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Designing a Technological Pathway to Empower Vocational Education and Training in the Circular Wood and Furniture Sector through Extended Reality

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Abstract: Extended Reality (XR) is a term that refers to virtual, augmented, and, more recently, mixed reality (VR/AR//MR), which are key enabling technologies of the Industry 4.0 (I4.0) and the simulated digital environment of the metaverse. XR enables the simulation of workplace scenarios, providing workers with training in a risk-free environment, resulting in cost savings, improved occupational risk prevention, and enhanced decision-making processes. XR is ideal for supporting digital transformation for organisations in fields such as production, occupational risk prevention, maintenance, and marketing. XR is also a key driver for training initiatives aimed at promoting good practices in the circular economy in specific sectors such as woodworking and furniture (W&F). The European Commission has recognised the potential of XR for the W&F sector, funding initiatives such as the European project, Allview, which seeks to identify the most appropriate and beneficial technologies of I4.0 with a green and digital transition focus from the perspective of vocational education and training (VET). This paper presents the work carried out within the framework of Allview, including the research and comparison of current software and hardware of XR tools suitable for VET in the W&F field, a review of successful examples of XR applied to W&F training actions, and an analysis of the opinions gathered from European students, teachers, and training organisations regarding the use of XR in education. As a result, the authors present a training pathway aimed at the development and implementation of a XR training scenario/lab/environment focused on VR, 360° videos, and MR, as a guideline for developing immersive XR training contents, contributing to the digital and green transformation of VET in the W&F sector.

Keywords: Extended reality; virtual reality; augmented reality; mixed reality; vocational education and training; circular economy; furniture; wood

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1. Introduction

1.1. Theoretical Background: Engineering and Technical Education

The field of engineering and technical education must keep up with the rapid evolution of science and technology and dynamically adapt to a changing world. In the past, engineering programs could remain unchanged for decades with professors simply repeating the same curriculum year after year in some cases. However, with unprecedented technological advancements, engineering education must now rapidly reformulate courses and programs, give rise to new engineering disciplines, and leverage technology to enhance various aspects of educational practice [1].

Thus, the forthcoming engineering educators must possess a specific set of knowledge, skills, and attitudes to ensure that they can provide a top-quality and easily accessible engineering education focused on addressing complex societal problems that may arise unexpectedly. To accomplish this, they need to have a comprehensive understanding of the engineering educational tradition, as well as innovative techniques that are typically supported by technology, and must seek positive synergies to promote sustainable progress. In this way, several studies suggest that Industry 4.0 (I4.0) technologies used for educational purposes can offer students real-life learning activities, while tackling the space and financial issues of educational centres [2–4].

At present, organisations of all educational areas are investing resources in researching and implementing I4.0 technologies with the aim of improving the teaching–learning process and developing competitive graduates [5]. In addition, taking advantage of digitalisation, new distance learning programs have also emerged [6]. Nevertheless, despite the emergence of new pedagogical practices and technologies, designers and educators in engineering programs face challenges in implementing innovative solutions due to insufficient information, design methodologies, and evaluation mechanisms [7].

1.2. The Allview Project

Vocational education and training (VET) providers in the wood and furniture (W&F) sector focus on teaching traditional woodworking and furniture manufacturing skills through practical workshops [8]. However, they often overlook training on innovative techniques and addressing environmental and societal challenges. As a result, workers and students may lack the necessary skills to keep up with digitalisation, green business models, and social integration. Some companies are successfully incorporating new skills related to topics such as Ambient Assisted Living (AAL), I4.0, and the circular economy (CE), while others struggle to do so.

Nevertheless, work-based learning refers to all forms of learning that takes place in a real work environment, and it has the effect of better preparing students for the labour market, it allows them to shorten the school-to-work transition period, and seems to offer good job prospects after graduation [9]. In the dual learning system, it is recommended for students and teachers to accomplish practical internships in companies [10].

To face this new learning scenario, the Allview project was created [11], aimed at establishing a Centre of Vocational Excellence (CoVE) for the European wood and furniture industry, and engaging key industry representatives and regional training authorities to support the foundation of a long-term EU dual training platform for the W&F sector.

This paper is the result of research conducted in the framework of the Allview project to explore new ways of training by using Extended Reality (XR) as a teaching and learning tool that could increase students' motivation and their performance in the learning process [12].

1.3. Extended Reality

Extended Reality (XR) is a 'catch-all' term for those immersive technologies that enhance or replace our world view. The term covers virtual, augmented and mixed reality (VR/AR/MR), which aim to advance digital transformation in business and society, in the framework of the I4.0 and in the simulated digital environment of the metaverse. Additionally, they make new uses possible and streamline production and communication procedures, which will affect how we learn, interact, and collaborate in the future. With XR, people use digital tools to access virtual spaces [13]. VR creates complete immersive and interactive environment spaces while, in AR, these spaces are superimposed onto the real world through virtual information data. As a combination of both technologies, MR blends the virtual world with the real world, allowing users to incorporate physical objects and surroundings into their interactions with virtual elements. Thus, in contrast to AR/MR, VR technology allows users to immerse themselves in a completely virtual environment, which can be a more social experience as users can communicate and collaborate with other avatars easily. However, AR/MR tends to be more of an individual experience, where the user can interact with virtual elements while incorporating physical objects and surroundings (Figure 1). Nevertheless, it is not appropriate to see XR technologies as competing products, as each technology has different potential uses and comes with its own strengths and weaknesses. For instance, depending on the circumstance, some individuals may choose to display information only when they are in motion, whereas in other scenarios they may crave a complete immersion in a virtual environment. Both AR and VR technologies offer tremendous opportunities for the education sector. Simulations of real-world scenarios can provide effective training for workers, enabling them to avoid dangerous situations and improve decision-making processes [14]. However, the enhanced reality feature of XR technologies can also offer valuable learning experiences [15].

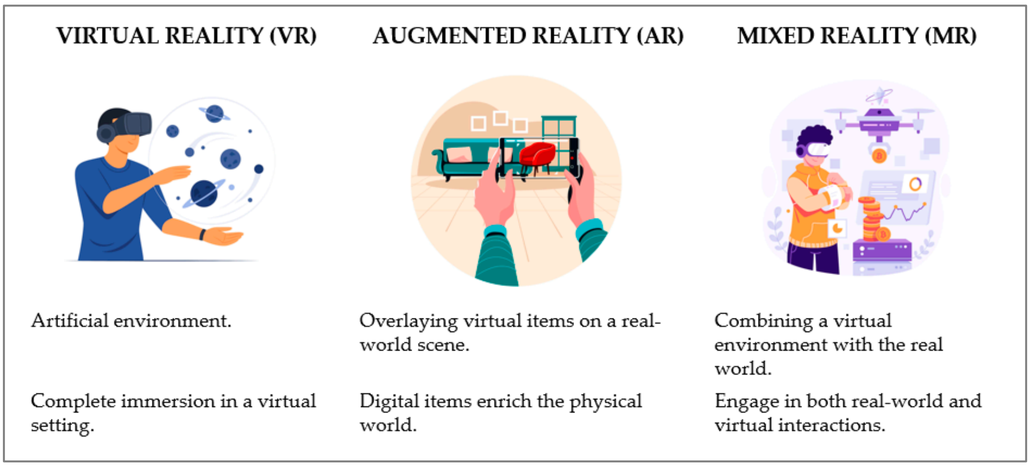

Figure 1. Virtual, augmented and mixed reality differences.

In addition, I4.0 technologies are seen as key drivers for the transition to a CE [16]. These technologies enable the redesign of products, business models, and supply chains toward a more circular and sustainable model [17]. Numerous researchers have explored the contributions that different I4.0 technologies can make to the CE transition [18]. XR has been identified as a technology that can support the CE in several ways. Firstly, virtualisation can facilitate the redesign of products to improve circularity, for example, by making products more repairable and modular [19–21]. Secondly, XR can improve disassembly and remanufacturing processes, e.g., by virtually testing the configuration of disassembly plants [22–24]. Finally, XR can provide remote assistance and guidance, such as through virtual handbooks for maintenance activities [19,25].

There are numerous applications on the market or under development for the immersive media XR in areas such as learning, marketing, healthcare, and manufacturing. Nevertheless, the lack of standardised technical and legal criteria, along with a clear workflow for material development, hinders the mass-market maturity of XR. At present, available products are still limited in terms of functionality and accessibility. In short, XR technologies are in an early stage of development, and further research and development are needed before they can be widely adopted by consumers [26]. However, there is no doubt that XR technology has the potential to transform many jobs in the future, which extends to the right training to perform well in these jobs. Unfortunately, the competencies and job descriptions with XR skills have not been clearly defined, leading to a gap in the field. The Virtual Dimension Centre (VDC) has addressed this gap by identifying the key skills and knowledge domains required for success in this field [27]. The VDC has analysed which job profiles stand to benefit most from XR and which knowledge domains are most relevant for success in these roles. XR technologies span multiple domains, including user interface design, hardware engineering, software design, industrial engineering, computer graphics, acoustics, haptics, and psychology. Of these, industrial engineering and haptics, have particularly strong applications in the wood and furniture (W&F) sector. Furthermore, the practical application of XR often necessitates specialised knowledge from various fields such as design, production, ergonomics, engineering, and marketing, as well as expertise specific to a given industry. These domains provide valuable opportunities for leveraging XR technology to enhance efficiency, productivity, and customer engagement. All these applications have a secondary effect as CE drivers, especially in education and training activities, as XR supports the understanding of interaction, facilitating learning, and safety in the working relationship between humans and machines [27].

It is evident that XR technologies are increasingly recognised as valuable tools for training activities, such as in the virtual design and maintenance of new processes, that effectively promote CE principles and benefits to the public and users [28]. Despite the numerous studies advocating for the incorporation of XR into VET programs to facilitate the transition towards a more circular industry, there remains a significant gap in knowledge regarding the available XR tools and how to implement them in VET programs. Therefore, a comprehensive understanding of the potential benefits and limitations of XR for VET programs is critical in supporting the successful integration of these technologies in training curricula.

The goal of this paper is twofold: to research and compare current software and hardware XR tools that best suit VET in the W&F field, and to design a training pathway using XR that contributes to pushing forward the CE and digital and green transformation in the W&F sector. The work considers free/open-source and proprietary/commercial software and hardware tools that are currently available and useful for the development of the teaching–learning process in the sector under study. Furthermore, existing use cases that can be applied to the W&F sector are shown. An analysis of the opinions gathered from European students, teachers, and training organisations on the uses of XR in education is also conducted. Finally, the paper presents a training pathway focused on the development and implementation of an XR training scenario/lab/environment focused on VR, 360° videos, and MR, to serve as a guideline for developing immersive XR training contents, contributing to the digital and green transformation of vocational education in the W&F sector.

The rest of the paper is organised as follows. Section 2 presents the results of an intensive study on the latest software and hardware of XR tools available that are suitable for immersive training. Section 3 shows some use cases of the technologies in XR for training in the field of W&F. Section 4 analyses teachers' and students' opinions about the use of XR for training. Section 5 details the VET pathway proposed, and is focused on the use of different XR technologies for creating an environment for immersive learning. Finally, Section 6 summarises the conclusions and future work.

2. Research on Available XR Software and Hardware Tools for Immersive Learning

In the field of VET there are many training programs that utilise XR technologies, primarily VR and AR. However, MR is a relatively new technology and not everyone has access to the required hardware and software. As a result, the adoption and integration of MR in educational settings are still in the early stages of exploration and development. Nonetheless, recent research and development efforts have demonstrated the potential of MR to enhance learning experiences and improve student engagement [29].

In this section, an extensive study on available XR technologies has been conducted, identifying those that are most suitable for immersive teaching and learning. In the next subsections they are enumerated and discussed, focusing on those solutions that address the needs of the proposed research, and organised by hardware and software tools. Finally, their advantages and disadvantages considering factors for their usability in teaching–learning are summarised.

2.1. Software

There are numerous software tools used in XR, such as those used to implement algorithms that manage sensors and digitise the physical world, as well as those that enable interaction between physical and virtual worlds. Programming environments facilitate the control of various elements implicated in XR applications, such as 3D geometry, textures, audio, visual display, user interface, and interactivity. Note that designing for XR requires a range of existing software skills, including 3D visual design and experience design and development. Table 1 presents an inventory of the most crucial programming and development tools that are currently available for these technologies, as well as the target software or hardware platforms/devices that are supported.

Table 1. Most programming and development tools of XR solutions on the market.

Software	Intended Platforms	Technologies		
		VR	AR	MR
Unity [30]	Web PC Mobile Devices Smart TV Game consoles Virtual/Extended Reality Devices	X	X	X
Unreal engine [31]	Web PC Smart TV Game consoles Virtual/Mixed Reality Devices	X	X	X
WebXR [32]	Web	X	X	
Native [33]	Depends on the platform	X	X	X

The choice of a software for XR development is dependent on several factors, including the developer's experience and the desired outcome, regardless of the sector. Among the software options listed in Table 1, Unity and Unreal engine offer the most potential. Unity is preferred by many developers due to its shallower learning curve and high interest among users. Thanks to its extensive developer community, Unity provides a wealth of resources for problem-solving and troubleshooting, enabling users to quickly find solutions to similar issues. Additionally, Unity's default settings are often more suitable for beginners and those prioritising optimisation over high-fidelity graphics. On the other hand, Unreal engine offers more advanced features and a powerful engine, making it the ideal choice for developers looking to create complex and visually stunning experiences. Therefore, developers should carefully evaluate their needs and choose software that meets their specific requirements [34].

Virtual reality software development kits (VR SDK) also provide the fundamental tools to design, create, and test VR experiences. These SDK are the building blocks to create VR experiences such as mobile apps, marketing experiences, training simulations, and more. VR SDK provides the tools to perform functions such as adding, cloning, and moving 3D objects. Additionally, these tools allow flexibility for non-developers, with many systems providing drag-and-drop functionality to customise experiences. These tools may sometimes be customised using an application programming interface (API). SDKs are typically designed to work with specific frameworks and hardware, although some can be used across multiple systems. Some VR SDKs also have the capability to create AR experiences, but it is important to note that AR SDKs are distinct tools that are specifically tailored to developing and testing AR apps. Thus, to be considered part of the VR SDK category, a product should offer functionality for creating custom VR experiences, allow for the editing of existing VR experiences, and be compatible with operating systems and hardware that can display VR content.

Within the framework of the Allview project [11], the SimLab SDK platform was selected as the best option to be included in the technological path for future content development [35]. SimLab [36] is a comprehensive, user-friendly, cost-effective, and featurepacked solution that simplifies the process of communicating ideas in 3D. With SimLab, users can easily import models, create dynamic visualisations, render, and develop basic VR scenes, which can be utilised to build completely interactive VR learning classes.

Special attention must be given to software tools that facilitate the creation of immersive 360° videos in VR. Virtual twins and 360° simulations present more practical, scalable, and non-intrusive training opportunities compared to on-site practice. These technologies offer a more immersive and authentic experience, as opposed to passive slide-based training methods. The camera used to record 360° videos captures images at a wide angle, providing a comprehensive view of the environment around it to the viewer. To create 360° videos, special cameras are required, some of which can capture 180° of vision with a single lens. However, to achieve a seamless 360° experience, two cameras are strategically placed to merge the two overlapping images. Popular cameras for this purpose include the Samsung Gear 360, the Nikon Myssion 360, and LG 360 Cam, but none of them offer a 4k image quality as in the GoPRO cameras. Specific software is needed to process 360° videos. Table 2 lists two such software tools.

Table 2. Software used for processing 360° videos.

Software	Description
3DVista [37]	It provides the necessary tools to produce immersive panoramas, interactive virtual tours, and comprehensive 2D and 3D floor plans, all with superior quality.
Matterport [38]	It is the industry benchmark for 3D space scanning. Its end-to-end solution lets users convert real-world environments into immersive digital twin models. With its features extending beyond panoramic images, Matterport enables anyone to scan and connect spaces to generate fully interactive 3D models.

2.2. Hardware

In recent years, there have been notable advancements in XR hardware, leading to the development of smaller, lighter, ergonomic, and more potent devices available at significantly lower prices. Several devices that are currently available to create immersive experiences within the virtuality spectrum are detailed in Table 3. As shown, some devices only support a single technology, while others can support the three technologies, VR, AR, and MR.

Table 3. Main hardware devices used on XR.

Solution	Development Platforms	XR Technologies			Degree of Immersion
		VR	AR	MR	
Smartphone/Tablet	Unity Unreal Nativo	X	X		Non-immersive
Google CardBoard [39]	Unity Unreal Nativo WeebVR	X	X		Immersive
HTC Vive [40]	Unity Unreal Nativo WeebVR	X			Immersive
Oculus Rift [1]	Unity Unreal Nativo WeebVR	X	X		Immersive

Table 3. *Cont.*

Solution	Development Platforms	XR Technologies			Degree of Immersion
		VR	AR	MR	
HTC Vive Pro [40]	Unity Unreal Nativo WeebVR	X	X	X	Immersive
CAVE [41]	Nativo	X			Semi-Immersive
Oculus Rift S [1]	Unity Unreal Nativo	X			Immersive
Hololens 2 [42]	Unity Unreal Nativo WeebVR		X	X	Immersive
Meta Quest Pro [43]	Unity Unreal Oculus SDK	X	X	X	Immersive
Meta Quest 2 [44]	Unity Unreal Oculus SDK	X	X	X	Immersive

[1] Currently Oculus Rift and Oculus Rift S are not available on the website of its official provider, Meta, but they can be found through various other suppliers.

It is worth mentioning that the hardware devices currently capable of creating MR experiences are still undergoing research and development. Many of these devices currently only offer beta libraries and SDK specifically for this system. Consequently, it is crucial to create a collaborative relationship between application programming teams and the developers of the device's SDK. This partnership should manifest as a feedback loop between the teams, derived from experimentation and debugging, to ensure the essential stability and reliability needed to drive the widespread adoption of MR. This will enable users to experience a new reality in which virtual and physical elements are integrated, revolutionising our digital presence.

2.3. Comparison of Technologies of XR

Finally, a summary comparison of the advantages and disadvantages of XR technologies is presented in Table 4, considering factors such as performance, usability, user experience, learning curve, collaborative learning capabilities, and the most appropriate type of learning for each technology.

Table 4. Advantages and disadvantages of 360° videos, VR, AR, and MR technologies for immersive training [45].

	360° Video	VR	AR	MR
Advantages	– Extremely high level of realism. – Faster VR production. – Customisable with your own 360° content (depending on the architecture module). – Possible to create your own content (if suitable equipment is available).	– Unlimited adaptability and expandability. – Complete freedom to play. – All scenarios are possible (including those that are impossible due to safety or production limitations). – Full interaction with 3D objects. – Powerful, visual feedback: users can see in real-time what is happening based on their actions.	– Easy to use (smartphone or tablet). – User maintains contact with the environment. – AR is generally cheaper than VR and MR due to easy access to hardware and software for creating AR experiences.	– Object recognition: integration of digital images with the environment. – User maintains contact with the environment.

Table 4. *Cont.*

	360° Video	VR	AR	MR
Disadvantages	– Post-production adjustments to existing video footage not possible: the videos must be refilmed. – Limited interaction with 360° content: choices can only be made via pop-up screens (branching) – Scenarios are limited: only what is safe, feasible and organised can be filmed. – Feedback remains limited: users can only experience what is possible in terms of safety, organisation, and feasibility.	– Realism is lower (due to computer animation) unless the software is of high-end quality. – Development is slower and there is a higher chance of encountering bugs. – Creating content yourself is difficult: the tools have a steep learning curve, unless the experiences are simple.	– No object recognition or integration with the environment: the digital image is added to elements from the environment. – Not particularly useful for soft skills training or topics open to interpretation.	– Expensive equipment (entry-level model starts from EUR 2000)
Collaborative learning	– Not possible	– Ideally suited for collaborative learning/design thinking.	– Possibly depending on the design.	– Ideally suited for collaborative learning/design thinking.
Types of learning	– Creating awareness. – Allowing you to experience unfamiliar situations. – Providing forms of training where 'live' interaction is not required (with the environment through a selection menu). – Offering soft skills training without real time feedback.	– Analysing installations or models. – Training procedural skills. – Forms of training where live interaction is required (environment reacts immediately to own actions). – Hard skills training (with real-time feedback).	– Assisted learning/learning on the spot. – Remote assistance.	– Assisted on-the-spot learning. – Remote assistance. – Suitable for training where object recognition is required: fixed setup, fixed procedure.

3. Use Cases of XR in VET for the W&F Sector towards a Circular and Green Transition

One of the greatest advantages of immersive technologies is the possibility of creating personalised and specific training for groups of people in a particular field. In the W&F sector, as well as many others, these technologies offer a new way of teaching, designing, manufacturing, and selling products. Within each of these processes, immersive environments can be created to streamline the learning of sub-processes ranging from design and material preparation to machining, safety, assembly, and distribution logistics. All of this can have a positive impact on the sustainability of products and processes by reducing costs and material consumption and enabling the digitisation of certain aspects of training. Therefore, immersive technologies can prepare students for the changes brought about by digitalisation, making them better equipped to handle new job demands in line with I4.0 and the CE.

Within the framework of the Allview project, a research analysis of use cases has been conducted [46]. In this section, we summarise four interesting tools and use cases related to the implementation of XR to enhance VET in the W&F sector.

3.1. VR Laboratory Environment as an Experimental Space for Students

ViRAI (Virtual Reality in Engineering Education) [47,48] is an innovative collaborative project of three German universities focused on the integration of VR technology in the teaching–learning activities of students in engineering and technical disciplines. The goal is not only to use VR as an immersive teaching–learning tool, but to delve deeper into

VR itself since it is a technology widely used in different industrial sectors. ViRAI is a versatile and customisable solution for both practical and theoretical skill training in the industry. It offers to manage the virtual visualisation of CAD machines designs in a virtual environment using a head-mounted display (HMD). Students can access a wide range of training exercises and activities. In [47,48] ViRAI was tested in higher education (HE) for engineering product development focused exercises.

One example of ViRAI's use in the W&F industry could be carpentry students learning to design and build a wooden table. Through ViRAI, students can access an immersive learning environment where they can design the table in a virtual environment using advanced 3D design tools. Once the design is complete, they can move on to the construction phase, where they will be guided through a series of detailed steps to build the table in the virtual environment. Students can practice building the table multiple times in the virtual environment, receiving immediate feedback on their work to improve their skills without concern for material waste or machinery cost.

3.2. Innovation in the Wood Industry—Collaboration with the Carpenters' Guild in Munich to Develop Craftguide

CraftguideVR [49] is a groundbreaking tool that uses 3D modeling software to create virtual environments and simulate woodworking tasks, ideal for students and professionals in the W&F industry. Using VR technology, CraftguideVR allows users to simulate woodworking tasks in a virtual environment, providing a safe and cost-effective way to train and improve their skills. CraftguideVR can be used to create exercises and applications based on original 3D data, but it requires additional technical knowledge and resources beyond the basic functionalities of the CraftguideVR tool itself.

CraftguideVR envisions an online platform that offers expert knowledge in various trades, including construction, woodworking, electrical work, and metalworking, and connects business and learning stakeholders. This encompasses institutions that offer VET and ongoing education providers in skilled trades, as well as companies that produce machinery and equipment. By creating a comprehensive network of professionals and resources, CraftguideVR aims to facilitate the exchange of knowledge and best practices in craft trades, foster innovation and collaboration, and ultimately contribute to the development of a highly skilled and competitive workforce. Undoubtedly, CraftguideVR has the potential to significantly improve VET in the W&F field, allowing students to practice and perfect their techniques before working with real materials and tools. However, its purpose is not to substitute physical real-life training but rather to supplement proficiency in the direct manipulation of the machine, bridging the gap between theoretical and practical aspects of the craft. This approach facilitates the trainees' comprehension and proper execution of work techniques. Moreover, it promotes occupational safety by ensuring that the machines are free from hazards, and safety guidelines are in place. CraftguideVR offers various training exercises, including a carpentry course structured according to the training requirements of the Munich Carpenters' Guild. The user is led through different work stages with flashing interface elements and alerted of any potential hazards. For instance, one exercise involves sawing a board to a right angle using a sliding table saw, enabling students to obtain valuable insight into carpentry machinery. This is just one example of the practical training exercises that CraftguideVR provides.

CraftguideVR has several advantages over traditional training methods. Firstly, it allows students to practice woodworking techniques without the risk of injury, reducing the number of accidents in the workplace. Additionally, it provides a more immersive and interactive learning experience, enhancing students' motivation and knowledge retention. Students also learn how to use VR/AR. Finally, CraftguideVR is a more cost-efficient training alternative, as it reduces the need for expensive materials and equipment.

3.3. WOOD-ED TABLE. A Virtual-Physical Training Tool

WOOD-ED TABLE [50] is an innovative tool based on XR that offers a comprehensive learning experience for training instructors and professionals in the W&F field. It combines virtual and physical training methods through a flexible and customisable solution, enabling users to practice and improve their skills in a safe virtual environment. Instructors and professionals can access the real-time feedback, skill acquisition, and evaluation of their work, which helps them identify and correct any mistakes or weaknesses through the tracking of movements. This feature is particularly useful in the early stages of learning, where material waste is a common issue. By preparing instructors in advance for this type of work, the result is a lower consumption of material and electricity, promoting sustainable training.

An example of a WOOD-ED TABLE use case is the training of instructors on complex woodworking techniques. In this scenario, the tool provides a virtual environment where instructors can practice and perfect their techniques, such as using a band saw, router, or lathe. They can also access a range of training materials and resources, including videos, animations, and interactive simulations. In addition, they can collaborate with other instructors and professionals in the field, sharing their expertise and knowledge.

The instructors' goal is to establish a secure setting where apprentices can learn the appropriate wood cutting techniques. For instance, with a virtual training table, the environment of four different machines can be reproduced: band saw, circular saw, jointer, and shaper. Learners start by taking control of the stationary wood cutting machine and setting up the machines. The system detects the position of the learners' hands and instructs them where to place them correctly to avoid the risk of accidents.

3.4. The Integration of Mixed Reality with Dynamic 365 Guides

Microsoft's Dynamic 365 Guides is a software platform that allows users to produce personalised manuals and interactive instructions with the use of holograms, videos, and photos. The platform is ideal for teaching users various machine operations, from straightforward machines to intricate computer-controlled ones, including step-by-step machine start-up, addressing error messages, and changing tools. Additionally, it can provide information on different materials, tools, and connections, making it a versatile and adaptable tool for VET in the W&F sector.

One significant advantage of this software is its open platform, which allows for customisation according to the user's preferences and requirements. Microsoft Dynamics 365 Guides is a mixed-reality application for Microsoft HoloLens that enables operators to learn during the flow of work by providing holographic instructions when and where they are needed. These instruction cards are visually tethered to the place where the work is carried out and include images, videos, and 3D holographic models, enabling operators to see precisely what needs to be completed and where, resulting in a faster completion of tasks with fewer errors and greater skill retention.

The creation of a guide is straightforward and requires no specialised 3D or programming skills. Users can start with the PC authoring app to create a guide consisting of step-by-step instructions, images, videos, and 3D holograms. After creating the guide on a PC, the HoloLens app can be used to connect the instruction cards and holograms to the physical workspace by picking them up and moving them to the correct location. The default library of 3D holograms can be used to start with, and users can also import their custom 3D models.

As part of the Allview project [11], two exercises are being developed using this platform, aimed at teaching users how to use a numerical control machine and how to assemble a piece of furniture. With its ease of use, versatility, and adaptability, Dynamic Guides 365 is a powerful tool for VET in the W&F furniture sector.

4. Teachers and Students' Opinions about the Use of XR Technologies in Education

One task of the Allview project is to know the level of acceptance of XR by students and teachers in teaching and learning. Their opinion is a valuable input in the decision of the type of hardware and software tools to use, the exercise design, or to identify what the needs of teachers in the W&F sector are with respect to XR [46]. Hence, we decided to gather the opinions of the different target groups. To achieve this, the authors followed guidelines outlined in [51,52] and the recommendations outlined in the report of practical guidance provided by CEDEFOP [53] for developing and implementing an establishment skill survey. It is focused for employers, but it is also recommended to be applied to the VET audience.

In this section we summarise the methodology of the questionnaire design and deployment, the gathering of responses and analysis method, and the conclusions reported from the opinions.

The first step was to define the goal of the survey and the methodology in designing the questions for the study sample, that was set to students, VET and higher education (HE) entities, and teachers in Europe who have experience learning or teaching using immersive technologies. The methodology design was the needs assessment survey, since the Allview consortium had firstly identified the needs and issues of the target audience. Note that the Allview consortium, which was composed of HE/VET representatives of the employment sector, teachers, students, and representatives of the W&F sector. Table 5 provides a summary of the focus of the questions.

Table 5. Set of questions by target group.

<table>
<tr><th>Target Group</th><th colspan="5">Question's Goal</th></tr>
<tr><td>Teachers/VET-HE organisations</td><td>To determine the origin of XR content used in the classroom</td><td rowspan="2">To identify the software and hardware resources currently employed in classrooms and educational settings.</td><td>To highlight the necessity for teacher training in this domain.</td><td rowspan="2">To ascertain the advantages obtained from the integration of XR technology in the classroom.</td><td rowspan="2">To determine the degree of satisfaction concerning the usage of AR, VR, and MR technologies.</td></tr>
<tr><td>Students</td><td></td><td>To determine the level of ease or difficulty for students to work with these tools in an educational setting.</td></tr>
</table>

The next step was to design the survey. Two surveys were designed by the authors, who are members of the Allview consortium. The survey for students was composed of seventeen clear and short questions, eight of them with Likert scale responses and nine open and closed responses. The survey for teachers and VET/HE institutions was composed of 23 questions, with a similar structure to the students' survey. Nine of the questions had Likert scale responses. The surveys were designed in five European languages: English, French, German, Italian, and Spanish.

The surveys were validated through the expert review of a subset of the Allview consortium members. It was conducted during the survey's design stage to ensure that each question measured the variables of interest adequately, without ambiguities or biases. A pilot test was conducted with a small sample of people to identify any potential issues with comprehension or interpretation. It is important to mention that no pre-test was carried out to assess the ability to use XR technology in students with vision disorders, spatial orientation disorders, motion sickness, etc. Although some scientific studies, as in [54,55], have found adverse effects in students' use of VR, such as dizziness after a prolonged session, these side effects were mild and temporary. Overall, more studies are needed to fully evaluate the side effects of prolonged use of virtual reality in education, and to identify best practices for reducing these side effects and ensuring the safety and comfort of students. The Allview consortium agreed that this was out of the study scope, although it could be beneficial to include in further actions for a more complete study.

Finally, the tool was chosen for launching the surveys and gathering and processing data. Since the sample was set to the European level and the target respondents were supposed to be familiar with ICT, online surveys were deemed the most suitable option, offering a broader reach.

Brief research was conducted to determine which free, online survey tool available on the internet would be used. It was similar to the one conducted by the authors in [56], where ten different tools were evaluated based on the indicators: number of surveys launched simultaneously, number of questions per survey, number of responses gathered per survey, level of customisation options, and availability of export options for data. Google Forms was selected as the tool for launching the online surveys and gathering the responses due to its flexibility, lack of constraints in the indicators identified, easy data exportation for analysis, and easy online access and sharing.

The surveys were launched in February 2022. They were announced on the Allview website, social media, and shared through the Allview partnership network to maximise the number of responses from target users specialising in fields such as the wood/furniture/architecture/manufacturing/ICT, etc. The survey was available for gathering data for two months. In total, 112 responses were gathered: 85 from students and 27 from teachers and VET/HE institutions in Europe. Regarding the information gathered, in the students' survey only the student profiles were reported. A total of 49.05% of respondents were students of HE degrees and 50.95% of respondents, students of VET degrees. A total of 88% of respondents were students of studies related to the wood and furniture sector, 8% of respondents were students of manufacturing and industrial engineering, and 4% of respondents were from other fields.

In the survey for teachers and institutions, the type of institution was the only demographic information provided. In total, 51.85% of respondents were teachers or board members of VET centres, 33.33% of respondents were teachers in HE institutions, and 14.81% of respondents were teachers or board members of other training institutions or activities. The responses gathered were thoroughly examined in the Allview project [46] and a summary is presented in the subsections below.

4.1. Teachers and Organisations Opinion

The results and percentages of the corresponding questions are presented in Figure 2. According to feedback from teachers, XR technologies are commonly used, with AR being the most prevalent form. More specifically, 45% of teachers have experience using AR, while 30% have worked with VR, and 25% have utilised MR technology. The primary applications of these technologies are for presenting augmented or virtual information (43%) and creating digital content (40%), while a smaller percentage of respondents are involved in software development (17%). In terms of content sources, most of the content is developed by both students and teachers (70%), followed by open access repositories (15%), and direct manufacturer sources (15%).

During the survey, participants were asked about the software and hardware they used.

The study found that the most commonly used software among teachers is 3D design software and visualisers, both for AR and VR applications. Development software, platforms, and engines were reported to be less frequently used. Regarding hardware, smartphones and VR goggles were the most popular devices. Providing teachers with specific exercises as examples for developing their own teaching materials, as well as offering tools or platforms for utilising these technologies in the classroom, could be beneficial. All participants who expressed a need for training reported that they had mainly taught themselves. To ensure proper implementation of these technologies in education, it is important to consider specific training for teachers and increased investment in both hardware and software.

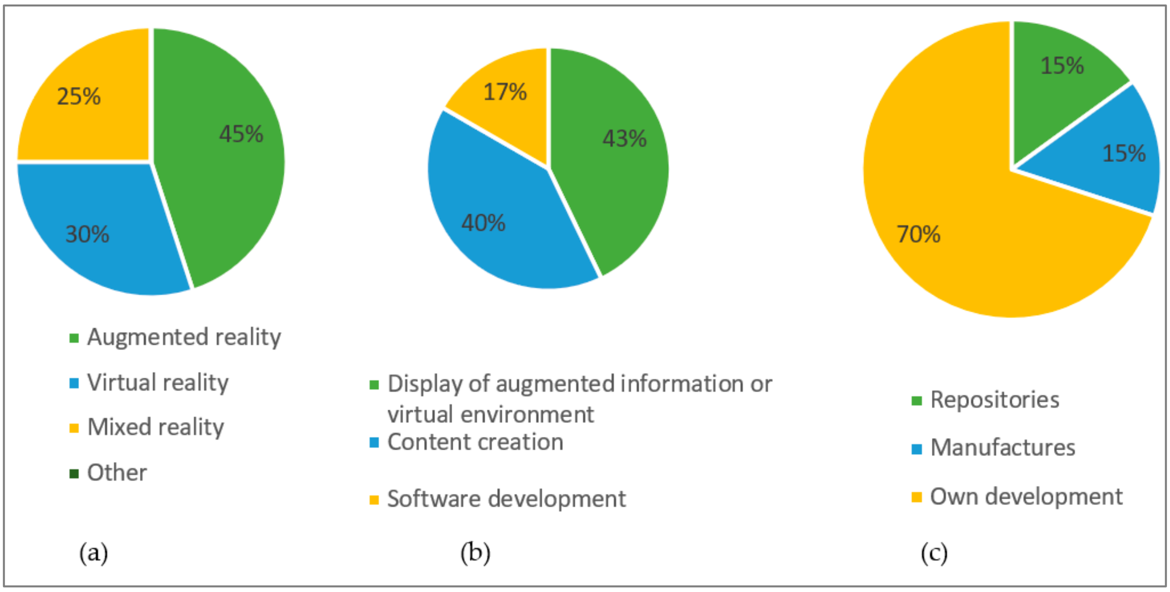

Figure 2. (**a**) Technologies used by teachers in their VET/HE institutions. (**b**) Main uses of these technologies. (**c**) Provenance of content.

As shown in Figure 3, nine statements are presented regarding the benefits that teachers have gained from using these technologies. Overall, the assessment has been positive, indicating that teachers are highly satisfied with both the implementation process and the results achieved. The implementation methodology has focused on utilising these technologies to improve explanations, demonstrations, and promoting collaboration and project-based learning in the classroom.

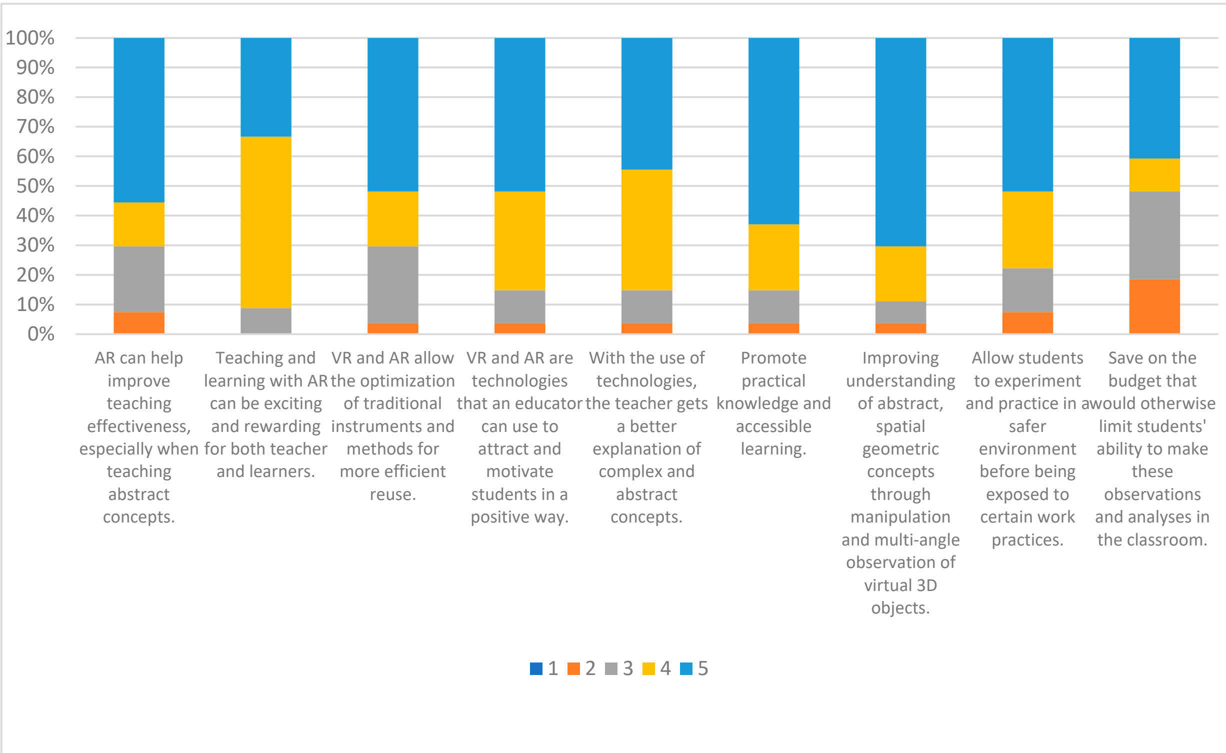

Figure 3. Teachers' opinions on the use of VR and AR. Benefits obtained for the teacher and the organisation (rated from 1 to 5, 5 being the highest rate).

Finally, Figure 4a depicts the participants' opinions regarding the helpfulness of these technologies for both learning and teaching, as well as the added value they bring to training. However, they emphasised the need to be more invested in the resources required for their integration. In terms of evaluating the three technologies under study (Figure 4b), the participants ranked AR in first place, VR in second place, and MR in third place. Nonetheless, they underscored the benefits and classroom applications of all three technologies.

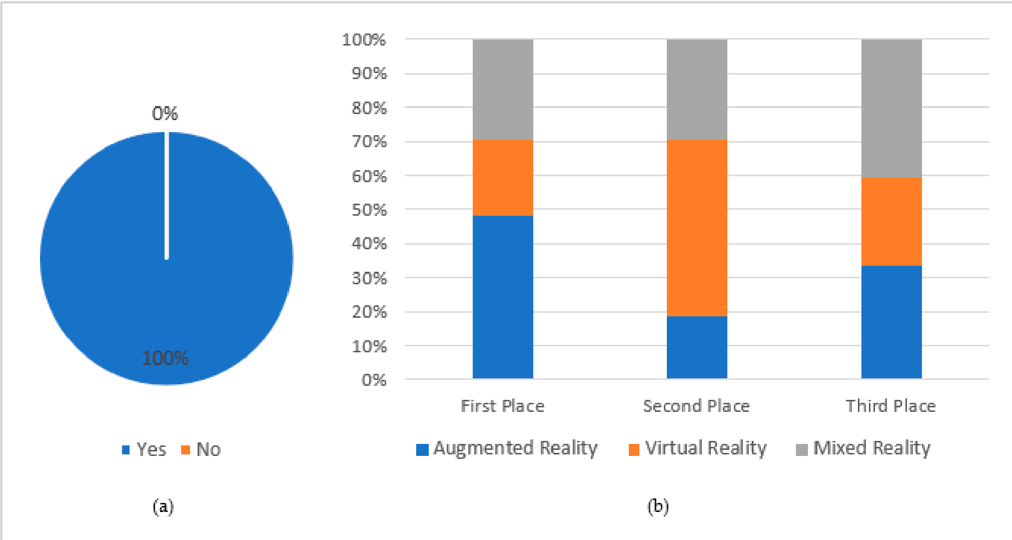

Figure 4. (**a**) Helpfulness of XR in the learning–teaching process. (**b**) Ranking of XR for teaching–learning activities.

4.2. Student Opinion

Most of the students interviewed had a background related to the W&F sector. All participants had used all three technologies. Among them, AR was the most widely used, with 48% of the participants having used it in their training, followed by MR at 39% and VR at 26%.

Figure 5 provides a summary of the responses of students regarding the impact of these technologies on their learning experience. The students stated that these technologies helped them better understand abstract concepts, learn more safely and effectively in practice, improve collaboration with teachers and peers, increase their interest in the subject matter, and motivate them to continue learning about these technologies and to create their own content. It appears that the use of these technologies provides added value not only during the learning process but also for their future careers.

Figure 6a shows the students' opinion regarding the level of difficulty in adapting to the use of XR technologies in the classroom. A total of 87% of respondents found it easy or very easy, likely due to their previous experience with them. Students were also asked whether they would recommend their use to other students. A vast majority of respondents (89%) answered 'yes' (Figure 6b). Finally, students were asked to choose between two courses: one using XR for teaching and learning and one using traditional teaching and learning tools, without XR. Figure 6c shows the results where 65% of respondents preferred subjects using XR.

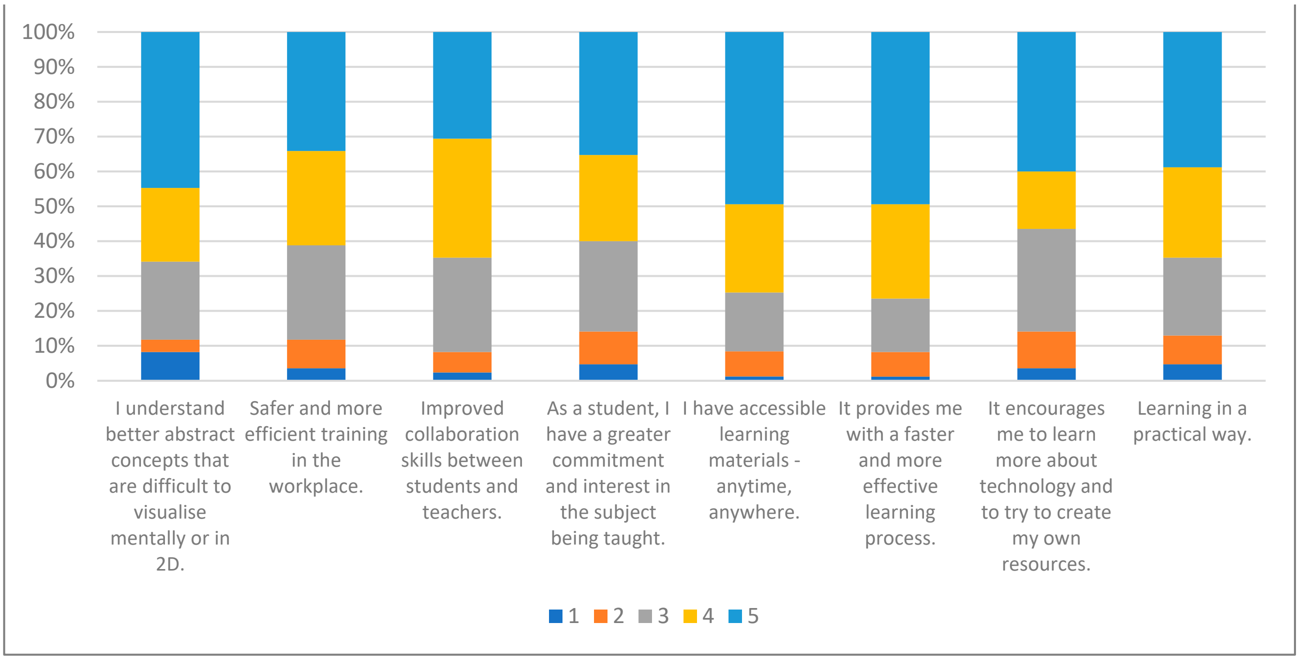

Figure 5. Students' opinion on the use of VR and AR. Benefits of working with those technologies. (Rated 1 to 5, 5 being the highest rate).

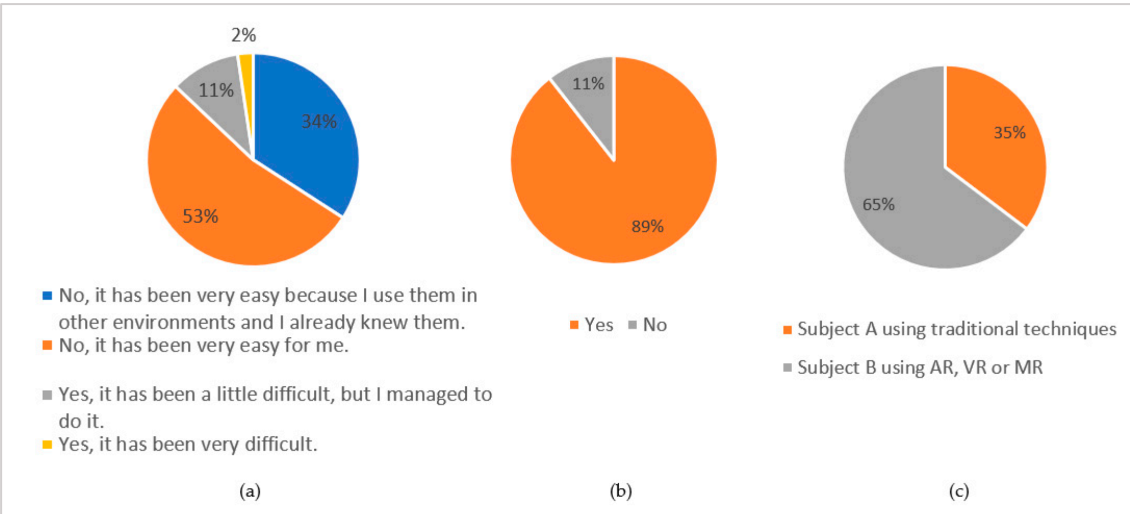

Figure 6. (**a**) Percentage of adaptation to these technologies. (**b**) Student recommendations. (**c**) Teaching preferences.

According to the general comments gathered from the students, showcasing their own designs through a 3D device or environment, and learning through these techniques, increases their interest in the subject matter, helps in developing new skills and competences, enriches their education and training with immersive experiences, and encourages them to take an active and autonomous role in their learning.

The results of teachers' and students' opinions on the implementation of XR technologies in education demonstrate the high level of acceptance of these technologies in the academic sphere. Teachers express their satisfaction with the positive outcomes that have resulted from their use, including improved teaching effectiveness, enhanced student motivation, and practical knowledge promotion. Students, on the other hand, report that the use of XR technologies makes it easier for them to understand complex concepts, improves collaborative learning, and increases their interest in the subjects.

These findings are in line with previous research emphasising the potential of digital technologies to enhance VET [57], especially the benefits of XR systems as perceived by students and teachers [58–60]. However, it is important to note that the literature also highlights existing obstacles to the wider implementation of XR technologies, such as issues surrounding funding and infrastructure [61].

5. Results and Discussion on the Design of a Technological Pathway Using XR Technologies

The results obtained from this study form the design of a technological pathway that utilises XR technologies in VET courses for the W&F sector.

Tables 6–9 provide a summary of the steps taken to select the most suitable software and hardware for the creation and visualisation of content. Key factors have been established for the selection of the appropriate software and hardware, with details presented in the tables.

Table 6. Main factors for basic hardware solutions.

Factors	Description
Processing	Capacity to handle or manage the implemented solution.
Visualisation	Capability to produce the final image or output.
Interaction	Level of interaction with the virtual or physical elements.
Integration	Ability to generate a mixed reality experience combining virtual and physical worlds.

Table 7. Main factors for basic software solutions.

Factors	Description
Multi-platform (MP)	The capability to deploy the solution created on various target platforms.
Device integration (DI)	Compatibility with capture devices and interaction with the physical environment.
Content management (CM)	Flexibility in integrating multimedia content.
Usability (U)	Level of user-friendliness and training.

Table 8. Level of adequacy for the analysed factors and hardware solutions (H: high; M: medium; L: low).

Hardware Solution	Factors			Applicability		
	Processing	Visualisation	Interaction	VR	AR	MR
BackPack	H				H	H
Mobile device	L	M	M	L	M	L
HMD		H	H	H	M	M
CAVE		M	M	H		
HMD Holographic		M	M		H	H
Environment digitisation cameras.		H	H		H	H

Table 9. Level of adequacy for the analysed factors and software solutions (H: high; M: medium; L: low).

Hardware Solution	Factors				Applicability		
	MP	DI	CM	U	VR	AR	MR
Unity	H	H	H	H	H	H	H
Unreal	M	M	H	H	H	H	H
Aframe		M	M	M	H	H	M
Godot	M	M	M	M	H	M	M
Cry-Engine	L	M	M	L	H	L	L
Amazon Lumberyard	M	M	H	L	H	M	M

Table 10 lists the factors that were considered when analysing 3D CAD information exchange formats, along with a brief description of each factor. Table 11 compares the identified formats according to key factors to determine their suitability for inclusion in the pathway. It is important to note that this analysis is limited to those formats that were identified as best suited for the Allview project based on specific needs and requirements, and that other formats may be more appropriate for different projects or applications. For instance, the formats listed in Table 11 were selected because they offer the best combination of key factors, such as standardisation, encapsulation, runtime to solution, understanding, materials, lighting, animations, and texture mapping, for the particular use case.

Table 10. Factors for the analysis of 3D CAD information exchange formats.

Factors	Description
Standardisation	Extent of adoption in the industry as well as in standardisation bodies.
Encapsulation	The ability of the exchange format to encapsulate and include all relevant content and information associated with a 3D model.
Runtime to solution	Efficiency of integrating the content into the solution in a timely manner.
Understanding	Ability to compress the data and reduce their size.
Materials	Ability to import materials and the degree of their accuracy and fidelity after being integrated into the solution.
Lighting	Ability to incorporate lighting and the accuracy of its representation in the solution.
Animations	Support for animations.
Texture mapping	Support for texture maps.

Table 11. The 3D CAD information exchange format vs. key factors (H: high; M: medium; L: low).

3D CAD Information Exchange Formats	Key Factors							
	Standardisation	Encapsulation	Runtime to Solution	Understanding	Materials	Lighting	Animations	Texture Mapping
Wavefront (.obj)	H	L	M	M	M			H
Collada (.dae)	M	M	H	M	M	M	M	H
X3D	M	M	H	H	H	H	H	H
3ds	H	L	H	L				H
glTF	H	H	H	H	H	H	H	H

Based on the previous analysis, we have established the level of suitability (high, medium, and low) for each software, hardware, and 3D CAD information exchange format for developing VR environments in VET courses for the W&F sector, as shown in Figure 7. Using this analysis, we propose a chart for selecting the technological path that includes the hardware and software solutions best suited for developing VR environments in VET for the W&F sector. The recommended solutions are Unity software, the VivePro headset, and gITF 3D CAD exchange format.

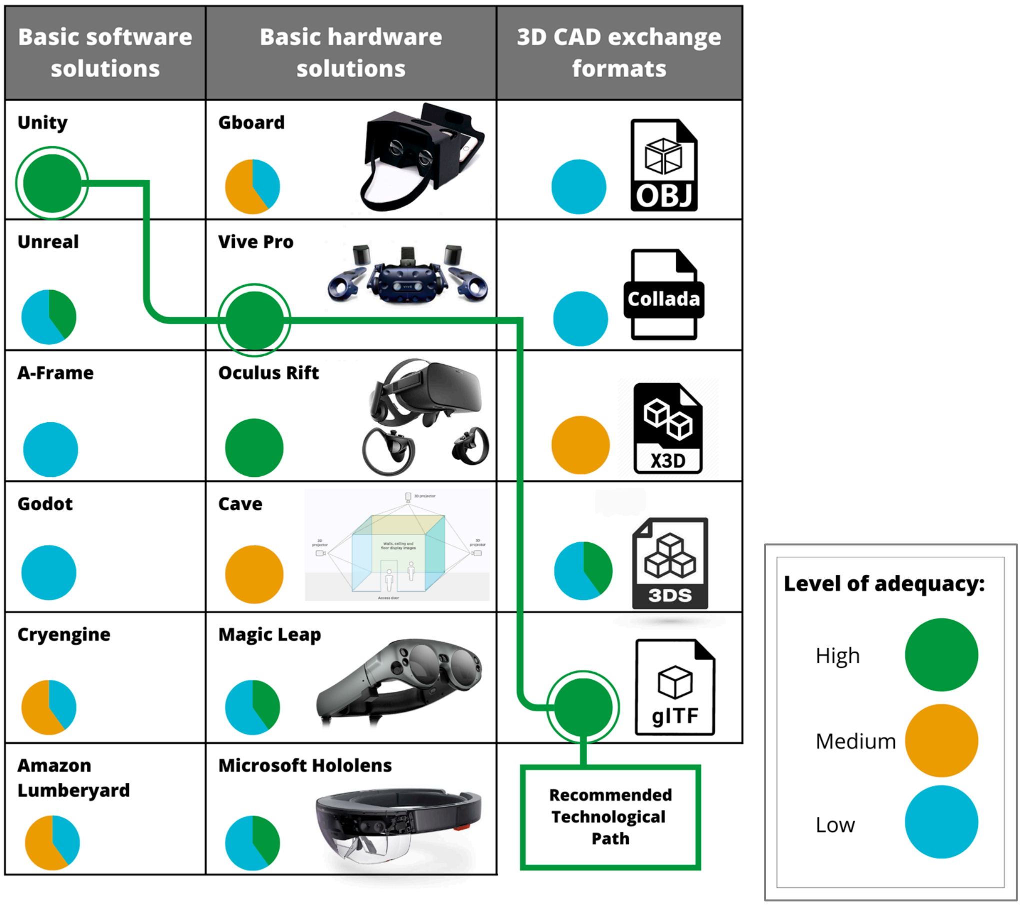

Figure 7. Technology pathway selection for the development of a VR environment.

Additionally, for creating 360° videos for training purposes, it is recommended to use the INSTA 360 Pro 2 camera. This device can record 4K video and 360° spatial audio, providing a more immersive VR experience. Virtual tours created using this method are effective teaching tools. Furthermore, there is 360° video processing software available that can simulate different scenarios, situations, and locations. This software can incorporate gamification or conditional actions to allow learners to compete against each other and earn badges as they learn. To process the captured footage, Insta's own software, Insta360Stitcher, will be required.

SimLab is also recommended as a tool for creating training applications that contain exercises, such as those related to the handling of complex woodworking machinery. This software provides tools for creating such experiences and can be useful for developing these exercises. SimLab can also be thought of as a content management system (CMS) that is focused on creating VR experiences and content, rather than web development. SimLab is a recommended platform for training centres to create their own content for VR experiences without requiring specific development skills. Therefore, it is an excellent tool to use for creating training applications that include exercises such as those related to the handling of complex woodworking machinery. For hardware, various VR devices such as HTC Vive Pro, Oculus Quest, or Pico Neo can be used.

It is also important to note that, although MR is not as widely used as VR and AR, it is still relevant and holds promise for the future of training in the W&F field for VET. As such, we have included it in this pathway. For MR training, the recommended solution is the use of Microsoft Dynamics 365 Guides platform, which can provide numerous advantages and benefits for both teachers and students, as explained in Section 3.4. By utilising this platform, it is possible to enhance learning and training performance by using customised machinery for each training centre. This approach standardises processes and enhances learning by providing step-by-step visual work instructions, demonstrating to users how to use their tools and parts in real work situations. To enable students to navigate in MR through the steps and work instructions of training exercises while also being evaluated, we recommend using MR glasses (HoloLens) as the hardware. This opens the door to developing guides for handling dangerous machinery with step-by-step instructions, including warning and caution messages.

Table 12 summarises the technological paths proposed above according to the recommended hardware and software technology.

Table 12. Technological pathway designed for the implementation of XR technologies as drivers for empowering VET in the circular W&F sector.

XR Technology/ Implementation Type	Software	Hardware	Examples of Training Exercises
VR/Environment development	Unity	HTC Vive Pro.	Applications can be used to display characteristic pieces for specific types of furniture, demonstrate design recommendations, provide an ergonomic guide, and showcase a catalogue of materials, etc.
360° Videos	Insta360 Stitcher	VR equipment or PC. Ricoh theta Z1 camera for 360 recording.	Interactive 360° tours of relevant locations in the W&F sector are also available.
VR/Content development	SimLab	HTC Vive Pro. Oculus Quest. Pico Neo.	This includes simulating the handling of complex or hazardous machinery with the aim of preparing students before encountering the actual machine, thus improving safety during the practical phase.
MR/Content development	Microsoft Dynamics 360 Guide	HoloLens	The creation of 3D furniture designs that can be integrated into real-world environments is possible. A training manual with examples of exercises is also provided.

It is important to highlight that the hardware and software technologies mentioned earlier not only facilitate the acquisition of specific competencies for the training course, but also enable the acquisition of transversal competences through the use of XR technologies. These technologies will equip students with the necessary skills to operate the commercial implementation of technology within the sector, such as in retail applications and furniture showrooms. In addition, XR technologies offer a deeper understanding of concepts, processes, and geometries, while promoting sustainable characteristics in design and prototyping, and in the operation of specific processes or workstations.

In conclusion, several research papers have been published focused on the analysis of the performance of XR in end-users, teachers, and learners, real use cases in VET/HE, or new XR-based exercises developed using any commercial tool. While most of them are focused on medicine, physics, or engineering disciplines to the best of the authors' knowledge, only a few of these works have focused on the W&F sector, and none of them has proposed a dedicated pathway with the hardware and software solutions recommended for developing training exercises for W&F training courses in VET, backed by a European consortium. Although novel and creative teaching and learning methods using XR seem to increase students' motivation, technology acceptance, and learning success, a detailed analysis working with this pathway is necessary to confirm its effectiveness and success, at least to identify its limitations, as its requirements and expectations have been pointed out above. Funding and infrastructure support, along with a big adoption effort, are necessary from the teachers' side to use XR as good stepping stones for didactic modifications to the teaching concept. Limitations can also come from the students' side as XR technology often requires expensive hardware and software, which can be a barrier to access for some students when they study at home. XR technology can also be challenging to set up and use, especially for students who are not familiar with it. These technical difficulties can also cause disruptions to the learning process, and some students may experience motion sickness or discomfort when using XR technology, affecting their ability to learn effectively. Finally, XR technology can also be a distraction for some students, pulling them away from the learning objectives, or disconnecting them from their peers or the instructor.

6. Conclusions and Future Work

This paper has highlighted the significant potential of XR technologies to transform the way we work, learn, and communicate in the future. XR technologies are key drivers of Industry 4.0 adoption, the metaverse, and the green and digital transition. Focusing specifically on the W&F sector, the authors have reviewed each of the XR technologies—VR, AR, and MR—and provided examples of how XR can be applied in areas such as design, maintenance, ergonomics, and industrial engineering. XR can improve efficiency, productivity, circularity, the redesign of products, disassembly, remanufacturing processes, can provide remote assistance and guidance for maintenance activities, increase customer engagement, and more. The scientific literature discussed in this contribution has pointed out the benefits and good a priori effectiveness of using XR technologies for learners of different disciplines and educational levels. However, despite numerous studies advocating for the incorporation of XR into VET programs, there is a lack of uniform technical and legal standards, and an unclear workflow for training content development, that could serve as guidance for teachers of VET in the W&F sector. There is a significant gap in knowledge regarding available XR tools and how to implement them in VET programs.

One contribution of this work has been to provide a comprehensive understanding of the potential benefits and limitations of XR for VET programs to support the successful integration of these technologies in training curricula. To accomplish this, the authors have researched and compared the current software and hardware XR tools that are best suited for VET in the W&F field, provided a set of use cases of XR applications for W&F training actions, and analysed the opinions of European students, teachers, and training organisations regarding the use of XR in education. The results of these three research actions have served as an input for developing the main contribution: a training pathway focused on the development and implementation of an XR training scenario/lab/environment focused on VR, 360° videos, and MR, which can serve as a guideline for developing immersive XR training contents, contributing to the digital and green transformation of VET in the W&F sector. The proposed training development pathway includes using 3D CAD information exchange format for the development of VR environments considering Unity software, VivePro headset, and gITF 3D CAD exchange format. For 360° video creation, the INSTA 360 Pro 2 hardware/camera is recommended to provide a more realistic VR experience. SimLab is also recommended to create training applications containing exercises related to the W&F sector and as a content management system. HTC Vive Pro, Oculus Quest, or Pico Neo are recommended as the driver hardware. Finally, for MR training, the Microsoft Dynamics 365 Guides platform is recommended together with HoloLens as MR glasses.

Although innovative and creative teaching and learning methods using XR appear to enhance students' motivation, technology acceptance, and learning outcomes, a thorough analysis of this pathway is required to confirm its efficacy and success, as well as to identify its limitations, as outlined above. It is crucial to remember that XR technology is simply a collection of hardware and software tools, and that tools alone cannot teach. Thus, funding and infrastructure support, along with a significant adoption effort, are necessary on the part of teachers to use XR as a useful tool for didactic modifications in teaching concepts. Limitations can also arise from the students' side, such as in the requirement for expensive hardware and software, which can create a barrier for some students when they are studying at home. Additionally, XR technology can be challenging to set up and use, especially for students who are not familiar with it.

In terms of future work, the authors, with the support of the Allview project, will undertake testing of the pathway to analyse its acceptance, effectiveness, and limitations by VET teachers. Additionally, exercises developed through the technological pathway will be tested by students and practitioners in pilots in VET centres of the Allview framework. The goal of this testing is to monitor the efficiency of the teaching–learning process and to evaluate the benefits and limitations for students in terms of skills, knowledge, and competences acquired, technology adoption, distraction, motion sickness, technical difficulties, or lack of interaction.

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