The SAFAR XR Framework for Safety Training

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Abstract. The Erasmus+ SAFAR project brings together pedagogical planning, trainer preparation and immersive technologies for safety-critical education and training. This article presents SAFAR as a structured extended reality (XR) training framework, focusing on its strategic, pedagogical and technological components. A descriptive approach is used to examine project outputs and explain how the framework connects digital transformation, educational guidance and scenario development. Its technological architecture combines Meta Quest 3 and HoloLens 2 with programmable virtual reality (VR) and digital twin applications developed in Unity3D, interactive 360° content authored in WARP-VR and 3DVista, and mixed reality (MR) guidance and remote assistance using Microsoft Dynamics 365. Individual scenarios address the specific needs of participating partners. An illustrative 360° forklift scenario developed in WARP-VR at Kia Slovakia documents one application within this architecture. Created as part of a student thesis, it extends teaching resources concerning safe working practices in a manufacturing environment. Case selection reflected workplace needs and available industry collaboration. Scenario development was complete and testing was ongoing during manuscript preparation. The article contributes a structured account of the SAFAR framework and its complementary VR and MR technologies, accompanied by an example of scenario development and student participation. Training effectiveness and situational-awareness outcomes are not evaluated here; a separate study will address testing results.

Keywords: extended reality; virtual reality; mixed reality; occupational safety and health; training framework; vocational education and training.

1 Introduction

Immersive technologies provide several ways of representing operational situations for occupational safety and health (OSH) education, crisis management and first-responder training. Virtual reality (VR) can present a constructed or recorded environment, while mixed reality (MR) can place visual information within the user's physical surround-

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ings. Applications in safety-critical industries include hazard-related scenarios, procedural instruction and preparation for situations that are difficult to reproduce during routine teaching. Reviews document this range of uses together with technical, pedagogical and implementation challenges [1]; [2]. Their relevance to training depends on the task being represented, the available interaction and the way the technology is incorporated into instruction.

The distinction between technological formats is therefore important. Programmable VR environments allow training content and interactions to be defined within an application; 360° authoring platforms combine recorded workplace views with interactive elements; and MR guidance connects instructions or remote assistance with a physical task. These formats involve different relationships between the learner, the environment and the trainer. Research on authentic learning with VR and MR and on MR training for lifting-platform operators provides examples of how occupational tasks can inform the choice of a technological approach [3]; [4]. A training framework needs to account for these differences when connecting educational objectives with technical implementation.

Individual applications also differ in what has been evaluated. Poyade et al. (2021) [5] combined VR safety training in chemical manufacturing with a psychological evaluation and distinguished measured learning from participants' perceptions of the experience. Wheeler et al. (2024) [6] assessed a firefighter learning environment and reported different patterns for motivational and knowledge-related outcomes. Development work on human–robot collaboration illustrates another industrial application of structured VR scenario design [7]. These studies provide useful context, but results from one intervention cannot establish the educational effectiveness of another. Reviews of VR safety training likewise identify differences in evaluation approaches, with greater attention to learning and participant reactions than to behavioural or organisational outcomes [8]; [9]; [10].

Alongside individual applications, educational institutions need ways to organise scenario development, prepare trainers and select technologies appropriate to their teaching resources. Reviews of immersive higher education and procedural training place instructional design and theoretical grounding alongside the technical characteristics of an application [11]; [12]. Manufacturing education raises related questions about development resources and integration into existing teaching activities [13]. Documenting how these elements are brought together can make the rationale of an XR training framework explicit and provide a basis for subsequent implementation and evaluation.

The Erasmus+ SAFAR project, Situational Awareness Training of Firefighters within an Immersive XR Training Site, addresses this organisational and educational context. The project focuses on firefighter training, with the University of Žilina's contribution also addressing crisis management education and selected workplace safety topics. SAFAR combines a Digital Transformation Roadmap, a Training Qualification Model, trainer guidance, a blended learning course and implementation-oriented resources [14]. Its extended reality (XR) architecture encompasses programmable VR environments, digital twin applications, interactive 360° content and MR assistance and

guidance. These technologies form complementary parts of the framework and are selected according to the educational task and the needs of participating partners.

The framework provides a shared structure for developing training resources, while the content of individual scenarios reflects local educational and operational needs. Within this arrangement, collaboration with Kia Slovakia provided both a practical workplace topic and an opportunity to create a 360° forklift scenario as part of a student thesis. The scenario is intended to extend students' experience of safe working practices in a specific manufacturing environment. Its selection reflects available industry collaboration and the scope of a feasible student development task. It illustrates one use of the framework's 360° technology; the framework also includes the separate programmable VR and MR approaches described in this article.

The aim of this article is to present the SAFAR project as a structured XR training framework for safety-critical vocational education and training (VET), higher education and enterprise training. The article describes its strategic and pedagogical components, explains the roles of its VR and MR hardware and software, and illustrates selected principles of scenario development through the VR_Forklift_Training case. The contribution is the documented organisation of the framework and its technological architecture, accompanied by one development example. Empirical evaluation of training effectiveness is outside the scope of this article.

2 Methodology

This article uses a descriptive approach to document the SAFAR framework and an illustrative case study of scenario development. The account draws on project outputs and training-related materials describing the framework, together with the WARP-VR scenario structure, authoring script and interface views. The methodological focus is the organisation, design rationale and implementation of training resources.

The approach consisted of two main steps. First, the SAFAR framework was examined through its strategic, pedagogical and implementation-oriented components. This description identifies the main framework elements, their interconnections and their roles in the integration of immersive technologies into VET, higher education and enterprise training. The technological analysis covers both hardware platforms and all software approaches included in the framework: Unity3D, WARP-VR, 3DVista, Dynamics 365 Remote Assist and Dynamics 365 Guides. Table 1 organises these components by technology type, purpose, use within SAFAR and indicative technical complexity.

Development of the framework involved six partner institutions with complementary expertise. Operational training content and learning objectives related to firefighting and crisis management involved Střední průmyslová škola chemická Pardubice, Ugniagesių gelbėtojų mokykla Vilnius and the University of Žilina, Faculty of Security Engineering. S.C.P. Serv Limited contributed technical development of immersive environments, while XR Effect Foundation and SBG Dresden contributed immersive technology expertise, methodological guidance and pedagogical integration.

This collaboration brought operational, pedagogical and technological perspectives into the framework.

Second, the VR_Forklift_Training scenario developed in WARP-VR for the manufacturing environment at Kia Slovakia was examined as one example of scenario development. The description addresses the reason for selecting the case, its educational purpose, the use of authentic 360° recordings, interactive elements, decision structure and feedback. Situational awareness is considered as a conceptual reference for design. The case documents the use of one authoring approach within the framework; it does not provide an empirical assessment of the framework or a comparison of its technologies.

3 Results

The results comprise a structured description of the SAFAR framework and its technological architecture, followed by an illustrative scenario developed within the project. The framework description covers strategic planning, pedagogical guidance and trainer preparation. The hardware and software sections explain the distinct roles of programmable VR, interactive 360° content and MR tools. The forklift case then documents the development of one training resource using the WARP-VR platform.

3.1 Key components of the SAFAR XR training framework

Beyond the technological development of XR training environments, SAFAR is structured around strategic, pedagogical and implementation-oriented components. This architecture links the creation of immersive scenarios with their planned integration into educational practice. It brings together digital transformation, pedagogical design, trainer support and the practical use of resources in safety-critical training organisations.

At the strategic level, the Digital Transformation Roadmap provides guidance for organisations planning the integration of XR technologies. At the pedagogical level, the SAFAR Training Qualification Model (TQM) defines the competence profile of the Digital Transformation Coach (DTC) and relates XR scenario design to educational frameworks including Technological Pedagogical Content Knowledge (TPACK), Substitution–Augmentation–Modification–Redefinition (SAMR), Bloom's Taxonomy and the Kirkpatrick Model. These provide reference points for technology selection, educational objectives and evaluation planning.

The Training Guidebook provides practical guidance for trainers, including technical preparation, scenario planning, lesson integration and implementation in training settings. The Blended Learning Course for Digital Transformation Coaches forms a further component of trainer preparation. Implementation-oriented outputs include the XR scenario database and the Best Practice Guide. Together, these components

establish a structure connecting organisational planning, pedagogy, trainer preparation and scenario development. Figure 1 summarises these relationships.

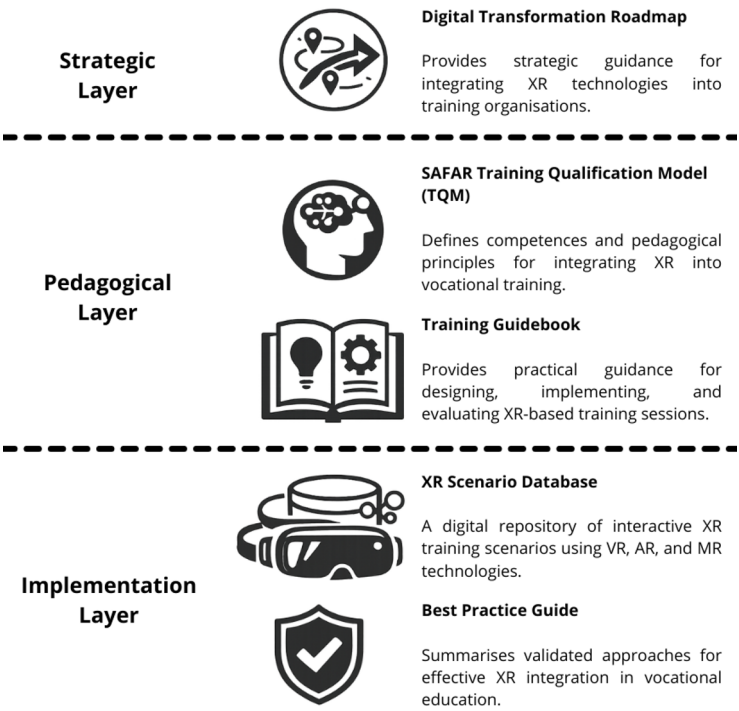


Figure 1 Components of the SAFAR XR Training Framework (Authors)

Individual scenarios are developed for the specific needs of participating partners. They therefore differ in subject matter, intended users and technological format. The framework provides common guidance and development resources, while each scenario requires content appropriate to its own educational and operational setting. The scenario database records such outputs within the wider structure of SAFAR. To implement these pedagogical and organisational components, SAFAR includes a combination of immersive hardware and software tools for creating, delivering and managing different types of training content. Their complementary functions are described below.

3.2 Hardware and software architecture of the SAFAR XR framework

The SAFAR architecture combines two primary immersive hardware platforms: Meta Quest 3 for VR and MR content and HoloLens 2 for MR applications. These are associated with several software approaches: programmable immersive environments and digital twin applications developed in Unity3D, interactive 360° content authored in WARP-VR and 3DVista, and procedural guidance and remote assistance using Dynamics 365 Guides and Remote Assist. The hardware and software components have distinct functions within the framework.

Table 1 presents the core technologies according to their type, purpose and use in SAFAR. Programmable development environments, 360° authoring platforms and MR tools are included as complementary approaches. The table describes the architecture of the framework as a whole.

Table 1 Core Hardware and Software Components of the SAFAR XR Framework (Authors)

Component / tool	Technology type	Main purpose in SAFAR	Use in the SAFAR project	Indicative technical complexity
Meta Quest 3	VR / MR hardware	Immersive delivery of VR and MR scenarios	Digital twin application and 360° scenarios	Medium
HoloLens 2	MR hardware	Hands-free guided and collaborative task support	Remote Assist and Guides	Medium
Unity3D	Programmable XR development platform	Creation of programmable immersive environments	Digital twin scenarios	High
WARP-VR	360° no-code authoring platform	Creation of interactive decision-based scenarios	360° scenario development	Low to medium
Dynamics 365 Remote Assist	MR support tool	Real-time expert guidance and mentoring	One-to-one remote procedural support	Low
Dynamics 365 Guides	MR guidance tool	Step-by-step procedural instruction	Guided task execution in real settings	Low

Note: The complexity categories are indicative author assessments for orientation, rather than results of comparative testing. They depend on the scope of implementation and the experience of the development or training team.

The selected technologies serve different training and development requirements. Unity3D provides a programmable route for immersive applications, WARP-VR and 3DVista provide authoring tools for recorded or panoramic content, and the HoloLens 2 applications connect guidance or collaboration with physical tasks. Technology selection can therefore be considered alongside the educational objective, required interactions and available development resources.

3.2.1 Programmable VR environment using Unity3D

For the development of programmable immersive environments and digital twin applications, the SAFAR consortium selected the Unity3D engine. Unity3D is a multiplatform development environment used to create interactive applications. Within the

SAFAR architecture, it provides the development route for software-defined virtual environments and interactions delivered through the immersive application.

This approach allows the environment, task structure and available interactions to be specified as part of application development. It involves programming and technical development work, which is reflected in the indicative complexity category in Table 1. In educational planning, the intended task and interaction requirements need to be communicated between domain experts and the development team. Unity3D consequently has a distinct role alongside the framework's 360° authoring platforms and MR applications.

3.2.2 Interactive 360° content using WARP-VR and 3DVista

The SAFAR framework also includes platforms for creating interactive content from 360° recordings and panoramas. WARP-VR and 3DVista provide authoring environments in which educators, trainers and scenario designers can organise scenes and add interactive elements without developing a separate immersive application. This route is relevant where existing workplace content can form the visual basis of a training activity.

WARP-VR is a web-based authoring platform for structuring and deploying interactive 360° training scenarios. Its interface provides tools for arranging scenes, introducing decision points and defining progression and feedback. Content can be delivered through standalone VR headsets as well as supported mobile and desktop devices. The platform also provides reporting functions for activity such as decisions and completion. These functions can supply information for reviewing scenario use; learning outcomes require an appropriate evaluation design [15].

3DVista is a virtual tour and 360° environment authoring tool for creating immersive walkthroughs, virtual scenes and training spaces. Its features include support for mono and stereo panoramas, interactive hotspots, embedded images, video and text, and navigation between scenes. Designers can use these functions to combine a visual environment with explanatory material and authored interactions [16]. Within SAFAR, 3DVista constitutes a separate option for developing interactive 360° resources.

Both platforms were adopted within SAFAR to make scenario creation and revision available through visual authoring tools. This is relevant to vocational institutions where educators and trainers contribute domain knowledge and may also participate directly in content production. The resulting interaction is shaped by the recorded or panoramic material and the elements available in the authoring platform. These characteristics need to be considered when defining the educational task.

3.2.3 Mixed reality support using Dynamics 365 Remote Assist and Guides

The framework includes a separate MR approach using HoloLens 2 for guided tasks and collaboration in physical environments. Dynamics 365 Remote Assist and Dynamics 365 Guides were adopted for remote procedural support and structured task guidance. The two applications provide different forms of interaction between training content, the trainee and the instructor.

Dynamics 365 Remote Assist connects an operator wearing the headset with a remote instructor or expert. During a session, the instructor can view the operator's surroundings and provide contextual guidance through audio communication and visual annotations. Spatial cues can be used to highlight relevant components or direct attention during a task. Within SAFAR, the application serves as a tool for one-to-one remote procedural support and mentoring, with the trainee carrying out the physical activity and the instructor providing guidance [17].

Dynamics 365 Guides provides step-by-step instructional content within the MR environment. Holographic instructions, images and three-dimensional cues can be associated with physical locations or task components. The application presents a predefined sequence that the trainee follows while performing the activity, with the instructor able to take a supervisory role. Its function within SAFAR is structured procedural guidance in a real setting [18].

These MR applications concern the combination of a physical task with visual guidance or remote collaboration. Their descriptions identify the instructional functions available within the framework; the article does not report measured effects on errors, skill retention or task performance. The applications are described as tools included during project development. Microsoft has announced that both will reach end of support on 31 December 2026, which needs to be considered when planning continued use of this MR toolchain [19].

3.3 Illustrative case study of the VR_Forklift_Training scenario

The VR_Forklift_Training scenario illustrates the development of one resource using the WARP-VR authoring approach described in Section 3.2.2. It was created from authentic 360° recordings in the manufacturing environment at Kia Slovakia s. r. o. The case demonstrates how selected content and authored interactions were combined within this technology. It provides a concrete development example alongside the description of the wider SAFAR architecture.

Selection of the case reflected a practical need for content concerning safe working practices and the available opportunity to collaborate with an industrial partner. For the university, the scenario extends teaching resources through which students can encounter safety-related observations and procedural decisions in a specific workplace. It was developed as part of a student thesis, connecting a defined academic task with project activity and collaboration with practice. This explains the inclusion of a manufacturing example within a project whose main focus is firefighter training and whose university contribution also encompasses crisis management education.

The development process brought together the selection of workplace content, acquisition of 360° recordings, organisation of the scenario script and authoring of interactive elements. The resulting scenario combines workplace views, predefined decision points, checks of selected operational procedures and immediate feedback. At the time of manuscript preparation, scenario development was complete and testing was

ongoing. Test methods and findings are reserved for a separate study; completion of the content is not presented as validation of a training intervention.

3.3.1 Scenario structure and interaction

The learner views recorded workplace scenes and selects from the interactions made available in the scenario. The script connects these choices to subsequent scenes or feedback. Figure 2 shows the view from the forklift cabin, where the visible options concern starting the forklift and moving off, switching on the beacon and fastening the seat belt. These are examples of the procedural choices represented in the authored content.



Figure 2 Forklift cabin view with interactive choices in VR_Forklift_Training (Authors)

English label key: left, “Start the forklift and move off”; upper centre, “Switch on the beacon”; right, “Fasten the seat belt”.

Figure 3 presents a screenshot of a section of the VR_Forklift_Training scenario flow on the WARP-VR authoring grid. The arrangement of nodes and connecting lines provides an overview of scene progression, alternative branches and their interconnections within the interface. Available actions and connections to subsequent scenes are defined during authoring and determine the learner's possible routes through the scenario.



Figure 3 Section of the VR_Forklift_Training scenario flow on the WARP-VR authoring grid (Authors)

The WARP-VR editor was used to position interactive elements over the recordings and associate them with the scenario structure. Figure 4 shows an authoring view containing a navigation hotspot and the corresponding editing controls. The platform interface allowed the recorded material, available choices and scenario progression to be organised without a separate programming implementation.

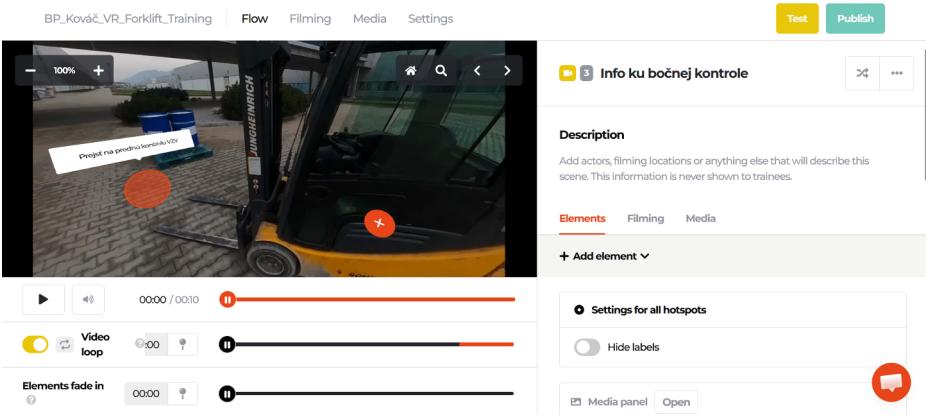


Figure 4 WARP-VR scene editor showing an interactive element over recorded forklift footage. (Authors)

English label key: the scene title reads "Information on the side inspection"; the hotspot reads "Proceed to the front inspection of the forklift".

3.3.2 Pedagogical design and situational awareness

The educational purpose is familiarisation with selected safe working practices through observation, procedural choices and feedback. The scenario is intended as an additional teaching resource that can be used alongside explanation, discussion and practical activities. Its 360° views represent the visual context of the workplace, while the authored choices provide material for considering the safety relevance of particular procedures.

Endsley's model distinguishes perception of relevant environmental elements, comprehension of their meaning and projection of their future status [20]. These concepts were used as a reference for the intended pedagogical functions of the scenario. Table 2 makes the conceptual mapping and its limitations explicit.

Table 2 Situational awareness as a conceptual reference for the forklift scenario. The mapping has not been empirically validated.

Design reference	Intended task in the scenario	Interpretive limitation
Perception	Observe relevant workplace or cabin elements in the 360° recordings.	Attention and perception were not measured.
Comprehension	Consider the safety relevance of a procedural choice and its feedback.	A predefined answer does not independently establish understanding.
Projection	Consider possible consequences before selecting an available action.	Fixed choices do not demonstrate anticipation in an open, changing situation.

In particular, selecting an expected response from predefined options may reflect recognition or recall rather than anticipation of events. The projection component is therefore treated as an intention of the task design, without claiming that the scenario measures or develops it. The same distinction between intended function and observed outcome applies to perception and comprehension. Immediate feedback is described as an authored feature whose educational effects require evaluation.

4 Discussion and conclusion

This article presents SAFAR as a structured XR training framework combining organisational planning, pedagogical guidance, trainer preparation and a range of immersive technologies. The contribution is the description of these components and their relationships, together with a development example at scenario level. The framework's technological scope includes programmable VR and digital twin applications, interactive 360° resources, and MR guidance and collaboration. This organisation makes the roles of the different technologies explicit within a common educational and implementation context.

The framework relates to research that considers immersive technology together with instructional design, authentic tasks and institutional implementation [11]; [3]; [1].

Within SAFAR, the Digital Transformation Roadmap, TQM, Training Guidebook and DTC course connect technology use with planning and trainer preparation. The scenario database and Best Practice Guide provide implementation-oriented resources. The article documents how these elements are organised; their effectiveness and the extent of their adoption require separate assessment.

The hardware and software architecture is a central part of this contribution. Unity3D provides an application-development route for programmable environments. WARP-VR and 3DVista provide authoring approaches based on 360° content. HoloLens 2, together with Remote Assist and Guides, provides MR functions for a trainee performing a physical task with remote support or structured instructions. These approaches differ in the environment presented, the interactions available and the role of the instructor. Decisions about their use should therefore start from the educational task and the resources available for content development and delivery.

The use of visual authoring platforms is particularly relevant where educators and trainers participate directly in scenario production. Within SAFAR, these platforms sit alongside the programmable development route and MR tools. The choice involves considerations of content, interaction and technical effort. The indicative categories in Table 1 describe these practical differences; they do not establish comparative costs, usability or educational effectiveness. More generally, reviews of procedural training and manufacturing education indicate the need to connect development decisions with instructional objectives and subsequent evaluation [12]; [13].

The forklift scenario provides one example within this broader framework. It connects the university's teaching needs with a workplace setting made available through collaboration with Kia Slovakia. Development as part of a student thesis also documents a feasible form of student participation in project activity. The practical contribution is the resulting 360° resource and the account of its creation. Its manufacturing focus reflects the specific opportunity and educational need, while other partners and technologies address their own training contexts. Sector-specific examples of immersive OSH training in the literature provide a relevant context for this approach [4]; [7]; [21].

Pedagogical interpretation requires a distinction between the functions built into a resource and the outcomes it produces. Studies of immersive learning report different patterns for motivation, perceived experience and measured knowledge [22]; [5]; [6]. For the presented scenario, workplace imagery, decision points and immediate feedback are documented design features. Their presence does not establish improvements in learning, retention, safety behaviour or situational awareness. In particular, the fixed-choice format limits the interpretation of projection within Endsley's model. The scenario also does not reproduce physical vehicle control or the unrestricted conditions of real forklift operation.

Implementation of the wider framework involves adequate hardware access, preparation of trainers, selection of the appropriate software and alignment of content with lesson objectives. Debriefing can be planned around observations and decisions in a VR scenario, while MR use requires attention to the physical task, instructional sequence and availability of an instructor or remote expert. These are planning considerations arising from the framework and the functions of the technologies. Continued

implementation also requires attention to software availability and lifecycle, including the announced end of support for the Dynamics 365 applications.

The principal limitation is that the article reports a framework description and one scenario development example without empirical evaluation results. It contains no reported expert assessment, trainer feedback, usability findings, comparison group, learning measures, retention data or evidence of transfer to operational practice. Testing of the completed forklift scenario was ongoing during manuscript preparation and will be addressed in a separate study. The single case also cannot establish the applicability or effectiveness of all components of the framework across participating organisations. Future evaluation should distinguish the usability of specific resources, learning outcomes and effects on practice, in line with the evaluation issues identified by Stefan et al. (2023). [8]

SAFAR provides a documented structure for relating strategic planning, pedagogical preparation and complementary VR and MR technologies to scenario development. The framework accommodates resources designed for the specific needs of participating partners, with technology selected according to the intended task. The VR_Forklift_Training scenario illustrates one use of the 360° authoring approach and shows how student thesis work can contribute to the production of project resources. The article's contribution is this account of the framework, its technological architecture and one concrete development output; assessment of training outcomes remains a separate stage of the research.

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