q4 – Do you know what AR/VR is?

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Q5 – Do you know that AR/VR can be used to support the training delivery?
Q6 – Have you used AR/VR tools to conduct training?
Q7 – Do you foresee limitations to the use of AR/VR tools for practical training?
Q8 – Do you have any concerns about using AR/VR tools for training? What are your opinions for using AR/VR tools for training?

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Q9 – What are the benefits you see in using AR/VR tools for training?
Q10 – Could AR/VR tools be used to replace face-to-face training, or it is a supplement to support conventional training routes? What could be the role of AR/VR tools in training?
Q11 – How did /is Covid-19 change the way you undertake training?