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Non-Destructive Testing

[T2.4. Completion and approval of the technical requirements of the Living Labs VR platform and network]

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Non-Destructive Testing

Revision	Date	Author/Organisation	Description
1st	31.03.2024	IIS - ISIM - BIBA - CESOL	T2.1. Research activities on VR platforms
2nd	28.06.2024	IIS - ISIM - BIBA - CESOL	T2.2. Evaluation & design of methodological and technical aspects of the platform for virtual living labs NET
3rd	27.09.2024	IIS - ISIM - BIBA - CESOL	T2.3. Evaluation & design of methodological and technical aspects of the VR application for PT NDT method
4th	30/09/2024	IIS	T2.4. Completion and approval of the technical requirements of the Living Labs VR platform and network

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1. Research activities on VR platforms and Living Labs

The project will design and implement a transnational virtual reality platform to carry out the practical part of a NDT non-destructive examination course (in this case with penetrating liquids) and to evaluate the practical knowledge related to this course.

Given the dynamics of accelerated scientific and technical development in many fields, it is necessary to continuously adapt systems, equipment, techniques, etc. in order to remain at a high competitive level. In the field of education/training/training, such adaptation to the current context is also necessary, through digitisation and the use of environmentally friendly methods/techniques with a positive impact on several levels (technical-scientific, economic, social and societal).

In order to meet these requirements, the project will design and implement a transnational virtual reality platform to carry out the practical part of a NDT nondestructive examination course (in this case with penetrating liquids) and to evaluate the practical knowledge related to this course. At the same time, a transnational network of virtual/real Living Lab laboratories will be set up in the project partner countries (one laboratory in each partner country), which, together with the VR virtual reality platform developed in the project, constitute modern, digitised and environmentally friendly techniques and methods of high relevance for education/training and training activities in the field of NDT examinations and testing. This will make it possible to combine the daily work of trainees and teachers/trainers with distance training/instruction activities.

A first step in this direction is to carry out research and literature review (during M1 to M3) on ways/possibilities of setting up transnational virtual reality platforms and a network of Living Lab (virtual/real) laboratories. The current modalities/possibilities for the realisation of such a platform will be analysed and the information may be updated with new data by the partners, if necessary, during the time allocated for this activity. All partners will be involved in this activity and specific information will be circulated between partners to know the latest ways/possibilities to realise such a platform.

Specific information gathering (standards, regulation, scientific article, personal experience of the partners) Descriptions: collecting input data for the VR system and living labs network: regulations, national and international standards, European directives, data from scientific papers or

personal experience, existing NDT penetrant testing procedure, data on materials and technologies.

Specific information gathering:

1.1 Establishing Transnational VR Platforms and Living Lab Networks: A Literature Review

A "living lab network" is a network of living laboratories, which are open research and innovation environments integrated into the real world and used for developing and testing technological, social, or economic solutions in real-life settings. These living labs often involve active participation of end-users and other stakeholders in the innovation process, thereby contributing to the creation of more relevant and better-tailored solutions to real needs.

Through a network of living labs, various organizations such as universities, research centers, private enterprises, and non-governmental organizations can collaborate to develop and implement innovative solutions in diverse fields such as information and communication technology, healthcare, urban mobility, renewable energies, and many others.

By integrating user feedback and experience into the development process, living labs can contribute to accelerating the innovation cycle, reducing the risks associated with launching new products or services to the market. Additionally, they provide a conducive environment for collaboration and knowledge exchange among diverse stakeholders, fostering synergies and generating added value.

In essence, a living lab network represents an open and collaborative innovation infrastructure that encourages active involvement of users and the community in the development of innovative solutions, resulting in more relevant and better-tailored products and services to real needs.

In recent years, the potential of virtual reality (VR) in education has garnered increasing attention, prompting scholars to explore its evolution, challenges, and future prospects. Discussions highlight the promise, progress, and challenges of VR in education, emphasizing its potential to revolutionize learning experiences. Insights into the evolution and future tendencies of AR/VR technologies are also offered, emphasizing their transformative impact across various domains. The establishment of transnational VR platforms emerges as a compelling prospect, advocating for VR as a tool for learning in the experience age and emphasizing its potential to engage learners and facilitate immersive educational experiences. The importance of transnational networks in fostering cultural exchange and collaboration is discussed, echoing the need for cross-border initiatives in education. Drawing insights from platform theory, the role of platforms in driving network effects and facilitating interactions across borders is underscored, exploring the future of platforms and their potential to transcend geographical boundaries and foster global collaboration in education. Additionally, examination of smart contract-based platforms, applications, and design patterns informs discussions on the integration of blockchain technology into VR platforms, offering opportunities for enhanced security, transparency, and interoperability.

By leveraging insights from these diverse sources, the establishment of transnational VR platforms holds promise for fostering collaboration, cultural exchange, and innovation in education. These platforms have the potential to transcend geographical boundaries, connect learners and educators worldwide, and facilitate immersive, interactive learning experiences on a global scale.

Virtual Reality (VR) has been increasingly used in the field of Non-Destructive Testing (NDT). It provides a standardized, reproducible environment for repeated and optimized training. VR training has been shown to be more effective than traditional teaching at developing technical, practical, and socio-emotional skills. It allows NDT specialists to gain personal experience in key practical stages of RT with the results tracking and get an examination of their actions according to an adapted curriculum.

Fig. 1 VR supports NDT radio operator training.

A good example of VR used in the field of Non-Destructive Testing (NDT) is Extende, a provider of innovative tools for training non-destructive testing (NDT) professionals, has recently unveiled TraiNDE RT, the latest addition to its TraiNDE product line. This virtual reality-based application aims to revolutionize NDT training by offering a database of exercises that replicate real-world inspection conditions across various applications, such as welded tubes and plates, castings, and X-ray and Gamma-ray tubes. TraiNDE RT considers factors like IQI, markers, and numbered bands, allowing operators to simulate radiographic images corresponding to different scenarios. Developed in the New Aquitaine region, this educational tool targets training centers, universities, and companies with internal training and certification needs. By providing a solution that can be used outside the workshop and when the actual radiation source is unavailable, Extende aims to meet the needs of customers seeking versatile training tools for NDT inspectors.

Fig. 2 Extende at the European NDT & CM conference in Prague (2021)

Virtual Reality (VR) has revolutionized training across various domains, including Non-Destructive Testing (NDT). Let's delve into the effectiveness of VR training and its impact on skill development:

- Enhanced Learning Environment:

An Enhanced Learning Environment represents a dynamic and interactive educational setting that leverages advanced technologies and innovative methodologies to optimize learning outcomes. In such environments, traditional teaching approaches are augmented with digital tools, virtual reality simulations, gamification elements, and collaborative platforms to engage students actively in the learning process. These environments are designed to cater to diverse learning styles and preferences, fostering personalized learning experiences and promoting student autonomy.

Through immersive experiences, real-world simulations, and interactive feedback mechanisms, learners are empowered to explore complex concepts, develop critical thinking skills, and apply theoretical knowledge to practical scenarios. Additionally, Enhanced Learning Environments facilitate continuous assessment and adaptive learning pathways, allowing educators to monitor progress, identify areas for improvement, and tailor instruction accordingly. By creating dynamic and experiential learning opportunities, Enhanced Learning Environments not only enhance student engagement and motivation but also cultivate a deeper understanding and retention of subject matter, preparing learners for success in an increasingly complex and dynamic world.

The paper titled "Exploring evolution of augmented and virtual reality education space in 2020 through systematic literature review," authored by Noah, Naheem, and Sanchari Das, meticulously delves into the advancements and trends of augmented and virtual reality

(AR/VR) in educational settings throughout the year 2020. Through a systematic analysis of pertinent literature, the authors provide a comprehensive overview of the roles, challenges, and developments within the AR/VR educational landscape. Published in the journal "Computer Animation and Virtual Worlds," this work not only contributes to the scholarly dialogue surrounding AR/VR but also serves as a valuable resource for educators and researchers navigating the dynamic terrain of immersive technologies in education.

Key aspects requiring additional attention in the utilization of augmented and virtual reality (AR/VR) in education may include:

1. Accessibility and equity: It is crucial for these technologies to be accessible to all students, regardless of their financial resources or socio-economic background. Efforts should be made to ensure that no category of students is excluded from the benefits offered by AR/VR in education.

2. Curriculum integration: AR/VR should be properly integrated into existing school curricula to support and enhance learning objectives. This requires collaboration between AR/VR content developers and educators to ensure alignment with educational standards.

3. Teacher training: Educators need to receive adequate training to effectively use AR/VR in teaching and to properly support their students' learning processes. This involves familiarization with the technologies, development of necessary skills, and understanding how they can be integrated into learning activities.

4. Assessment and monitoring: It is important to assess the impact and effectiveness of using AR/VR in education. Evaluation systems should be developed to measure both academic progress and student engagement and motivation in the learning process.
5. Ethics and safety: Clear guidelines and policies are needed to address issues related to data privacy, information security, and ethical use of AR/VR technologies in the educational context.

By addressing these key aspects, education can significantly benefit from the potential offered by augmented and virtual reality in improving the teaching and learning process in the field of Non-Destructive Testing (NDT).

- Case Study: Walter Garcia:

Walter Garcia's journey through his nursing education during the COVID-19 pandemic underscores the challenges faced by students in technical fields when traditional, hands-on learning opportunities become inaccessible. As his university shifted abruptly to virtual instruction, Walter found himself unable to participate in critical practical classes aimed at developing essential technical skills like patient triage and emergency evacuation.

However, Walter's fortunes changed when his lab teacher, William O'Donovan, introduced a Virtual Reality (VR) application designed

for medical training. With approval from the nursing school dean, they equipped students with Head Mounting Display (HMD) headsets and licenses to access immersive medical emergency simulations. This innovative approach allowed Walter and his peers to engage in practical learning experiences within virtual emergency rooms, offering a realistic and risk-free environment to hone their skills.

The adoption of VR training is part of a broader trend in education, where immersive technologies are increasingly leveraged to address the limitations of traditional teaching methods. VR simulations provide standardized and reproducible environments conducive to optimized training. They facilitate gamification, performance metrics, and collaborative features, enhancing engagement and proficiency-based learning. Constructivist learning principles underpin the effectiveness of VR training, as students actively construct knowledge within immersive virtual environments, leading to increased motivation, interactivity, and personalized learning experiences.

Research supporting the efficacy of VR training across various educational fields further underscores its potential as a pedagogical tool. A systematic review of 92 experiments revealed that VR training outperforms traditional methods in developing students' technical, practical, and socio-emotional skills. Particularly in areas like health and safety, engineering, and technical education, students exposed to VR instruction demonstrated higher learning assessments and efficiency in utilizing inputs and time, indicating the superiority of VR training over conventional approaches.

In summary, Walter's experience highlights the transformative impact of VR training in addressing the challenges of practical education, offering students like him invaluable opportunities to acquire and refine essential skills in simulated yet immersive environments. As VR technology continues to advance and become more accessible, its role in shaping the future of education appears increasingly promising.

Key Benefits of VR Training:

- Faster Proficiency: VR accelerates learning without compromising effectiveness.
- Reduced Onboarding Time: New employees adapt more swiftly.
- Improved Customer Service: Well-prepared employees enhance customer satisfaction.
- Enhanced Workplace Safety: VR allows safe practice in realistic scenarios.
- Decreased Turnover: Effective training leads to better job satisfaction.
- Culture Assimilation: VR aids in teaching organizational culture.

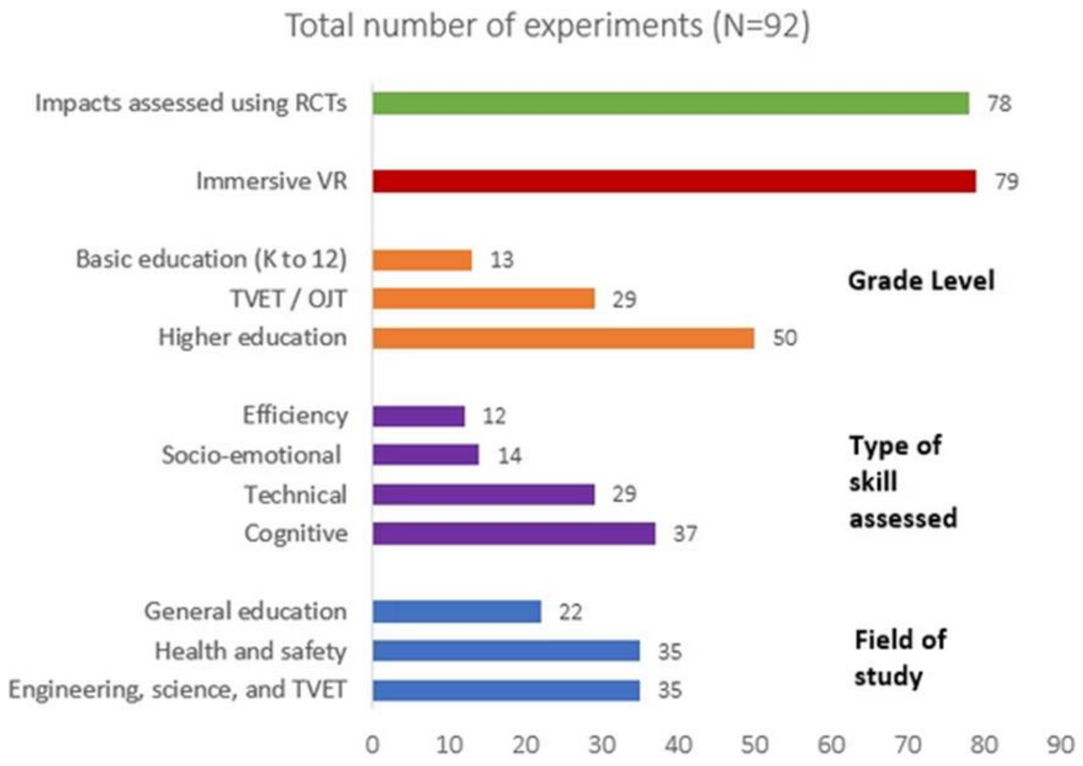

Fig. 3Primary experiments statistics of VR effects on student learning. Source: Angel-Urdinola, Castillo-Castro, and Hoyos (2021).

The study's main findings can be summarized as follows:

A sum of 72 tests shows that VR preparing is similarly or more helpful for further develop understudy learning results than conventional preparation. For each extra hour of preparing, understudies presented to VR preparing score 3% higher in learning evaluations, when contrasted with understudies presented to similar curricular substance conveyed through customary preparation strategies. After completing their courses, students who have completed VR training report 20 percent higher levels of confidence and self-efficacy regarding learning. By and large, up to 30 percent more proficient (utilizing data sources, time, or potentially keeping away from execution blunders) than understudies presented to conventional preparation each extra hour of guidance.

1.2 Importance of VR platforms and Living Labs in technical training and innovation

VR labs offer an immersive, experiential, and interactive platform that transcends traditional teaching methods. They foster critical thinking, problem-solving skills, and creativity. VR training is an effective replacement for instructor-led and on-the-job training because it significantly reduces time spent training without sacrificing effectiveness or engagement.

Living labs involve users continuously from the initial stage, offering two significant benefits. Firstly, it provides an opportunity to create a service highly aligned with users' real contexts of use by incorporating their voices and adjusting interactions over time. Secondly, it offers a valuable learning opportunity for users and stakeholders, allowing them to engage in the design process, discuss different viewpoints, and deepen their understanding of challenges. This participatory approach fosters a sense of ownership and enables users to recognize their issues as their own challenges, leading to more constructive opinions and innovative perspectives. Additionally, companies benefit from direct dialogue with users, gaining insights into undiscovered viewpoints and correcting any wrong assumptions. Overall, living labs facilitate collaborative learning and co-creation, enriching stakeholders' perspectives and enhancing the quality-of-service creation.

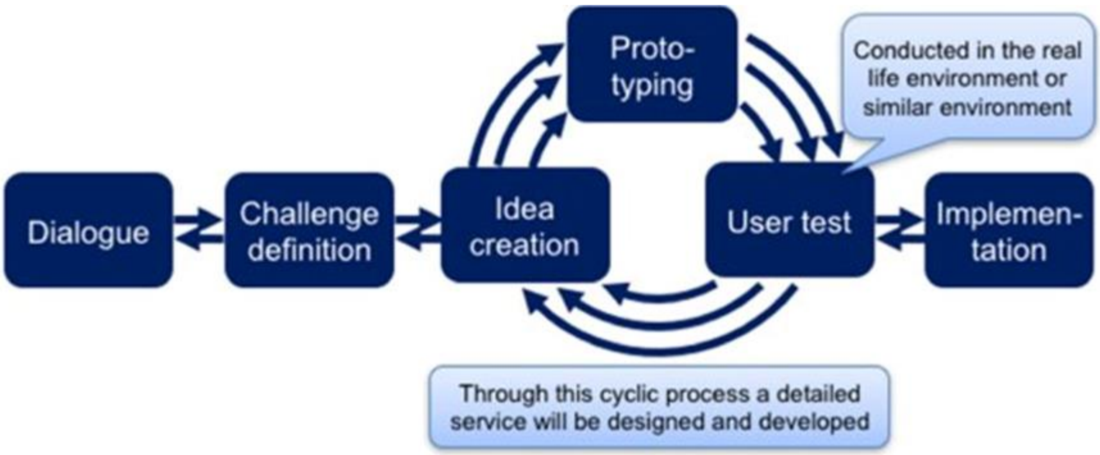

Fig. 4 Living lab process. Source: Yasuoka, Mika, et al. "Living labs as a methodology for service design-An analysis based on cases and discussions from a systems approach viewpoint." DS 92: Proceedings of the DESIGN 2018 15th International Design Conference.

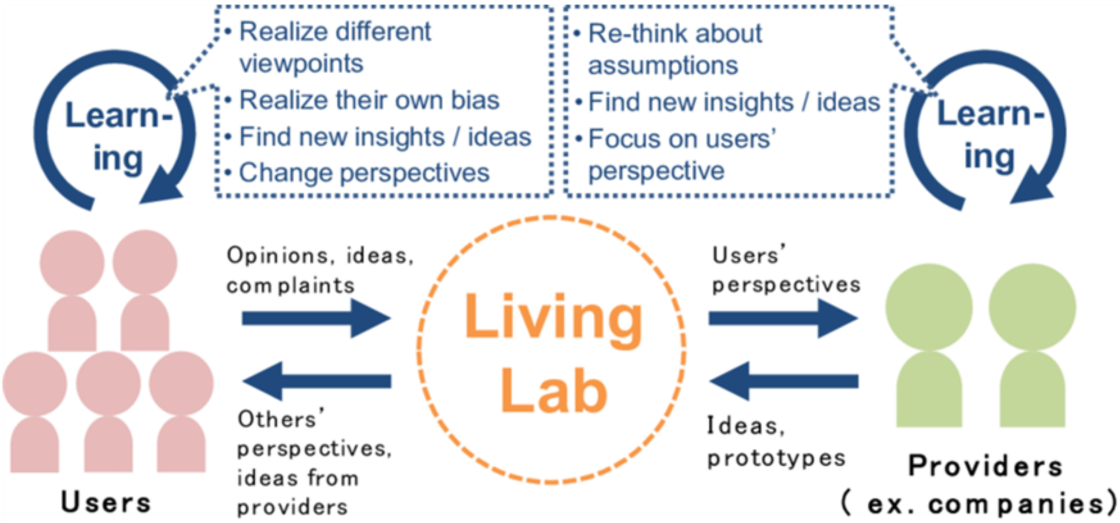

Fig. 5 Living lab as learning process. Source: Yasuoka, Mika, et al. "Living labs as a methodology for service design-An analysis based on cases and discussions from a systems approach viewpoint." DS 92: Proceedings of the DESIGN 2018 15th International Design

The Medical Delta Living Lab Rehabilitation Technology exemplifies the importance of VR platforms and living labs in technical training and innovation. Through collaborations between academic institutions and rehabilitation centers, the living lab facilitates the development, testing, and implementation of technological innovations in a realistic rehabilitation environment. By utilizing robotics, sensor technology, and e-Rehabilitation, the lab aims to improve body functions, mobility, and self-reliance of patients, ultimately enabling a faster transition from hospital or rehabilitation center to home. An exemplary project within this living lab is SenseGlove, a glove integrated with pressure points for hand rehabilitation exercises in a VR environment, offering patients the opportunity for self-guided rehabilitation without constant therapist supervision. This innovative approach demonstrates the potential of VR platforms and living labs in advancing technical training and enhancing rehabilitation outcomes.

Fig. 6 Medical Delta Living Lab Rehabilitation Technology

Another example of the importance of VR platforms in technical training and innovation is the project by researchers at AFRL (Air Force Research Laboratory), which uses augmented reality (AR) to streamline non-destructive inspection (NDI) processes for aircraft maintenance. NDI involves detecting flaws in materials or structures without causing damage. This task is complex and demanding, especially when inspectors need to access hard-to-reach areas. To simplify the process, researchers are developing an AR system to display all necessary information directly within the inspector's field of view. This includes the area to be scanned, equipment displays, technical documents, and other materials, eliminating the need to navigate multiple displays simultaneously. Users can control and customize the display through verbal commands and gestures, enhancing their focus on the inspection task. Future developments aim to further improve guidance and automate sensor positioning. The goal is to make the technology seamlessly integrated into maintenance processes, ultimately facilitating faster and more efficient inspections.

Fig. 7 AFRL researchers demonstrate augmented reality for aircraft inspections, presenting all essential information in the user's field of view, streamlining the process.

1.3 Best Practices and Challenges in Establishing Living Lab Networks (Virtual/Real)

Living labs are usually organized around the development of a particular innovation focused on solving a particular problem. In practice, there are also living labs that are defined by a geographic region that serves as the setting for multiple living labs focusing on various issues. These regions characterized tasks can more readily be alluded to as a living lab stage. Such a stage expects to shape a favorable place for development, as opposed to straightforwardly creating advancements. The administration of a living lab stage is worried about leading to various living lab drives inside a specific metropolitan region and making supporting circumstances.

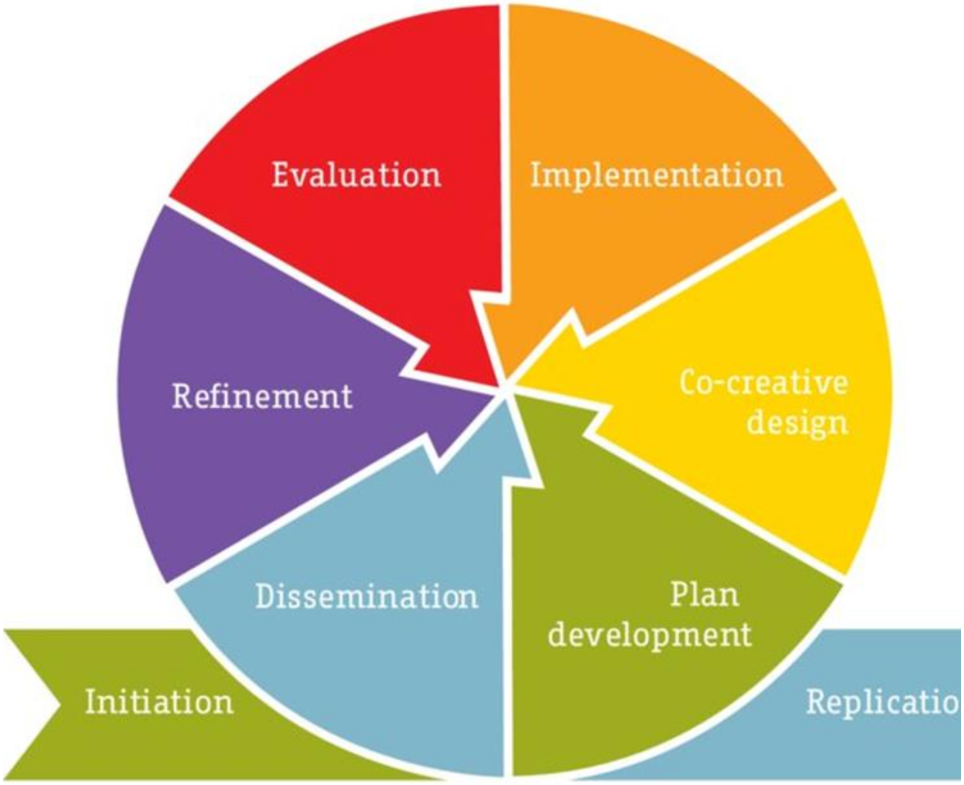

Fig. 8 Replication: Successful solutions birthed from the living lab can be replicated and scaled elsewhere. The scalability and transferability of these solutions are encouraged, with lessons learned from one project informing and inspiring future initiati

Fig. 8: The steps in the living lab way of working. Source: Steen, Kris, and Ellen Van Bueren. "Urban Living Labs: A living lab way of working." (2017).

Let's delve deeper into the sequential stages of the living lab methodology:

1. Initiation: The journey of a living lab project commences with the identification of a pressing problem or opportunity. Stakeholders come together, formulating a team, setting objectives, and procuring necessary resources to establish the living lab.

2. Plan Development: With a clear understanding of the problem at hand, the team meticulously crafts a comprehensive plan for the living lab. This blueprint delineates the scope, objectives, and activities to be undertaken. It is imperative to engage a diverse array of participants, including end-users, researchers, and industry partners, to ensure a holistic approach.

3. Co-Creative Design: At the core of the living lab methodology lies co-creation, where participants collaboratively design innovative solutions. Through

workshops, brainstorming sessions, and prototype development, stakeholders engage in a dynamic exchange of ideas aimed at crafting solutions that effectively address real-world challenges.

4. Implementation: Once the design phase is complete, the focus shifts towards the implementation of the solution in real-world settings. This entails rigorous testing, piloting, and refinement, with continuous feedback from end-users and stakeholders guiding the process.
5. Evaluation: A critical aspect of the living lab approach is the rigorous evaluation of the implemented solution. Researchers meticulously collect and analyze data, measuring the success of the solution against predefined criteria. Insights gleaned from the evaluation process inform future iterations and improvements.
6. Refinement: Continuous improvement is ingrained in the ethos of the living lab methodology. Armed with insights from the evaluation phase, the living lab team iteratively refines the solution, incorporating feedback, lessons learned, and emerging insights to ensure its ongoing evolution and effectiveness.
7. Dissemination: Sharing knowledge and outcomes is paramount in the living lab paradigm. The team disseminates results through various channels, including reports, workshops, conferences, and publications, fostering a culture of transparency and shared learning.

In the realm of technical training and innovation, the integration of Virtual Reality (VR) platforms within living lab networks presents both significant opportunities and challenges. VR platforms offer immersive and interactive environments that can revolutionize technical training by providing realistic simulations and hands-on experiences. However, setting up effective living lab networks to harness the full potential of VR platforms requires careful consideration of various factors.

One of the best practices in establishing living lab networks for VR-based technical training is collaboration among stakeholders. Bringing together academia, industry partners, and research institutions fosters a diverse range of perspectives and expertise, ensuring that the training solutions developed are comprehensive and tailored to industry needs. Additionally, involving end-users early in the design and development process ensures that the training programs meet their specific requirements and challenges.

Another key practice is the utilization of state-of-the-art VR technology and infrastructure. Investing in high-quality VR hardware and software platforms enables realistic simulations and enhances the effectiveness of technical training programs. Moreover, integrating VR platforms with other emerging technologies such as artificial intelligence and data analytics can further enhance the learning experience and provide valuable insights for continuous improvement.

However, despite the promising potential of VR platforms in technical training, several challenges need to be addressed in setting up living lab networks. One such challenge is the cost associated with acquiring and maintaining VR equipment and infrastructure. Establishing and operating VR labs require substantial financial investment, which may pose a barrier for smaller institutions or organizations with limited resources.

Another challenge is the need for skilled personnel to develop and facilitate VR-based training programs. Designing immersive and effective simulations requires expertise in both VR technology and the subject matter being taught. Therefore, recruiting and retaining qualified instructors and technical staff is essential for the success of VR training initiatives within living lab networks.

Furthermore, ensuring interoperability and compatibility between different VR platforms and systems can be a challenge, particularly when collaborating with multiple partners or using off-the-shelf VR solutions. Standardization efforts and collaboration with industry leaders can help address this challenge and promote seamless integration and data exchange across VR platforms.

In the context of Industry 4.0, characterized by technological advancements and digitization, living lab projects play a crucial role in exploring the potentials and addressing the challenges of this new industrial landscape.

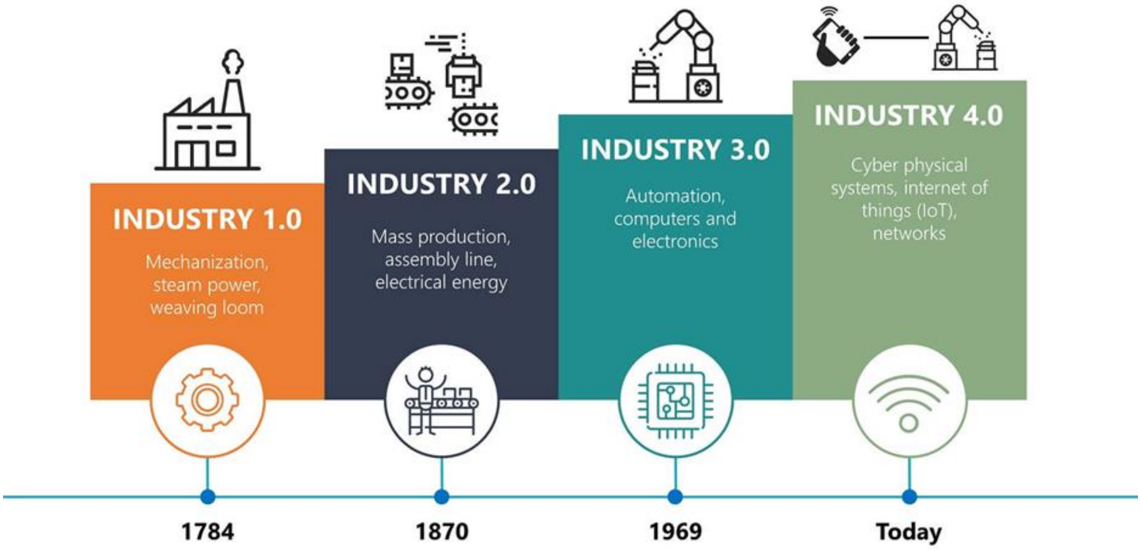

Fig. 9 Representation of the industry evolution until now, made by Lvivity

Recognizing the importance of Industry 4.0, the Flemish Government has incorporated it as one of the central transitions in its Vision2050, emphasizing the need for a sustainable and competitive industry. Living Lab Industry 4.0 initiatives focus on demonstrating advanced techniques within specific sectors, aiming to sensitize and inform a broad spectrum of companies about the latest technological innovations. These projects are collaborative efforts involving research institutions and industry partners, with a focus on smarter products, processes, and business models. Smarter products entail the integration of software to enhance physical products, employing faster design techniques and sustainable materials. Smarter processes involve optimizing production for efficiency, durability, and customization, leveraging technologies like 3D printing and digital twins. Additionally, smarter business models entail the development of new customer-supplier relationships, digital platforms, and utilization of big data to drive innovation and competitiveness. Through living lab initiatives, researchers tailor their efforts to meet the specific industrial conditions of various sectors, fostering innovation and adaptation in the industry 4.0 era.

In conclusion, while VR platforms hold immense potential for transforming technical training and innovation, establishing effective living lab networks to leverage this technology requires careful planning, collaboration, and investment. By adopting best practices and addressing key challenges, living lab networks can harness the power of VR platforms to drive technical excellence and innovation in various industries.

1.4 Transnational Virtual Reality Platforms

Virtual reality (VR) has been used in vocational education for many years, but its potential as a learning tool has only recently been recognized. VR can be used to create a simulated environment used to develop a subject.

Virtual reality (VR) technology is rapidly gaining popularity in both the education and business sectors, offering learners new ways to learn and interact with immersive and interactive information and experiences. One of the most common VR applications in education is vocational training, being a tool used to discuss and learn different aspects about a new concept, such as: how to use a piece of equipment or how to perform a work task [1]. VR simulations are based on experiences presented to improve the skills of the learners before working with real cases, deepening the topics according to their pace and interests. Virtual reality offers truly innovative opportunities to revolutionize the education system by enabling experiential learning, engagement and availability of a wide range of educational resources.

VR has also proven to be an effective tool for teaching learners how to interact with other people, how to manage stress or how to deal with difficult situations at work. Transnational VR platforms represent a significant evolution in the field of virtual reality (VR), with a significant impact on the contemporary digital and social environment. These platforms are characterized by global accessibility, allowing users to interact in a common virtual environment.

Transnational VR platforms are complex digital systems that allow users to access and interact with VR content in an immersive virtual environment. These VR platforms bring the real world into the virtual world, facilitating cross-border collaboration and communication regardless of their physical location [2]. Virtual reality (VR) technology offers innovative experiences in three-dimensional digital spaces. The platforms are accessed by VR content developers providing development tools, technical support and distribution channels to users around the world.

Communication and collaboration between users is achieved through personalized avatars and integrated communication tools. These social interactions can range from voice conversations and text messaging to collaboration through virtual activities and social events. Transnational VR platforms are composed of a set of integrated hardware and software technologies. Users navigate the platforms immersively using specific devices (VR headsets, laptops and smartphones) with which they immerse themselves in that virtual environment. Hardware requirements for accessing cross-border VR platforms may vary by platform and application. Communication can be done through voice, text and gestures, creating a more natural and engaging relationship. Through these platforms, companies have the opportunity to create and test products and services in a virtual environment before launching them into production. Due to their digital nature, transnational VR platforms are accessible to users worldwide, without being limited by distance, regardless of their geographic location. The interface and content are often available in multiple languages to serve an international audience [3]. Real-time translation tools can thus be integrated, allowing users to communicate with people who speak different languages. For this reason the demand for transnational VR platforms is growing and more and more companies are developing and investing in such solutions. Virtual reality has proven to be useful in several fields, being one of the fastest growing technologies in recent times.

Through transnational VR platforms, immersive meetings and conferences can be organized allowing participants from different countries to connect and interact remotely. Engineers, designers and other professionals can collaborate on complex projects, from reviewing 3D models to discussions in a shared virtual space. Also, VR platforms can be used by companies to give employees the opportunity to learn and develop their practical skills in various fields [4].

A major significance of transnational VR platforms lies in their ability to facilitate human interaction in a compartmentalized virtual space. Through avatars and virtual interfaces, users can communicate, collaborate and explore together, regardless of the physical distance between them. This opens up new opportunities for international collaboration in areas such as education, research, arts and entertainment.

Transnational VR platforms are of particular interest in the context of globalization and digital interconnectivity, favoring the exchange of information from various fields. This transnational interaction can help increase understanding and tolerance between different groups and communities through the exchange of ideas and experiences in a shared virtual environment.

Transnational VR platforms also have a significant impact on the creative industry globally by allowing content creators to leverage their creative potential in an amplified way, stimulating innovation and technological development in this field.

Through these platforms, users can experience and explore new virtual worlds, collaborate in innovative ways, and contribute to the ongoing evolution of the contemporary digital environment.

1.5 key components and functionalities of such platforms

Virtual Reality (VR) is a revolutionary technology that allows us to experience digital worlds as if we were present in their midst. The key components and functionalities of VR platforms interact with each other to create an immersive and innovative virtual environment [5].

VR platforms are made up of a combination of hardware and software that allow users to experience virtual reality (VR):

1. hardware devices: VR headsets are the primary devices used to provide users with access to virtual worlds. They include two screens, one for each eye, which project stereoscopic images to create the illusion of depth and can be connected to various platforms such as: PCs, game consoles or mobile devices. The most popular VR headsets are Oculus Rift, HTC Vive, PlayStation VR, and Oculus Quest. Headsets and controllers are devices through which 3D images and sounds are captured by the user to interact with the virtual environment. Stereoscopic images and sounds are produced to create an immersive experience. Controllers allow users to interact with the VR environment, move around and manipulate objects.
   Tracking sensors monitor and reproduce the movements of the user's head and body in a virtual environment, by means of special integrated cameras. Examples of VR controllers include Oculus Touch, HTC Vive Controllers, and PlayStation Move.
2. management software: Specialized software is required to configure and control VR devices, as well as navigate the user interface, generating and rendering VR experiences through graphics, sound and interactivity.

3. computer: The computer plays an essential role in VR platforms with the ability to access and run VR software through high-quality images. The computer-processed data accurately reflects the user's position and movements, as well as audio effects, in the virtual environment. It is also used to manage VR platform content and settings, including downloading and

installing VR games and apps, updating VR device software, and customizing settings to optimize user experience.

4. content stores: Content stores include apps, experiences, and other types of content as well as reviews, ratings, and usage recommendations. Users can browse the store to discover and download the content they want. Examples of VR content stores: Oculus Store, SteamVR, Viveport, PlayStation Store.
5. experiences: VR (virtual reality) platform experiences are immersive interactions and adventures in virtual environments, created and simulated by specialized software and hardware [6]. These can range from educational virtual learning applications, films, interactive activities to training simulators. Users are transported into detailed and realistic virtual worlds with the ability to customize and control their VR experiences.
6. communities and social interactions: Platforms facilitate interaction and communication between users by participating in multiplayer experiences, through voice chat or text messaging in a virtual environment.
7. content development and creation: VR platforms are technology environments and infrastructures that enable the development, distribution and use of virtual reality applications and experiences through tools and resources such as software development kits (SDKs), graphics engine, tutorials and documentation.
8. technical support for users: Technical support for users of VR platforms is the services and assistance provided to help users solve problems and obtain technical assistance in using VR devices and applications. These services are provided by VR device manufacturers through: user guides, live email or chat support, community forums.

Components included in the structure of the virtual reality operating platform are:

1. main virtual frame: The main virtual frame is the foundation of the platform and includes the primary interface through which users interact with the virtual reality system to perform various operations by navigating through menus, buttons, indicators and other interactive elements.
2. virtual reality operations processing module: Processing virtual reality operations within a VR platform involves a series of steps and technologies that work together to provide users with an immersive and immersive experience in the virtual world. The process begins by capturing the user's movement and position in space using special cameras, sensors or other technologies [8]. The platform then generates the 3D graphics corresponding to the virtual environment in a stereoscopic manner in parallel with the sound display simulating spatial sound. While the user interacts with the virtual environment, the VR platform processes his actions and responds to him in real time.
3. menu module: The menu module of VR platforms represents the user interface (UI) through which users navigate to choose the desired components. The main menu is the entry point into the VR user interface, and includes easy-to-use navigation options. The menu module includes custom settings options to allow access to the available content library. It also has functionality to inform users about content updates.
4. verification module: The verification module ensures software and application updates, testing of key device functionalities as well as user data protection.
5. delete module: The delete module is connected to the menu module and refers to the process by which users can delete desired content from the library or uninstall applications. To avoid accidental deletion, the delete module should include the co-sign function before deletion. Deletion of selected content must be complete and effective.
6. the accounting module: The accounting module ensures the financial operations of the VR platform in accordance with the legislation in force. Thus, it has the role of managing user accounts and the billing process for the products offered by the platform. It can also generate financial reports and statistics relevant to the platform's activity.

   Virtual reality (VR) technologies used in vocational training prepare learners for various careers through realistic simulations that can help develop the necessary skills in a safe environment, improving performance and productivity in the workplace. Thus VR allows the creation of realistic virtual environments to train learners in various work scenarios. Trainees can also be trained safely to deal with dangerous or imminent situations. Learners can experience complex processes in a virtual environment without affecting real equipment. The virtual reality operating platform includes a main virtual frame, a menu module, and various other modules for processing and verifying the performance of various components.[7].

VR Platform Functionalities:

1. - immersion: Immersion in the functionality of the VR platform places the user in the middle of a virtual environment through the headset and controllers enabling haptic interaction through tactile sensations during the VR experience. Spatial 3D sound and movement control in a natural and intuitive way play a crucial role for complete immersion.
2. - interactivity: Interactivity in VR platforms focuses on making it easier for the user to interact with the VR environment, manipulate objects and move in space as naturally and intuitively as possible with the virtual environment.
3. - presence:The presence of the user in the functionality of a VR platform creates an immersive and realistic experience so that the user feels that he is part of the created virtual world, even if his body is in the real environment.
4. - simulating real-world environments: Simulating real-world environments in VR platforms involves digitally creating various aspects of real-world environments through advanced graphics, sound, and interactivity technologies to provide users with as realistic an experience as possible [9].
5. - Education and Training: Education and training with the help of VR platforms have revolutionized the way learners learn and prepare for various fields benefiting from the simulation of practical environments and scenarios facilitating interactive discussions, collaborative activities for all social categories even for people with disabilities.
6. - entertainment: The VR platform offers various forms of immersive entertainment through interactive games, documentary film screenings and other social activities that bring people together in a shared virtual space.

7. - collaboration: VR platforms allow users to interact with each other in shared virtual environments.
8. - telepresence: Telepresence in VR platforms gives users the ability to be present and interact in real time with other people even if they are physically located at a distance in other locations.

The virtual reality learning platform introduces an object identification system using machine learning, enabling interactive scenes in an imaginary environment[10]. The system uses a library of interactive features and information that enhance the immersive learning experience. Teachers can issue work requirements, create assignments, and check assignment results. Learners can access the platform to complete work tasks and interact with the environment that simulates the real work environment.

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1.6 Review existing transnational VR platforms in technical training and education

This study provides a comprehensive overview of virtual reality (VR) applications in the educational and training field, available on various existing platforms.

Virtual reality (VR) presents both challenges and opportunities in the educational sector. VR technologies can serve as educational and training tools, with the advantage of being completely controllable, practical, and safe. Advances in 3D visualization technology allow for the use of an increasingly diverse range of educational and training materials in virtual reality environments [1].

Virtual reality platforms are used in technical training and education to enhance learning experiences. They offer opportunities in multiple fields, such as collaborative assembly tasks in mechanical engineering, technical translation teaching in non-linguistic institutions, environmental education in technical universities, entrepreneurial education, and laboratory process training in the medical field.

Virtual reality involves using a headset to block the view of the real physical environment and instead provide a stereoscopic display of computer-generated 3D graphics, aiming to immerse users in a virtual environment. VR hardware can track users' body movements in real-time, allowing them to perform actions and experience their consequences, which is practically impossible in real life. These technical features of VR allow learners to feel as if they are present in the virtual environment and to experience events in it, thereby increasing their engagement.

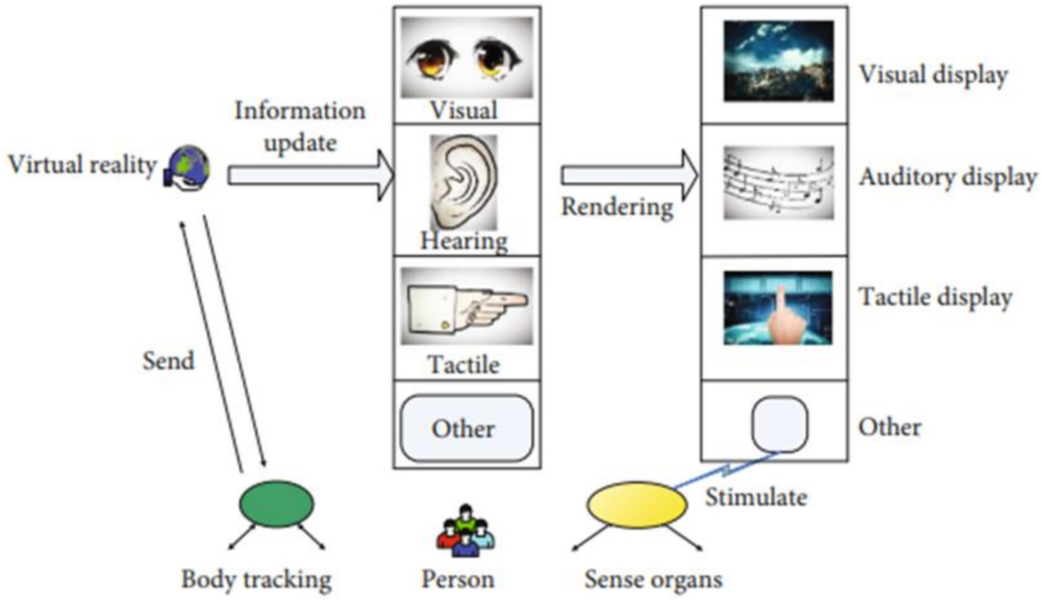

Fig. 10 Virtual reality system's conceptual model [2]

The distinctiveness of VR in terms of graphics, interactivity, and body movement opens up new learning opportunities. These capabilities have led to intensive investigation of the educational benefits of VR, particularly in the fields of scientific and engineering education. The use of transnational VR platforms in technical education and virtual training brings some significant advantages. Here are some of them:

1. Global Accessibility: Transnational VR platforms pave the way for access to high-quality educational content and experiences globally. They allow learners

from diverse countries and regions to enjoy the same learning resources and opportunities, regardless of their geographical location.

2. International Collaboration: The use of VR facilitates collaboration and interaction among students and educators worldwide. Through these platforms, learners can work together on projects, exchange ideas, and learn from each other, without being constrained by the physical distance that separates them.
3. Cultural Diversity: Integrating transnational VR platforms into the educational context provides learners with the opportunity to explore and understand diverse cultures and perspectives. This aspect contributes to the development of intercultural understanding and familiarizes learners with global diversity.
4. Realistic and Authentic Experiences: By simulating realistic environments and situations, VR platforms offer learners the opportunity to experience and practice authentically. For example, in the technical field, these platforms can recreate complex interactions with equipment, troubleshooting technical problems, and working with virtual machines and systems.
5. Resource Efficiency: The use of transnational VR platforms eliminates the need for costly transportation and physical resources, such as laboratory equipment or study materials. This leads to a significant reduction in costs associated with the acquisition, maintenance, and storage of these resources.
6. Flexibility and Adaptability: VR platforms offer the possibility of adapting content and learning experiences according to the needs and competence levels of learners. This flexibility facilitates the customization of the learning process and allows each learner to progress at their own pace.
7. Innovation and Continuous Updates: Integrating transnational VR platforms into the educational context provides access to the latest technologies and innovations in the field. These platforms are constantly evolving, constantly adding new features and content, which contributes to maintaining the relevance and continuous updating of technical education and virtual training.

These advantages highlight the potential of transnational VR platforms in technical education and virtual training, opening new opportunities for learners and educators to connect, collaborate, and learn in a global and virtual environment.

It is essential to emphasize that, despite the significant potential of virtual reality (VR) in the field of education and training, its implementation must be accompanied by careful pedagogical design and proper integration into the curriculum. Additionally, access to VR equipment and content, as well as ongoing progress in the development of VR educational applications, will continue to influence the adoption of this technology in educational settings.

1.6.1 Transnational VR platforms currently available for technical education and virtual training

Transnational VR platforms currently available for technical education and virtual training have demonstrated significant potential in enhancing learning experiences. In the academic literature, the development and implementation of such platforms have been documented, including mixed reality-based systems used for mechanical engineering concepts [3], virtual-real platforms for technical translation teaching [4], [5] and VR-based teaching platforms with interactive features [6]. These platforms are designed to facilitate collaborative tasks, utilizing authentic materials and promoting interactive learning, thereby enhancing students' technical competencies and intercultural communication skills.

Furthermore, in higher education, transnational virtual projects have been reported, used to develop intercultural communication skills through collaborative research among students. Such initiatives are considered to provide valuable opportunities for students to engage in intercultural interactions, strengthening their adaptability and problem-solving skills in diverse educational settings.

1. Engage by Immersive VR Education: Engage is a transnational VR platform that provides learning and collaboration experiences in virtual reality and is used in a variety of fields, including technical education and vocational training. This platform offers an extensive range of interactive tools, such as the ability to create VR presentations, virtual course delivery and interactive simulations. Engage is an environment that facilitates a range of interactive educational experiences within virtual reality, providing educators with the tools to develop and deliver virtual lessons, presentations and simulations. The platform is also compatible with a variety of VR headsets, including Oculus Rift, HTC Vive and Windows Mixed Reality devices. Engage also enables live streaming and recording of sessions, making it easy to share and review content later.

With advanced visualization and interactivity capabilities, Engage becomes attractive for educators to explore its educational potential [8]. This platform can be used to enhance learning experiences by helping to visualize abstract concepts and increase student engagement and motivation [9]. In a recent study, the authors propose the use of an immersive virtualization-based regulatory standards training method to improve student knowledge retention compared to traditional online models, which is the main metric used in this paper to demonstrate the effectiveness of the method [10]. The platform has also been found to be usable for training purposes, such as regulatory standards training, where it has been shown to improve knowledge retention compared to traditional online models [11]. Overall, Engage by Immersive VR Education offers a number of applications in education and training, providing immersive experiences that contribute to improved learning outcomes and engagement [12].

2. AltspaceVR: AltspaceVR is a social and collaborative virtual reality (VR) platform with applications in education. Through it, users can interact in virtual spaces, participate in events and collaborate in various activities. AltspaceVR provides facilities for organising learning and training sessions, allowing users to create and customise their virtual avatars and interact with other participants in virtual spaces. It is also compatible with a range of VR headsets, including Oculus Quest, Oculus Rift, HTC Vive and Windows Mixed Reality devices. Features include spatial audio, which allows users to hear conversations based on proximity to other users, as well as support for live events, presentations and workshops, all of which contribute to its adaptability in educational contexts.

AltspaceVR has partnered with various organisations, brands and content creators to deliver unique experiences and events. These collaborations include engaging artists, musicians, educators and companies with the aim of bringing engaging and immersive content to the platform.

The AltspaceVR platform faces the challenge of user isolation after removing the VR headset. To address this issue, users and communities have integrated the Discord platform for ongoing communication and community activities. AltspaceVR provides a unique virtual space with a virtual representation of the user, a system menu, and three-dimensional shortcut icons for applications, enhancing immersion in virtual reality and simplifying operations. In addition, AltspaceVR provides a stage for ephemeral but rewarding community experiences, while Discord acts as an environment for collaboration and communication, forming a tightly coupled communicative ecology. This platform enables the creation of virtual environments populated by autonomous virtual agents, using a comprehensive architecture with various software components for their simulation and development. [13], [14], [15], [16].

3. Oculus Education: Oculus, owned by Facebook, offers a VR education platform that includes educational content and apps as well as tools for teachers. Oculus

Education offers tools for managing virtual classrooms as well as access to a wide range of educational experiences.

Oculus Education is a sub-division of Oculus focused on providing educational content and tools for virtual reality (VR). This entity offers a curated selection of educational apps and experiences through the Oculus Store and is compatible with a range of VR headsets, including Oculus Quest and Oculus Rift. Oculus Education provides resources for educators, such as lesson plans, tutorials and case studies, focusing on effectively integrating VR into learning environments. It also offers functionality such as Oculus for Business, which makes it easy to manage and deploy VR experiences within educational environments.

The Oculus platform has been explored and used in various educational contexts. Studies have investigated the reuse of existing VR applications for educational purposes [17], and in a specific line of research, a VR platform has been developed for road safety education, incorporating elements of serious games and Oculus Rift/Quest technology [18].

The Oculus sensor vane system has also been adapted to improve aeronautical surveillance and reconnaissance capabilities on Lockheed Martin C-130 aircraft [19]. Furthermore, the Oculus project involved the deployment of airborne sensors on a C-130 aircraft, with a focus on designing an intercom system to reduce high levels of internal noise [20]. These varied examples illustrate the versatility of the Oculus platform in educational and operational contexts, highlighting its potential for immersive learning experiences and specialised mission support.

4. ClassVR: is a transnational VR platform developed specifically for education, with a focus on developing VR educational content. It provides teachers with tools to create and manage VR experiences in the classroom, allowing students to explore technical topics and participate in interactive activities, offering a wide range of lessons and interactive educational experiences, as well as tools to manage virtual classrooms [21], [22]. It provides a diversity of pre-defined educational content in a variety of areas such as science, history, geography and others. The platform also features a content management system, allowing educators to easily implement and manage virtual reality (VR) experiences for students. ClassVR is compatible with a variety of VR headsets, including Oculus Quest, and provides tools for teachers to monitor student progress and engagement in the VR environment.

The ClassVR platform optimizes the management of multiple VR devices via wireless signals and control devices, reducing administrative tasks for teachers and saving time in classroom activities [23]. This VR-based learning environment enables immersive experiences with industrial collaborative robot manipulators, facilitating detailed exploration of behaviors and functionalities that are difficult to replicate in the physical classroom environment [24]. In addition, the platform integrates cloud-based artificial intelligence, providing features such as interactive learning and flipped classroom approaches to promote active learning and contribute to educational reform [25].

ClassVR also has mechanisms for adjusting VR modes, facilitating a more optimal user experience, such as walking simulation and the ability to take notes during lessons.

5. Nearpod Platform: is an interactive and versatile educational platform that integrates support for Virtual Reality (VR) experiences. This platform enables teachers to create and deliver lessons in the VR environment, providing learners with an engaging way to explore technical topics and participate in interactive simulations, as well as the ability to creatively plan lessons and access self-paced learning opportunities using VR technology. In particular, Nearpod offers interactive activities, creative lesson planning, self-paced study, online assessment and high levels of engagement, thus enhancing learners' learning experiences through the use of innovative technology in the classroom [26], [27]

This platform enhances learners' learning experiences by providing a new and engaging environment that includes features such as online assessments and high levels of engagement [28]. Nearpod also supports independent learning outside the traditional classroom context, and is particularly valuable in contexts such as online learning and emergency situations [29]. Furthermore, the use of Nearpod VR in developing message models within science disciplines demonstrates high validity, utility and effectiveness in stimulating learner enthusiasm and engagement in the learning process [30]. In addition, Nearpod has been applied in the development of a virtual reality platform for sensory integration studies, demonstrating its effectiveness in providing multimodal sensory stimuli and real-time monitoring of human movement.

6. Labster Platform: Labster is a transnational VR platform specialising in virtual lab simulations, with a particular focus on learning science and technical skills. Through the VR experiences offered by this platform, learners have the opportunity to explore and experiment in virtual laboratories, facilitating a practical understanding of scientific and technical concepts.

The Labster platform has a diverse range of functionality tailored to modern trends in mechatronic systems development and customisation of high-performance I/O stacks. A remarkable aspect of the platform is the "oscillating" platform it offers, which allows for controllable non-periodic and non-stationary movements. This feature facilitates specific tasks such as dispensing and dispersing liquids [31]. In addition, Labster also provides a robot arm and control hardware for hands-on projects, with an emphasis on teamwork and industrial development processes in mechatronic system design education [32]. In order to overcome the limitations of traditional I/O systems, Labster has introduced LabStor, a modular and extensible platform that enables the development of custom I/O stacks. It enables significant performance improvements through the use of custom I/O stacks and stack compositions [33]. LabStor is a modular platform for creating custom I/O stacks in user space, enabling the development of single-purpose modules, such as I/O schedulers, for custom performance improvements of up to 60% in various applications. [34].

In addition, Labster integrates an overclocked laboratory platform for testing control algorithms in dynamic positioning of marine vessels. This process is achieved by using open-loop step response identification and a MOOS-based communication structure for platform control [35].

7. EON Reality: EON Reality is an international corporation specialising in providing virtual reality (VR) solutions for education and technical training. Their core platform, known as EON Experience AVR, provides VR educational content and authoring tools for creating personalized VR experiences. Through partnerships with educational institutions and companies around the world, EON Reality provides tailored solutions for virtual learning.

These integrated platforms developed by EON Reality incorporate hardware components, such as steering wheels and pedals, to facilitate user interaction with the virtual environment [36]. They also provide didactic sub-assemblies that present electrical reality standards, thus enabling simulation and understanding of electrical concepts and principles [37]. Also, the use of virtual reality technology within EON Reality platforms allows for a fast and efficient expression of vehicle design factors [38].

In addition, the platforms developed by EON Reality can simulate training for production operations, providing integrated functionalities in a compact framework, which facilitates efficient training and acquisition of necessary skills [39].

Also, a virtual reality experience platform developed by Liu Yuanjiang and Zhou Zhonghou uses motion execution mechanisms to allow movement in six degrees of freedom, thus helping to improve response time, reduce noise and vibration [40].

8. Veative Labs: Veative Labs is a transnational virtual reality (VR) platform specializing in technical training and education in science, technology, engineering and mathematics (STEM). This platform offers an extensive range of VR content, including interactive simulations, virtual experiments and themed courses tailored to specific educational needs.

Veative Labs focuses on facilitating value co-creation within research ecosystems by providing tools for collaborative experimentation and knowledge sharing [41]. The platform also provides a non-moving responsive installation solution for labs, providing multi-level stability and damping during vibration to prevent damage and ensure safety [42]. In addition, Veative Labs provides a cloud-based educational solution, called V-Lab, that allows instructors to easily and securely configure test banks for computer networks, thereby improving learning experiences and student efficiency [43].

In addition, the Virtual Lab Collaboration and Accessibility Platform (VLCAP) developed by Veative Labs supports the creation of over 150 virtual labs in India, providing user-centric tools and mechanisms for building multidisciplinary experiments with enhanced scalability and security features [44].

9. Alchemy VR: Alchemy VR is a transnational platform specialising in the delivery of educational content in the virtual reality (VR) environment. It collaborates with educational institutions and museums around the world to develop immersive VR experiences in diverse fields such as history, geography, biology and astronomy.

The Alchemy VR platform is distinguished by its unique interactive approach, which aims to alter self-perception through facial manipulation and the creation of virtual spaces [45], [46]. It provides a virtual chemistry lab environment, allowing learners to learn practical processes in a simulated environment before experiencing a real lab, which contributes to improved understanding and learning experiences [47]. A virtual reality platform has also been developed for multisensory integration studies, allowing the delivery of varied sensory stimuli with real-time tracking and control capabilities, validated by reaction time tasks for investigating peripersonal space [48]. In addition, Alchemy VR serves as a provocative benchmark for meta-learning research, providing a 3D video game with a procedurally resampled causal structure that allows evaluation of reinforcement learning agents and testing of meta-learning capabilities [49].

10. zSpace: is a transnational VR platform that combines learning experiences in augmented virtual reality. By integrating VR with augmented reality elements, zSpace provides three-dimensional interactions and hands-on experiences in a variety of fields, including technical and vocational training and STEM.

Introducing zSpace into the educational environment allows trainers to engage learners in a more dynamic and engaging way, leading to improved learning outcomes and better retention.

One of the key ways in which zSpace improves learning outcomes is by increasing learner engagement. The interactive nature of the technology captures learners' attention and keeps them actively engaged in the learning process. This increased engagement leads to better concentration and motivation, which translates into improved academic performance. Furthermore, zSpace's hands-on approach allows students to explore concepts in a more tangible way, facilitating understanding and assimilation of abstract concepts.

By providing an interactive and engaging learning experience, zSpace has been shown to improve student learning outcomes in a variety of subject areas.

zSpace is a platform that provides a unique virtual environment for a variety of activities. It integrates elements of precision positioning platforms [50], recursive web navigation systems [51] and intelligent spatial location systems [52]. The platform facilitates participation in activities such as training, racing and social interactions in a comfortable virtual environment [53]. zSpace also enables sharing of ZCubes through a networked recursive web navigation system, facilitating collaboration [54]. Through innovative mechanisms and flexible hinges, zSpace provides precise multi-axis motion amplification, ensuring a high level of precision and control for users. Overall, zSpace is a versatile and interactive virtual space that integrates various technologies to provide a dynamic user experience.

11. Immerse Learning: is a transnational VR platform focused on providing custom VR learning solutions for educational organisations and institutions. It focuses on providing hands-on experiences and virtual simulations for technical training and skills development.

In the context of evolving educational technologies, immersive learning platforms use technologies such as Virtual Reality (VR) and Augmented Reality (AR) to create immersive educational experiences [55]. These platforms provide a simulated environment for learning and also facilitate adaptive learning systems (ALS) by dynamically adapting content and learning processes according to the user's matrices [56]. Immersive learning in modern education is geared towards developing psychomotor skills, such as learning table tennis moves through interactive multimedia applications [57].

Also, the technological evolution of education towards the concept of Education 5.0 emphasizes the use of emerging technologies, such as VR, AR and blockchain, to revolutionize learning and bridge the gap between physical and virtual learning environments [58]. Such platforms are designed to enhance learner engagement, provide personalized learning experiences, encourage collaboration, and increase access to education [59].

12. SimLabIT: SimLabit is a transnational VR platform specializing in virtual simulations and training, with applications in various industries, including technical and educational fields. This platform provides VR solutions that allow learners to train in a safe and immersive virtual environment.

Within this platform, SimLabit stands out as a versatile tool designed to serve various simulation purposes. Offering a simplified way of creating the simulator, it allows learners to directly describe physics models, thus reducing the time and effort required without compromising reliability [60]. For example, the SIMLAB project, part of the PRESTO project, has contributed to the development and verification of distributed algorithms for storage networking and other network problems, using the C++ programming language and common libraries to ensure cross-platform compatibility [61].

In addition, SIMLAB is used as a circuit simulation environment for educational and research purposes, benefiting from an easy-to-use interface and a powerful simulation engine capable of running both in batch and interactive modes [62]. On the other hand, SimBit represents a high-performance population genetics simulator capable of simulating various scenarios and tracking QTLs, highlighting its superior performance in various simulations according to benchmarking tests [63].

13. Oculus Rift Platform: Oculus Rift is a virtual reality (VR) platform developed by Oculus VR, a company owned by Facebook. It was one of the first commercial VR systems to capture the attention of the general public.

Oculus Rift is a virtual reality (VR) platform used for technical training purposes, with extensive capabilities in areas such as engineering and construction. It provides interactive simulations, allowing users to experience various technical scenarios in a safe and controlled virtual environment. By interacting with virtual objects and equipment, users benefit from hands-on experiences and can develop specific skills such as using complex equipment or troubleshooting.

The platform also facilitates real-time collaboration between users, simulating teamwork or technical support situations. It also provides tools to monitor and evaluate users' progress during training sessions, allowing training to be adjusted according to individual needs. However, effective use of Oculus Rift in technical training may require the creation of custom content and integration with other technologies or systems to ensure a complete and effective training experience.

Oculus Rift offers the ability to create interactive simulations in the virtual environment. This allows users to train and experiment with various technical scenarios in a safe and controlled environment, it can be used to simulate the assembly or disassembly of complex components.

Through the Oculus Rift, users can interact with virtual objects and equipment, giving them a hands-on experience in a virtual environment. This enables learning through exploration and experimentation, helping users to become familiar with procedures and develop the necessary technical skills. It can facilitate real-time technical training and collaboration between users. Users can be connected in the same virtual environment and interact and collaborate in real time, simulating teamwork or technical support situations.

One study developed a low-cost VR platform for sensory integration in postural control targeting patients with vestibular dysfunction [64]. Another research introduced a virtual reality experience platform with motion execution mechanisms for six-degree-of-freedom motion [65]. In addition, a virtual reality application was designed for children in hospitals, implementing a virtual playground Oculus Rift DK2 headset [66] . Furthermore, a unique VR platform for multisensory integration studies was presented, allowing real-time tracking of human movement and avatar control [67] . Finally, a tool combining the Oculus Rift DK1 with a remote device to provide immersive telepresence experiences at a low cost [68]. These applications diverse the versatility and potential of the Oculus Rift platform in different virtual reality settings.

These are just a few examples of transnational VR platforms currently available. It is important to mention that the VR market is constantly evolving and new platforms and apps are constantly being developed and released. It is therefore recommended to research and explore the options available to find the right platform for your specific needs in the field of technical education and virtual training.

These platforms aim to provide immersive and engaging educational experiences through the use of virtual reality. They offer a range of features and content tailored to the needs of trainers and learners. It is important to note that the availability of these platforms and their specific features may vary over time, so it is advisable to visit the respective websites for the latest information.

1.6.2 National and international standards

According to the information presented on the online platform of the Romanian Standards Association (ASRO), the regulations for standards in the field of virtual and augmented reality (AR and VR) are managed by the International Electrotechnical Commission (IEC). The IEC is responsible for developing and updating standards in these areas, including for displays used in smart glasses.

Recently, the IEC Technical Committee 100 issued a new document on haptic technology, which aims to investigate and standardise the human sense of touch. The ISO/IEC JTC 1 joint technical committee is also active in the development of standards for IT applications, with a particular focus on cloud and volumetric video technologies.

Within ISO/IEC JTC 1, Subcommittee 24 deals with interfaces for IT-based applications, covering areas such as computer graphics, virtual reality, image processing, environmental data representation, support for mixed and augmented reality, and interaction and visual presentation of information.

In parallel, IEC TC 110 is responsible for developing standards for electronic displays, including OLED, 3D, holographic and flexible displays. In this context, IEC has issued standards such as IEC 62341-2-1 for OLED displays, which sets out the essential ratings and characteristics of OLED display modules. IEC 62629-41-1 has also been published, which is a technical report on 3D and holographic display devices, contributing to the clarification and standardisation of these emerging technologies [69].

Fig. 11 Fig. 2 Illustration of metaverse immersion [69]

International regulations

According to information presented in the European Commission (EC) policy paper, the wider field of mixed reality (XR) brings to the fore a number of challenges and regulatory needs, addressing issues of data protection and privacy, the management of harmful online content, as well as fundamental rights, including freedom of expression and non-discrimination, with a particular focus on the protection of people with special needs, including children.

These regulatory priorities, identified through the analysis carried out under the TechEthos project, are contextualised in relation to the Charter of Fundamental Rights of the European Union (CFREU), the General Data Protection Regulation (GDPR), the Digital Services Directive (DSA), the Digital Single Market Regulation (DMSR) and the proposed Artificial Intelligence (AI) Bill.

The EC has initiated regulations to promote competition in the XR sector, focusing in particular on enterprise-level meta-virtual services. These regulations aim to prevent the dominance of large technology companies in this space, in line with EU values and fundamental rights [70].

At the same time, the EC aims to develop an open and interoperable metaverse where different companies, regardless of their size, can contribute to a common basis for immersive web services. The EC is also facilitating the creation of regulatory sandboxes to encourage collaboration and innovation within the metaverse industry.

EC projections point to significant growth in the virtual worlds and metaverse market over the next decade, which stimulates the development of regulatory policies to support digital skills, businesses, infrastructures and public services.

Within this framework, the EC is working with Member States to support women developers of XR and metavers, with funding from the Digital Europe Programme and the Creative Europe Programme to promote inclusion and diversity.

In addition, the EC is interested in long-term collaboration with web3 and metaverse, setting out plans to support emerging technologies and proposing partnerships for research and development under Horizon Europe.

To support these efforts, the EC is developing a range of tools, such as DestinE, Local Digital Gemineries and the European Digital Ocean Gemini, to promote scientific research, smart urban development and personalised healthcare, reflecting its commitment to innovation and progress in XR and metaverse technologies. [71]

1.6.3 Existing NDT penetrant testing procedure

To enhance the proficiency in penetration testing skills, transnational VR platforms tailored for testing penetrating liquids within NDT environments have been developed [72]. These platforms leverage open-source software and feature moderate hardware requirements, rendering them accessible for educational purposes [73]. Moreover, the integration of non-destructive testing techniques such as liquid penetration testing with robotic arms enhances the automation of industrial inspections, ensuring precision and accuracy while reducing time consumption [74]. Additionally, the utilization of electronic sensor arrays in conjunction with optical microspectroscopy facilitates real-time monitoring of surface wetting dynamics and electronic differentiation between liquids [75]. Collectively, these advancements in VR platforms and automation technologies substantially contribute to enhancing the efficiency and effectiveness of non-destructive testing processes across various industrial applications. **Geppeteau** is a cutting-edge haptic device aimed at transforming virtual reality user experience by providing tactile sensations of interacting with virtual liquids. This state-of-the-art technology employs a string-driven mechanism housed within customizable vessel enclosures to replicate the behavior of fluids in a variety of vessel shapes, as presented in the following figure.

Fig. 12 Geppetteau employs a pulley system based on strings to dynamically adjust the center of gravity of a vessel, creating haptic feedback sensations of virtual fluids. This technology has the capability to enhance various common vessel profiles, as illustrated by four sample vessel shapes on the left. Users in any physical environment (middle) can engage with virtual fluids in simulated settings (right) [76]

A standout feature of Geppeteau is its capacity to dynamically adjust the center of gravity of the simulated liquid through a pulley system, enabling users to perceive the changing weight and motion of the virtual fluids. This distinctive haptic interface heightens the authenticity of virtual liquid interactions, delivering a more immersive and captivating experience for users. The article underscores the diverse applications of Geppeteau in educational, training, and entertainment settings, where users can participate in virtual wet labs, chemical reactions, and other fluid-centric activities. By seamlessly integrating Geppeteau into virtual environments using popular game engines like Unity and Unreal, users can engage with virtual fluids in a lifelike and intuitive manner. Moreover, the article emphasizes the significance of synchronizing haptic and visual cues to establish a seamless user experience. Geppeteau's ability to offer tactile feedback that aligns with visual elements enhances the overall immersion and realism of virtual fluid interactions. In conclusion, Geppeteau stands as a significant breakthrough in haptic technology for virtual environments, providing users with a distinctive and captivating means to engage with virtual liquids. Its innovative design and functionalities unlock new avenues for exploring the tactile sensations associated with handling liquids in virtual reality, positioning it as an asset for research, education, and entertainment endeavors [76]. Michael Engel and the IBM Research team have developed an integrated platform for analyzing nanoscale liquids using a sensor array based on 2-dimensional materials. This innovative platform combines electronic and optical sensing to characterize liquids at the nanometer scale, allowing for electronic differentiation between liquids and providing detailed molecular fingerprinting. Real-time monitoring of surface wetting dynamics is enabled, showcasing high sensitivity through the recording of topographies and optical spectra of individual sessile oil emulsion droplets with volumes below ten attoliters. The integration of two-dimensional materials in the sensor array opens up possibilities for advancing lab-on-chip analysis from the microscale to the nanoscale, with significant implications for industrial technologies in fields like chemical engineering, biotechnology, and natural resources recovery.

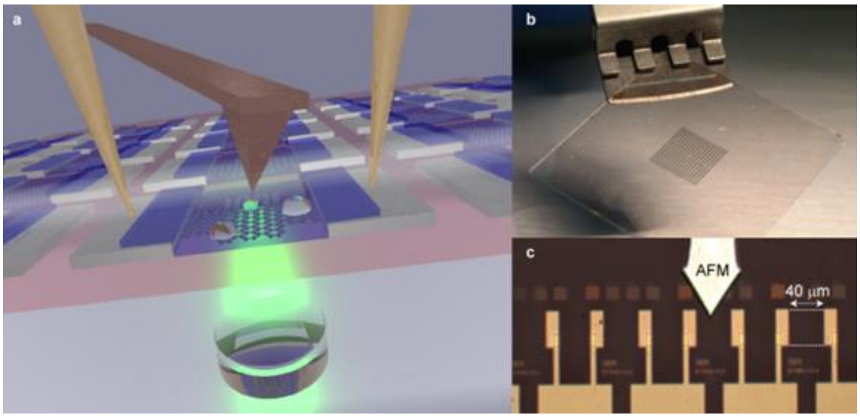

Fig. 13 a), b) and c)

(a) The conceptual illustration of the analysis platform showcases an integrated 2-dimensional sensor array for conducting simultaneous optical, electronic, and topographic measurements on nanoscale liquid droplets.

(b) A photo of the optically transparent analysis chip reveals the integrated 2-dimensional device array positioned at the center of the platform.

(c) An optical micrograph of the platform displays individual measurement sites within the integrated 2-dimensional sensor array, with an atomic force microscope (AFM) cantilever approaching the platform from above. The location and active area of a specific 2-dimensional sensor site are emphasized by dashed lines [77].

Moreover, the platform's functionality extends to non-destructive testing (NDT) for penetrating liquids, presenting a novel method for liquid analysis in diverse industrial applications. By combining electronic and optical sensing techniques as in figure 6, the platform offers a comprehensive solution for characterizing nanoscale liquids, making it a valuable asset for industries seeking precise liquid analysis and quality control [77].

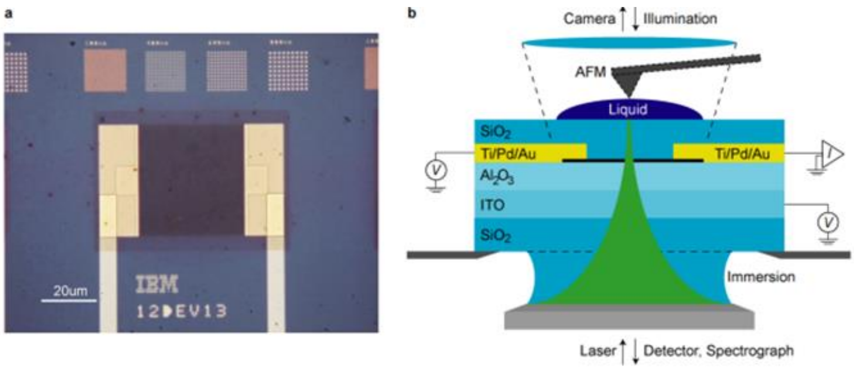

Fig. 14 a) and b)

(a) An individual measurement site on the analysis platform featuring an integrated 2-dimensional sensor.

(b) A diagrammatic cross-section of the analysis platform with the integrated 2-dimensional sensor illustrating optical, electronic, and topographic measurement modes. The platform's device stack is configured to operate within an inverted immersion microscope, facilitating confocal micro-spectroscopy from beneath the sample with enhanced optical excitation and collection efficiency. Each device is individually accessible and can be linked to an external electric transport measurement system. Atomic force microscopy and optical microscopy can be conducted from the top of the analysis platform [77].

The main practical implications of this article are:

1. The development of this integrated platform provides a powerful tool for the experimental characterization of nanoscale liquids, with potential implications for various industrial technologies;
2. The platform's ability to differentiate between liquids electronically and determine their molecular fingerprint can be valuable in fields such as chemical analysis, pharmaceutical research, and quality control;
3. The real-time monitoring of surface wetting dynamics offered by the platform can have applications in areas like surface coating optimization, microfluidics, and nanofluidics;
4. The high sensitivity of the platform allows for the detailed analysis of individual sessile droplets, which can be useful in studying phenomena like liquid-solid interactions and surface tension.

Overall, this platform opens up new possibilities for studying and understanding nanoscale liquids, offering potential benefits in various scientific and industrial domains.

An relevant informations can be found in the technical article „Non-destructive testing operations simulation in virtual reality environment” the authors explores how the evaluation of probes in the context of NDT is enhanced through interactive simulations, real-time feedback mechanisms, and data analysis tools within a VR environment. It is delves into the simulation setup, probe manipulation, data visualization, feedback mechanisms, performance metrics, scenario variation, and skill development aspects of probe evaluation in a VR setting.

Non-destructive testing (NDT) is essential for detecting defects and ensuring the quality of materials and components without causing damage. Traditional NDT training methods often lack the immersive and interactive elements necessary for comprehensive skill development. The integration of virtual reality (VR) technology offers a promising solution to enhance NDT training by providing a realistic and dynamic learning environment. [78].

Simulation Setup: In a VR environment, the simulation setup is designed to replicate real-world testing scenarios, allowing trainees to interact with virtual probes and simulate NDT inspections. By mimicking actual testing processes, trainees can gain hands-on experience and familiarity with probe operations in a controlled and immersive setting.

Probe Manipulation: Trainees in a VR environment can manipulate virtual probes using VR controllers or input devices, enabling them to position, orient, and operate the probes as they would in a physical setting. This hands-on interaction facilitates practice in probe handling and maneuvering, contributing to skill development and proficiency in NDT operations, as depicted in figures below.

Fig. 15 Testing samples and the quality indicators [78].

As probes are used within the VR environment, data related to the testing process is generated and displayed in real-time. This data includes probe positioning, signal strength, defect detection, and other relevant parameters. Visualizations and overlays aid trainees in interpreting and analyzing the data effectively, enhancing their understanding of NDT principles.

VR environments incorporate feedback mechanisms to provide trainees with real-time guidance and assessment during probe evaluation. Visual cues, auditory signals, or haptic feedback indicate successful probe placement, defect detection, or adherence to testing protocols. This immediate feedback enhances learning outcomes and performance.

The VR environment tracks and records trainees' performance metrics related to probe evaluation, such as accuracy, efficiency, and adherence to testing standards. These metrics enable the assessment of trainees' proficiency, identification of areas for improvement, and customization of training programs to individual learning needs.

VR environments allow for the creation of diverse testing scenarios with varying complexity and challenges. Trainees can practice using different types of probes, encounter simulated defects, and navigate through scenarios that simulate real-world testing conditions. This variation enhances trainees' adaptability and readiness for different NDT scenarios [78].

Conclusion:

The use of VR platforms has been shown to enhance teaching efficiency, develop entrepreneurial skills, improve workflow efficiency in laboratories, and conserve resources. These platforms enable users to interact with virtual objects, acquire technical knowledge, and engage in research activities. They provide realistic simulations, authentic materials, and discussion forums to enhance learning outcomes. The positive results and high level of acceptance of VR platforms indicate their potential to support location-based training sessions in various industries, including technical and educational environments.

Regarding the use of VR in NDT training for penetrant liquids, virtual reality can provide a simulated environment for trainees to practice and develop their skills in conducting penetration tests. VR can offer a realistic and interactive training experience, allowing trainees to simulate the steps of the procedure and practice defect detection and interpretation. These typically involve physical inspection and the use of specialized equipment and materials. VR platforms can provide a simulated environment for trainees to practice and familiarize themselves with NDT techniques in a safe and controlled manner.

In conclusion, the incorporation of VR technology into NDT training programs yields substantial advantages in skill enhancement, safety, and cost efficiency. By utilizing VR simulators, NDT specialists can elevate their competency in testing procedures, thereby contributing to the overall excellence and dependability of non-destructive testing operations.

The information about existing non-destructive testing (NDT) procedures for penetrant testing using transnational platforms in virtual reality (VR) is lacking, necessitating the need to create such a platform.

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1.7 Successful implementations and lessons learned

In the field of education, there is an increasing use of concepts such as distance learning and open universities for teaching and learning. However, the teaching of science, technology, and engineering still lags behind in adopting new technological approaches, especially in terms of online distance learning. This discrepancy is due to the fact that these fields often require laboratory activities to ensure efficient acquisition of skills and practical experience. In many cases, it is difficult to provide online access to these laboratories. Either the real laboratory needs to be adapted for remote access, or a fully virtual laboratory based on software needs to be created. The future seems to belong to this latter concept, as it offers significant advantages over real laboratories controlled remotely.

The implementation of transnational VR platforms for training and education in technical NDT applications varies across countries and regions due to differing levels of acceptance and effectiveness. In the field of computer maintenance education, the acceptance of VR practical training platforms by college students was significantly higher at 67.4% compared to traditional platforms [1]. Furthermore, the development of software solutions based on virtual reality technology for training industry specialists in non-destructive testing involves a comprehensive multi-component approach, emphasizing the creation of a detailed training environment [2], [3]. Additionally, contemporary trends in education highlight the digitalization of teaching materials and the simulation of technical laboratories to enhance the practical skills of technical professionals [4]. These variations in implementation reflect the evolving landscape of educational technologies and the diverse needs of learners in different global contexts.

Furthermore, the successful implementation of transnational VR platforms for training and education in the field of non-destructive testing (NDT) applications has demonstrated significant benefits. These platforms enable immersive training experiences without exposing individuals to hazardous conditions, such as in nuclear power plants or gas transmission pipelines [5], [6], [7]. By utilizing VR technology, instructors can assess and enhance levels of competence among NDT practitioners, focusing on technical skills, knowledge, and behavior [8]. Moreover, the use of VR technology in design and technical graphics education has had a positive impact on pedagogical practices, enhancing the learning experience for both instructors and students [9]. These successful implementations underscore the effectiveness of VR platforms in strengthening training, improving levels of competence, and transforming educational practices in NDT applications.

Here are a few examples of Highlight successful implementations:

Geppeteau represents a significant advancement in haptic technology for virtual environments, offering users a unique and engaging way to interact with virtual fluids. Its innovative design and capabilities open up new possibilities for exploring the tactile sensations of handling liquids in virtual reality, making it a valuable tool for research, education, and entertainment purposes.

Geppeteau is an advanced haptic device aimed at transforming virtual reality user experience by providing tactile sensations of interacting with virtual liquids. This state-of-the-art technology employs a string-driven mechanism housed within customizable vessel enclosures to replicate the behavior of fluids in a variety of vessel shapes. A standout feature of Geppeteau is its capacity to dynamically adjust the center of gravity of the simulated liquid through a pulley system, enabling users to perceive the changing weight and motion of the virtual fluids. This distinctive haptic interface heightens the authenticity of virtual liquid interactions, delivering a more immersive and captivating experience for users.

Geppeteau stands as a significant breakthrough in haptic technology for virtual environments, providing users with a distinctive and captivating means to engage with virtual liquids. Its innovative design and functionalities unlock new avenues for exploring the tactile sensations associated with handling liquids in virtual reality, positioning it as a valuable asset for research, education, and entertainment endeavors. Participants in the studies reported that Geppetteau effectively conveyed realistic tactile experiences across a range of physical vessel shapes, virtual liquid volumes, and viscosities [10].

From the relevant article „A platform for analysis of nanoscale liquids with an integrated sensor array based on 2-d material", can be extract some very useful highlights:

- The platform seamlessly integrates a two-dimensional electronic device array with optical micro-spectroscopy and atomic force microscopy. This fusion can be vividly portrayed in a Virtual Reality (VR) environment, offering a holistic perspective of the liquid analysis procedure.
- Real-time monitoring of surface wetting dynamics is facilitated by the platform. In a VR setup, this dynamic visualization of data in real-time can enrich the comprehension of how liquids interact with surfaces at the nanometer scale.

- The platform excels in electronically distinguishing between different liquids and identifying a liquid's unique molecular fingerprint. In a VR landscape, this differentiation process can be visually depicted to highlight the distinct electronic signatures of various liquids.
- Demonstrating remarkable sensitivity, the platform captures topographies and optical spectra of individual, spatially isolated sessile oil emulsion droplets with volumes less than ten attoliters. In a VR platform, this sensitivity can be accentuated through interactive visualizations of these minuscule liquid structures.
- Enhanced Visualization: VR technology enhances the visualization of the sensor array and liquid analysis process, providing a comprehensive understanding of real-time measurement techniques.
- Real-time Monitoring: VR enables real-time monitoring of surface wetting dynamics, facilitating the observation and analysis of liquid interactions at the nanometer scale, uncovering patterns not easily visible with traditional methods.
- Interactive Differentiation: In VR, differentiation between liquids is visually interactive, presenting unique electronic signatures of each liquid for improved user engagement and understanding.
- Sensitivity Display: VR platforms demonstrate the system's sensitivity in capturing detailed information from small liquid volumes, emphasizing measurement precision through interactive visualizations.
- Industrial Simulation: VR simulations of industrial applications showcase the practical application of 2D material-based measurements in real-world scenarios, aiding in understanding the implications for various industries [11].

The article outlines potential applications in industrial analytics, chemical engineering, biotechnology, and natural resources recovery. Through a VR platform, these industrial scenarios can be simulated to showcase how the integrated measurement functionalities based on 2D materials can be effectively utilized in practical settings.

By harnessing VR technology to visualize the processes and data elucidated in the article, users can delve deeper into understanding the capabilities and implications of the platform for liquid Non-Destructive Testing (NDT) at the nanoscale [11].

Another relevant highlights can be fiind in the article „Non-destructive testing operations simulation in virtual reality environment":

- The VR application-based approach to NDT training helps improve skills essential for accurate testing and diligent execution of NDT procedures.
- The simulator provides a visual representation of X-ray images with a sufficient level of accuracy, demonstrating the impact of X-ray parameters on image quality.
- Innovations in the VR simulator software include enhanced functionality, realistic virtual environment objects, and remote access for training and knowledge testing.
- The integration of VR technology into NDT training programs offers significant benefits in terms of skill development, safety, and cost-effectiveness. By leveraging VR simulators, NDT specialists can enhance their proficiency in testing procedures and contribute to the overall quality and reliability of non-destructive testing operations. [12].

1.7.1 The lessons learned from the literature regarding the use of transnational VR platforms

From the reference „Virtual Reality Platforms For Education and Training in Industry" some technical lessons can be selected:

- The authoring system provides trainers with a tool that requires minimal computer knowledge, allowing experts in the field of training diverse options for creativity;
- Trainers can create training scenarios using the authoring system, which saves the scenarios as scenario files containing specific data for concrete training tasks;
- The authoring system fulfills both the technical and functional, as well as the pedagogical and didactic aspects of the content, enabling the implementation of technical know-how required for existing technical options cost-effectively;
- Suitable converters are available to import information from other systems, such as CAD applications, into the authoring system, providing flexibility in scenario development [13].

Contributions of the paper "Practical Aspects of VR-technology Usage for Industry-based NDT Specialists Learning" include:

- The paper presents a comprehensive multi-component approach to creating a training environment using virtual reality (VR) technology for industry specialists in nondestructive testing (NDT);

- It discusses the practical application of VR technology in training, retraining, and advanced training of industry specialists in NDT;
- The article provides insights into the course structure, lesson plan, and illustrations of the training process in a virtual environment;
- It highlights the goals and tasks of the training environment, emphasizing the use of VR technology for practical training purposes;
- The paper also lists the main directions of solution development and scaling for VR-based training in NDT, indicating potential future advancements in the field.

Overall, the paper contributes to the understanding and implementation of VR technology in the training of industry-based NDT specialists, providing a comprehensive approach, course structure, and insights into the training process in a virtual environment [14].

The lessons learned from the article „A platform for analysis of nanoscale liquids with an integrated sensor array based on 2-d material" are as follows:

- The development of this integrated platform provides a powerful tool for the experimental characterization of nanoscale liquids, with potential implications for various industrial technologies;
- The platform's ability to differentiate between liquids electronically and determine their molecular fingerprint can be valuable in fields such as chemical analysis, pharmaceutical research, and quality control;
- The real-time monitoring of surface wetting dynamics offered by the platform can have applications in areas like surface coating optimization, microfluidics, and nanofluidics;
- The high sensitivity of the platform allows for the detailed analysis of individual sessile droplets, which can be useful in studying phenomena like liquid-solid interactions and surface tension.

Overall, this platform opens up new possibilities for studying and understanding nanoscale liquids, offering potential benefits in various scientific and industrial domains.

In conclusion, integrating a VR platform for liquid NDT offers users an immersive and interactive experience, enhancing their understanding of the platform's capabilities for liquid analysis at the nanoscale [11].

Another relevant lessons can be find in the article „Non-destructive testing operations simulation in virtual reality environment":

- The VR application-based approach to NDT training helps improve skills essential for accurate testing and diligent execution of NDT procedures.
- The simulator provides a visual representation of X-ray images with a sufficient level of accuracy, demonstrating the impact of X-ray parameters on image quality.
- Innovations in the VR simulator software include enhanced functionality, realistic virtual environment objects, and remote access for training and knowledge testing.
- The integration of VR technology into NDT training programs offers significant benefits in terms of skill development, safety, and cost-effectiveness. By leveraging VR simulators, NDT specialists can enhance their proficiency in testing procedures and contribute to the overall quality and reliability of non-destructive testing operations.
- Implemented VR application based approach to radio examination operations training helps to achieve relatively safe and cheap NDT specialists' testing skills improvement. Such skills are essential for prompt and diligent execution of all preparatory stages and correct NDT conduction [15].

The utilization of a VR application-based approach in NDT training plays an essential role in enhancing the necessary skills for precise testing and meticulous execution of NDT procedures. Through the simulator, users are presented with a visual depiction of X-ray images that exhibit a satisfactory level of accuracy, effectively illustrating the influence of X-ray parameters on image quality. The VR simulator software introduces advancements in functionality, featuring realistic virtual environment elements and enabling remote access for training and knowledge assessment [15].

1.7.2 Conclusions:

- With the rapid advancement of technology, virtual reality (VR) has emerged as a powerful tool for transforming the training experience in NDT operations.
- Through the lens of virtual reality, NDT training transcends traditional boundaries, empowering practitioners to elevate their expertise and drive innovation in the field of non-destructive testing.
- Benefits of VR in NDT Training Virtual reality offers a dynamic and immersive platform for NDT training, allowing practitioners to engage in realistic simulations of testing procedures
- The adoption of VR simulation in NDT training represents a transformative shift in the way professionals acquire and enhance their skills. The immersive and interactive nature of VR technology offers a unique opportunity for trainees to engage in realistic testing scenarios, ultimately contributing to the

overall quality and reliability of non-destructive testing operations. As the field of NDT continues to evolve, the integration of VR training solutions is poised to play a pivotal role in shaping the future of NDT education and practice.

- The utilization of VR technology in NDT training offers a dynamic and interactive approach that significantly enhances probe evaluation processes. By leveraging interactive simulations, real-time feedback mechanisms, and data analysis tools, VR environments provide a realistic platform for trainees to practice probe evaluation techniques and improve their proficiency in NDT operations. This innovative approach not only enhances training outcomes but also contributes to the overall quality and safety of NDT practices in various industries.

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1.8 Hardware and software needed to develop transnational VR platforms

1.8.1 Hardware

- **Interactive Touchscreen Board:** An important support element is to have an interactive touchscreen board. This is fundamental to the development of the platform and VR application. It will make it possible to visualize, manipulate, and handle manually the digital models of the parts under test and create in an easy-to-use way the interface of the application. An interactive touchscreen board could be the one that would give us the facility to interact with 3D models, do digital testing, and provide feedback on the same against the results of the NDT testing. Such technology will help reduce the testing time, accelerate the testing process, and raise the accuracy of the results because the teacher can interact more actively online with the students. It will further enhance the user interface through an interactive environment for the testers by using an interactive touchscreen board. It enables them to navigate and manipulate the 3D models among them, which in turn makes defect identification and inspection easier. Testing and monitoring activities of project partners require an interactive touchscreen board. It is, therefore, relevant to develop an advanced VR platform and application for NDT liquid penetrant testing. The training in liquid penetrant examination shall be designed through realistic scenarios. Scenarios for the multiple configurations of welded parts/materials to be analyzed in different types of materials on which different defects/imperfections will be simulated. In this activity, the industrial partners can also make some contributions by proposing test cases because the same one will be based on real applications from their work. In this respect, this transnational VR platform proposes to use a Unity 3D game engine, where practical application scenarios could be built in, such as NDT liquid penetrant testing. This multi-functional tool will be further complemented by the acquisition of an interactive touchscreen board basic building block for enhanced user interaction and visualization in the VR application.

- **VR Head-Mounted Displays (HMDs)** Several critical factors should guide the selection process when considering VR headsets for integration with the Unity 3D game engine and interactive touchscreen board. Firstly, the display quality of the VR headset is paramount for delivering an immersive experience. Opting for headsets with high-resolution screens, such as those with higher resolutions, ensures crisp visuals and minimizes the "screen door effect," where visible gaps between pixels can detract from immersion [2]. A high refresh rate, ideally, contributes to smoother motion rendering, reducing the likelihood of motion sickness and enhancing overall comfort during extended use. Accurate and reliable tracking technology enables seamless interaction within the virtual environment. Inside-out tracking systems, which utilize onboard sensors to track the user's movements without the need for external sensors, offer convenience and flexibility [1]. However, for applications requiring precise positional tracking, such as in-depth NDT liquid penetrant testing scenarios, external sensor-based tracking systems may be preferred for their higher accuracy. Comfort is another crucial consideration when selecting VR headsets. Models with ergonomic designs, adjustable head straps, and ample cushioning ensure a comfortable fit for users of varying head sizes and shapes [1]. Additionally, features such as lightweight construction and balanced weight distribution help minimize fatigue during prolonged VR sessions, enhancing user comfort and immersion. Connectivity options and compatibility with the game engines such as Unity 3D game engine and the interactive touchscreen board should also be carefully evaluated. Headsets offering seamless integration with Unity's development environment and robust support for industry-standard VR development frameworks ensure a smooth workflow and efficient development process. Moreover, considering compatibility with the interactive touchscreen board ensures cohesive integration between hardware components, facilitating interactive user experiences and enhancing overall functionality. Furthermore, audio plays a crucial role in creating a fully immersive VR experience. VR headsets equipped with integrated or detachable audio solutions, such as built-in headphones or audio jacks for external headphones, provide spatial audio cues that enhance immersion and realism. Selecting headsets with high-quality audio reproduction capabilities further enhances the overall VR experience, allowing users to fully immerse themselves in the virtual environment [5].

The are many big competitors for VR HMDs such as the HTC Vive, Valve Index, Oculus Rift, Oculus Quest, Oculus Go, and PlayStation [4]. The Oculus Rift is probably the best-documented of the devices. In terms of the actual display, the HTC Vive provides similar specifications to the Oculus Rift. The main difference to the other wired HMDs lies in their tracking range. Opposed to many other approaches the Vive is designed for room-scale use allowing different application areas.

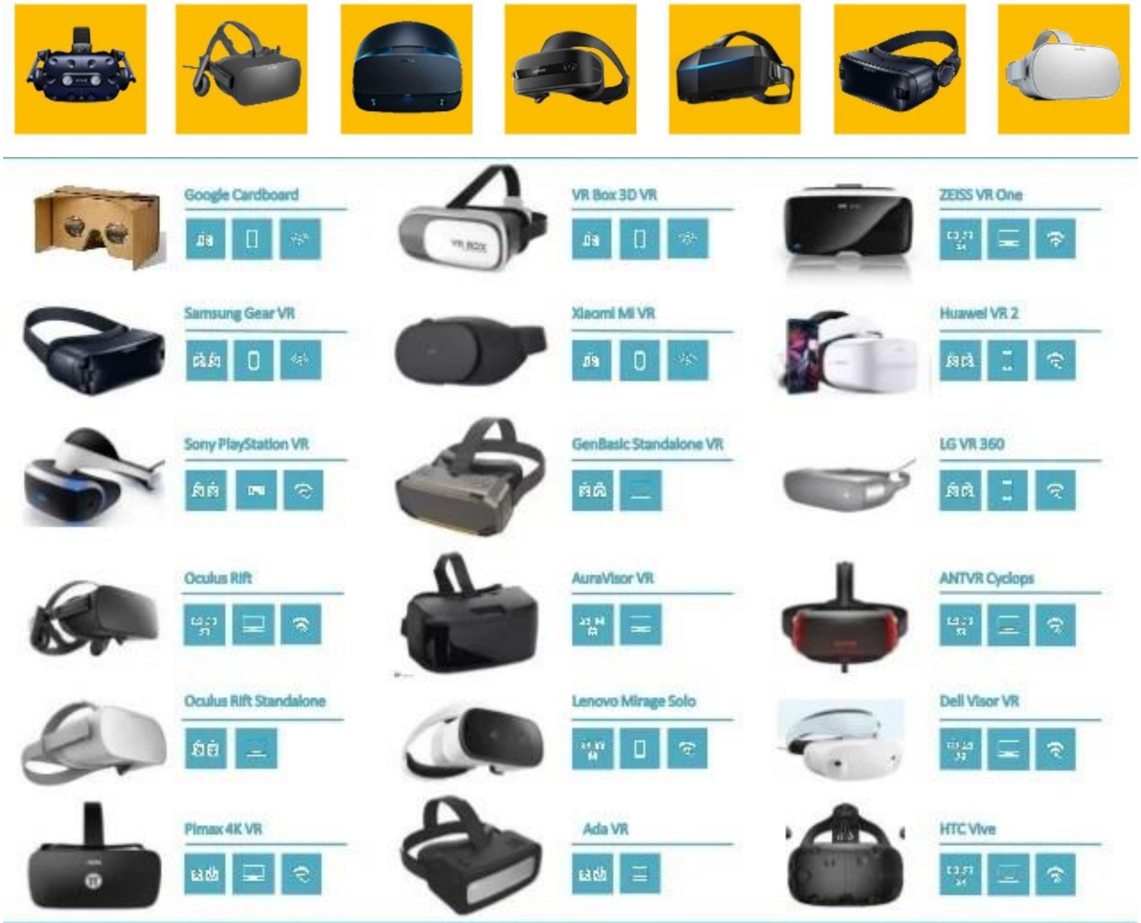

Fig. 16 Different VR HMDs Models [4]

By carefully considering the above factors and prioritizing, the specific requirements of the project and by mutual understanding of the project partners can choose VR headsets that align with the goals and deliver a compelling and immersive VR platform for NDT liquid penetrant testing scenarios.

- **VR Controllers** VR HMD controllers are worn on the hand; they provide discrete input via buttons and continuous input through top-mounted joysticks or touchpads. The controllers may be wired or wireless. Various factors influence the choice of VR controllers, including compatibility, functionality, and user experience. The development of a VR platform should leverage the use of controllers that have the right balance of features, performance, user experience, and compatibility with proposed VR hardware and software [2]. Most VR headset manufacturers offer proprietary controllers that can function seamlessly inside their own VR systems.

The controllers usually are optimized for tracking accuracy, ergonomics, and integration with the headset tracking technology to ensure a well-integrated and reliable user experience. Implementing control devices within the VR system can affect the level of interactivity between the anatomy learning system and the users. We can consider that with the availability of different VR control devices, it is possible to produce various levels of interactivity according to the features and functions of each tool [7]. The control devices of the VR system are featured in different ways. It is expected that using the different VR system control devices, the results shall be in the form of an acceptability and satisfaction level of users. There are numerous VR controllers in the market, each coming with its peculiar features and functionalities. However, within this project's scope, we will propose an explanation of one of the reliable ones: VIVE Controllers.

VIVE Controllers are a set of two wireless joysticks whose movements are tracked by two base stations. These base stations periodically transmit light across the VIVE Controllers. The position and movement of the VIVE Controllers are calculated from this gap or time difference between the light pulses. In essence, this kind of tracking system gives rise to accurate and responsive input, which is indeed essential in immersive VR experiences. VIVE Controllers come with buttons that can trigger instructions inside the system [6]. Of all the third-party controllers available for use with VR systems, it's among the most reliable as far as user satisfaction and ease of use are concerned. Other reasons include settling for controllers that support development frameworks like Unity. Control options should also be considered based on functionality and features provided such as the layout of buttons, motion tracking, and ergonomics [7].

A controller that can provide more input options, intuitive controls, and responsive feedback will allow for an enhanced user experience and further immersive interactions in a VR platform. Selection of the VR controller should be compatible, mainly based on specific needs and requirements for functionality and user experience towards seamless VR.

1.8.2 Software

- **Open Platforms**: Many open platforms for software development can be found in development nowadays. While PlayStation VR targets the entertainment market and they are not going to open the interface to the public, other hardware manufacturers, such as Oculus and HTC, published their SDK (Software Development Kits) to the public for developing VR [3].

- **Unity 3D Game Engine:** Unity Game Engine is the reliable choice when it comes to developing virtual reality experiences, because of its varied functionalities devoted just to the development of immersive VR worlds [8], such as:

- Unity's high-definition render pipeline (HDRP) and Universal Render Pipeline (URP) provide advanced functionality in rendering support; both enable developers to achieve reliable visual fidelity within VR environments. By supporting advanced rendering techniques like HDRP and URP, Unity can create immersive VR experiences [8].
- Unity's Shader Graph and Visual Effects Graph provides intuitive node-based interfaces to implement shaders and effects, respectively, in VR applications. Using them, for instance, dynamic particle systems, volumetric lighting, or shader-driven the most complicated visual effects can be reached to enhance a VR application with visual richness and interactivity [8].
- Unity's XR Interaction Toolkit provides the foundation necessary for the development and implication of VR interactions along with locomotion mechanics within VR applications. This toolkit gives developers a chance to enable intuitive and immersive VR interactions, as well as enhance user engagement and presence by showing hand presence and object manipulation right through teleportation and smooth locomotion in VR. [8]

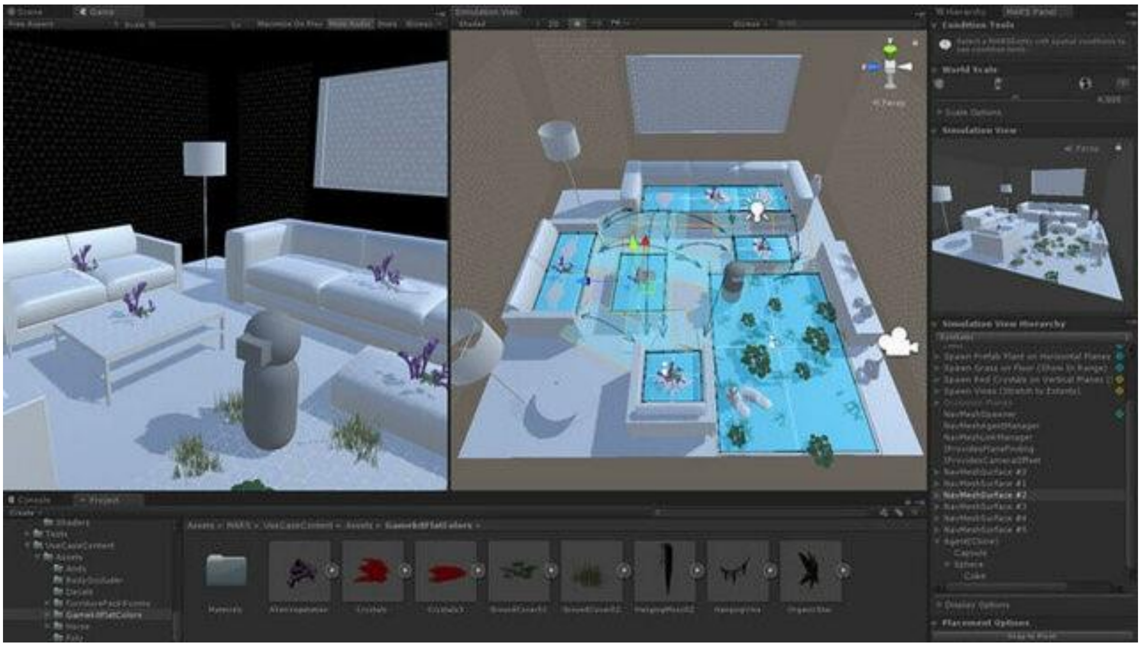

Fig. 17 . Unity 3D Game Engine Development Environment [11]

- It features a physics engine that offers robust simulation capabilities to correctly model the physical interactions present within the virtual environment. It hence will enable developers to model real interactions between virtual objects and users using rigid body dynamics, collision detection, and constraints, thus allowing natural and intuitive interaction in VR experiences [8].

- Unity's multi-platform support allows developers to target many VR devices, including HMDs, standalone VR headsets, and mobile VR platforms. With built-in support for various platforms such as Oculus Rift, HTC Vive, PlayStation VR, and Oculus Quest, Unity provides development surroundings for creating VR experiences that can reach a wide variety of VR users [8].

Fig. 18 Unity Supported Platforms [8]

- Unity provides a set of performance optimization techniques to enable smooth and responsive VR experiences. Occlusion culling, level of detail systems, asynchronous reprojection, and dynamic resolution scaling are among the available techniques in Unity that can help a developer maximize frame rates, minimize latency, and optimize resource usage in VR applications [8].
- Unity's scripting APIs make it possible for developers to customize VR solutions that fit their specific requirements. From the integration of external SDKs, and custom locomotion mechanics, to AI-driven behaviors, Unity offers flexibility and control for the developer to realize their VR experience [8].

The following detail the specific reasons as to why the use of Unity is necessary in the development process for VR platforms:

- **Visualization and Interaction with 3D Models**
  Unity's advanced rendering allows designers to create complex detailed 3D models, which are necessary for the user to visualize the part that must be tested in the VR world. Its rendering engine supports several techniques of lighting and shading to achieve realistic digital models of the actual world components. Similarly, the physics engine allows the simulation to interact realistically with the models [10].
- **User-Friendly Interface Creation**

Unity provides tools for the creation of intuitive UIs. To create an aesthetic and ergonomic interface for such interactive scenarios. Using Unity's UI tools kit developers can create intuitive interfaces [9].

- **Real-Time Feedback and Interaction**
  Developers can build features that provide instant feedback, allowing users to make informed decisions about status quickly. Also, Unity's networking makes interactions between multiple users possible in real-time, thereby making collaboration and communication possible [10].
- **Engaging and Interactive Environment**
  Due to its strong support for VR platforms such as Oculus Rift and HTC Vive, Unity is well-suited for the development of immersive and fascinating virtual reality environments. Various intuitive interface tools facilitate the development process while strong graphics and real-time rendering account for high-quality visual performance. Its Asset Store and fully customizable scripting capabilities help in creating better and more immersive experiences in Virtual Reality [9].
- **Flexibility for Scenario Design**
  Unity provides flexible design tools for creating diverse scenes, depending on needs, using Unity modeling and scripting capabilities. Another relevant use of Unity is that its asset store gives access to a huge library of pre-framed assets and scripts, which accelerates the work of scenario design and ensures its quality [10].
- **Streamlined Development Process**
  Unity's integrated development environment streamlines the development process for the VR platform and application. Its intuitive interface and comprehensive feature set enable rapid prototyping and iteration, reducing development time and costs. Furthermore, Unity's cross-platform compatibility ensures that the VR application can be deployed to a wide range of devices, maximizing its accessibility and impact [9].

- VR Development Tools and Kits

Specialized functionality for the creation of VR applications is provided through VR development tools and SDKs. The APIs of such tools interface with VR hardware, application input controls, and performance optimization amongst other functionalities including spatial audio and multiplayer networking.

The suggested hardware and software are determined by initial research and requirements. As the project progresses, there may be changes in requirements or a need for additional hardware, software, or modifications to the existing setup during the development phase.

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1.9 compatibility, scalability, and accessibility considerations

1.9.1 Compatibility

There are several key factors in the regard of the project for developing a VR platform for liquid penetrant NDT testing, which must be highly considered in terms of their compatibility. Firstly, being one of the most important VR equipment, an interactive touchscreen board must be well-compatible with the Unity development of VR [1]. It would ensure the user interaction well with 3D models and perform digital testing within the VR space [4].

Another critical compatibility issue is that of the operating systems. Further investigation is necessary to establish the levels of support Unity provides for different operating systems such as Windows, Mac, and Linux during the development of Virtual Reality [1]. This is very necessary in establishing the various operating systems that are compatible with the hardware components [5] required for the Virtual Reality platform. Compatibility with a variety of operating systems is crucial to ensure the usability of the developed system across diverse user environments [4]. Hence, exploring compatibility in Unity for various operating systems solely for the development of VR will develop a reliable solution [1]. Testing of compatibility on these operating systems shall be imperative at deployment to find out and fix any problems that may be faced. Also, compatibility extends to hardware components such as VR controllers, headsets, and peripherals [3]. The interaction devices must interface with the VR platform, for users to interact in an immersive and natural manner. Compatibility with various hardware configurations and software needs rigorous testing to ensure the maximum performance and functionality of these devices [5]. Compatibility issues also extend to networking infrastructure. The VR platform may require compatibility with protocols or standards that are part of networking [4] [5].

1.9.2 Scalability

Scalability is another important aspect that the project needs to consider, along with compatibility. With seamless integration with Unity for developing VR, scalability is among the most important deciding factors of the platform regarding adaptability and growth potential [1].

Scalability, concerning the interactive touchscreen board, is needed first to ensure easy integration of enhancements or added features whenever and as needed in the project's life. This allows the Virtual Reality platform to grow with changing needs on the users' end and the technological atmosphere. Besides, scalability issues pertain to operating systems, too. Much research needs to be done regarding assessing the scalability of Unity in different operating systems such as Windows, Macintosh, or Linux. This study is vital in understanding how well the platform will scale up as the amount of data and user interaction increases over a different operating environment. Besides, the scalability issues also include networking infrastructure. The VR platform should be able to scale up, considering increased network traffic or communication between multiple users or devices. It should, therefore, support compatibility with scalable networking protocols and standards [5].

1.9.3 Accessibility Considerations

Accessibility in virtual reality refers to the design and implementation of virtual reality systems in ways that ensure their usability by people with a wide variety of impairments. For example, it may pertain to considerations for visual, auditory, and motor impairments, such as providing alternative interaction methods and customizable interfaces so that VR experiences can be inclusive and usable for everyone [7].

The following are some basic features of accessibility that help in enhanced usability and inclusivity:

- User Interface Design
    - Clear and Intuitive Interface: To design an interface that is user-friendly and whose controls are simple, easy to navigate, and appropriately labeled to assure convenient access by all users [6].
    - Simplifying Menus and Options: Menus and options shall be reduced to lessen the confusion at selection and provide smooth navigation [6].
    - Icons and Symbols: The employment of icons and symbols that are easily recognizable by shape, size, and color, among other aspects, helps users to understand better.

However, it needs to be considered that even the basic implementation of accessibility features in the VR environment faces challenges with designing intuitive and navigable user interfaces for varied abilities, lack of standards within the industry on accessibility features, and additional cost and resources required for the implementation and testing of such features are also major deterrents [8]. The criticality of implementing those features would need to be analyzed, and future approaches would be adjusted accordingly.

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1.10 Exploring Effective Instructional Design Principles for VR-Based Learning

1.10.1 Instructional Design

Instructional design is a systematic method used to describe appropriate instruction, encourage learning, and apply educational descriptive and prescriptive theories (Smith & Ragan, 2005) [1].

In examining effective instructional design principles for VR-based learning, extensive literature was reviewed to gather insights from scholarly articles, research papers, and educational resources. Several instructional design models were examined during the review process to understand their applicability and effectiveness in VR-based learning. Prominent models included the Kolbs, ADDIE (Analysis, Design, Development, Implementation, Evaluation) model, SAM (Successive Approximation Model), ARCS (Attention, Relevance, Confidence, Satisfaction) model, and Gagne's Nine Events of Instruction and Bloom's Taxonomy Model. Overall, through the examination of instructional design principles and models, valuable insights were gained into the key considerations and strategies for designing effective VR-based learning experiences. By leveraging the strengths of instructional design models and aligning those with principles of effective instruction, educators and instructional designers can create immersive and engaging learning environments that maximize the potential of VR technology to enhance learning outcomes. Following the review of instructional design models, the next step involved analyzing how these models align with and support effective instructional design principles for VR-based learning. Key principles identified through the literature review included learner-centeredness, clarity of objectives, active learning, feedback, and assessment. By examining how each instructional design model addresses these principles, insights were gained into their strengths, limitations, and suitability for designing VR-based learning experiences [5] [6] [7] [8] [9] [11].

After examining several instructional design models, Kolb's experiential learning model is proposed to be more appropriate for VR-based learning. The model is explained as under:

Kolb's Experiential Learning Theory

Experience encompasses both the activity of creating and reflecting on personal experiences and the outcome of participating in various activities [2]. Experiential learning, first proposed by Kolb (1984) [3], differs from traditional didactic instruction by emphasizing independent judgment, free-thinking, and personal experience. It involves an interactive process where learners gain personal experience, understand core learning tasks, and explore the relationship between concepts and their implications. Kolb's experiential learning cycle includes four stages: (1) concrete experience, (2) observation and reflection, (3) forming abstract concepts and generalizations, and (4) testing in new situations. This cycle is continuous, and each experience influences future learning.

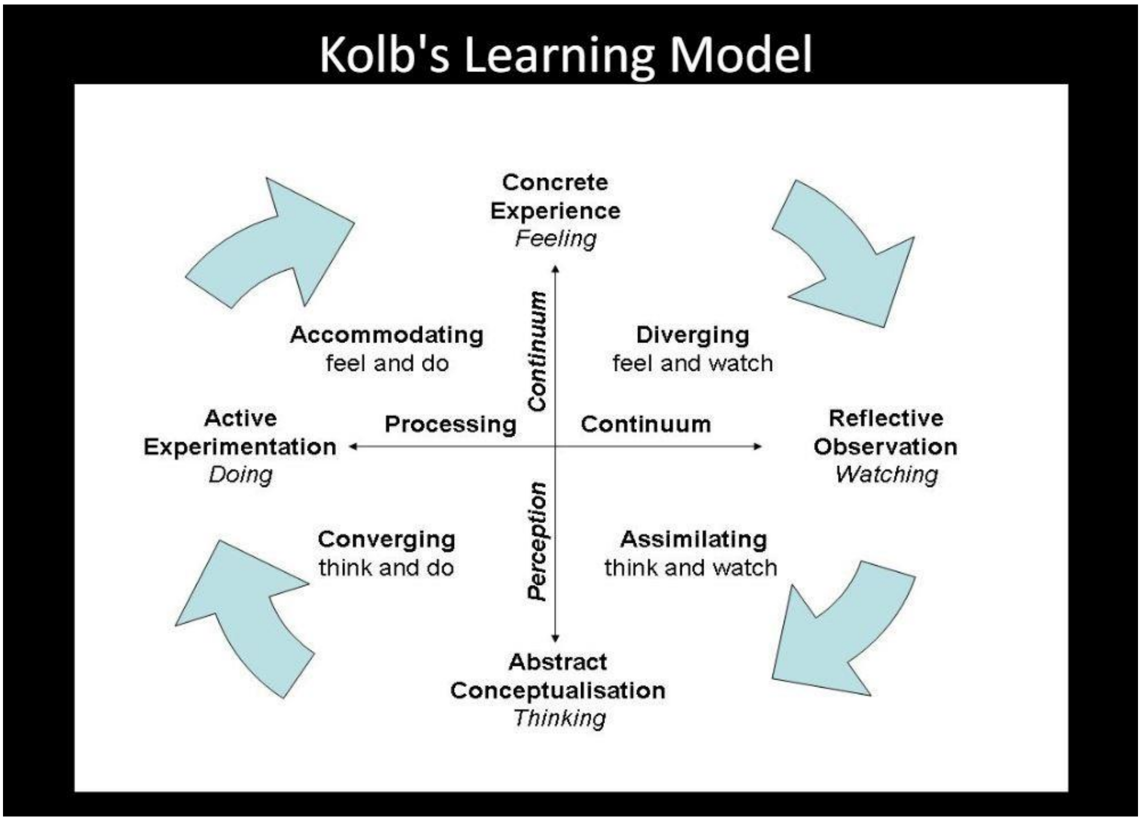

Fig. 19 Kolb's Learning Model [4]

Kolb's Learning Styles

- **Diverging (Concrete, Reflective)**
  - Emphasizes the innovative and imaginative approach to doing things.
  - Views concrete situations from many perspectives and adapts by observation rather than by action.
  - Interested in people and tends to be feeling-oriented.
  - Likes such activities as cooperative groups and brainstorming.

- **Assimilating (Abstract, Reflective)**
  - Pulls several different observations and thoughts into an integrated whole.
  - Likes to reason inductively and create models and theories.
  - Likes to design projects and experiments.

- **Converging (Abstract, Active)**
    - Emphasizes the practical application of ideas and solving problems.
    - Likes decision-making, problem-solving, and the practicable application of ideas.
    - Prefers technical problems over interpersonal issues.

- Accommodating (Concrete, Active)
    - Uses trial and error rather than thought and reflection.
    - Good at adapting to changing circumstances; solves problems in an intuitive, trial-and-error manner, such as discovery learning.
    - Also tends to be at ease with people.

Kolb’s Learning Cycle

Kolb's learning theory sets out four distinct learning styles based on a four-stage learning cycle [4].

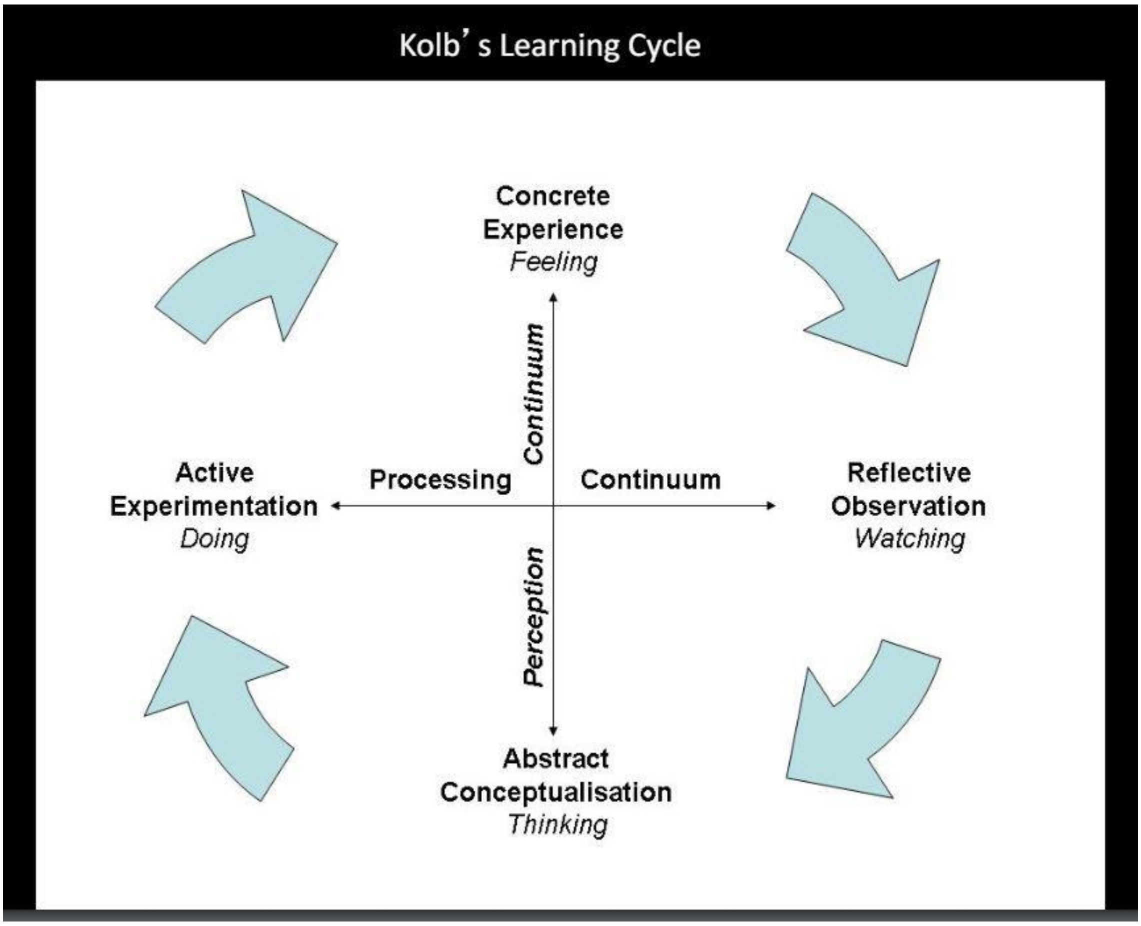

Fig. 20 Kolb’s Learning Cycle [4]

- Concrete Experience (Feeling) Learning from specific experiences and relating to people. Sensitive to other's feelings.
- Reflective Observation (Watching) Observing before making a judgment by viewing the environment from different perspectives. Looks for the meaning of things.
- Abstract Conceptualization (Thinking) Logical analysis of ideas and acting on the intellectual understanding of a situation.
- Active Experimentation (Doing) Ability to get things done by influencing people and events through action. Includes risk-taking.

Kolb's Six Main Characteristics of Experiential Learning

According to Kolb [4], "Learning is the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping experience and transforming it" [4].

The six main characteristics of experiential learning are as under:

1. Learning is best conceived as a process, not in terms of outcomes.
2. Learning is a continuous process grounded in experience.
3. Learning requires the resolution of conflicts between opposing modes of adaptation to the world (learning is by its very nature full of tension).
4. Learning is a holistic process of adaptation to the world.
5. Learning involves transactions between the person and the environment.
6. Learning is the process of creating knowledge that is the result of the transaction between social knowledge and personal knowledge.

The theory of experiential learning has been increasingly associated with digital technologies in general, but also with VR in specific. In VR studies, the theory of experiential learning is one of the most widely applied learning theories for VR-enabled learning [5]. For instance, advocated the use of VR as a tool for experiential learning as it supports learners to apply knowledge and experience consequences [6]. VR accommodates the experiential learning theory, as it allows learners to explore, experience, and examine their environments freely, even if hazardous and inaccessible [7] [8] [9]. Studies [10] on the development of an interactive, collaborative virtual learning environment on Kolb's experiential learning framework to obtain concrete learning experiences through active experimentation. Studies [11] from different research fields (e.g., education, and medicine) advocated the potential of VR as this technology allows the inducement of interactivity. VR provides a rich and engaging educational context that supports experiential learning as students can experience learning by doing it. This raises interest and motivation which effectively supports knowledge retention and skills acquisition [11].

Kolb's work is probably the "most scholarly influential and cited model" regarding experiential learning theory [12] and has been successfully applied in multiple research fields (e.g., business, engineering, medicine) including the field of VR [5]. Thus, we propose this theory as an effective instructional design principle for VR-based learning as our theoretical foundation.

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1.11 Discuss interactive simulations, virtual labs, and experiential learning in VR

1.11.1 Interactive Simulations

The advantages of simulated laboratories are that preliminary exercises can be carried out by simulation to accelerate the actual learning process on-site or to guide learners' expectations [1]. This preparation can also increase safety, as one can familiarize oneself with the equipment without having to operate the devices [2]. A complete simulation in virtual space can also save high costs for expensive experiments and equipment, despite initial investments in the creation of such a simulation [3] [4] [5]. Another advantage is that by randomizing parameters of a laboratory exercise, e.g. closeness to reality can at least be approximated with the involvement of existing equipment, input variables of an experiment, or random disturbance factors involved [2].

In interactive simulations, there is virtual immersion and hands-on learning by the users through activities such as variable manipulation, conducting experiments, and observing results. Real-time feedback, user-modifiable parameters, and visual displays of these simulations allow for critical thinking and conceptual understanding from the users. They offer remote access and collaboration, thus making the learning process more accessible. Overall, interactive simulations are a productive and effective method of learning to replace traditional laboratory settings, hence allowing learners to be an integral part of their learning process and acquire practical abilities within a wide range of disciplines [8].

At the same time, however, the costs and expertise required to develop such simulations should not be underestimated.

1.11.2 Virtual Labs

Laboratories can be used for different purposes and distinguish between three basic types of laboratories [1]: The development laboratory (development), the research laboratory (research), and the teaching-learning laboratory (educational) [8]. In the development laboratory products are designed, developed, and tested. Experiments are conducted to generate sufficient data to support this process. Specific questions or requirements are asked that need to be answered to advance the practical design of products, e.g. in the development of vehicles. On the other hand, more advanced questions are investigated in the research laboratory, which contributes to the existing wealth of knowledge of a discipline. There is no claim to develop a product of any kind but to gain generalizable knowledge. However, students or learners in general use the laboratory for another purpose: to learn something that practicing engineers already know and apply in one of the other types of laboratories [1]. Thus, the teaching-learning laboratory can be classified chronologically before entering the professional world and during engineering education [7]. This could be particularly important for the project since the scenarios could be potentially teaching-learning laboratories with didactic objectives. The concrete learning contents of a teaching-learning laboratory are in turn shaped by the discipline. The usefulness of such a separation of terms is also evident in the clear delimitation of objectives in the corresponding decision field of the Berlin Model [1].

1.11.3 Classification by Media and Technologies

It is not uncommon that a lab is defined by certain media and technologies, as can be read from the denominations of computer labs, gaming labs, or virtual labs. These denominations do not contribute, so far, to an understanding of the content, further methods, or even discipline these environments deal with, let alone whether objectives are learning and teaching labs. For instance, a computer lab can be used remotely, with partners in other computer labs to develop software. A gaming lab could use serious games whereby there is a didactic objective given, but it is not clear whether the implementation is via desktop computers, smartphones, or virtual reality glasses [9]. Such definitions are very seldom referred to in the literature, where a suitable idea for the reader using these is normally assumed [8]

Virtual labs are virtual platforms that are availed to learners where they can conduct laboratory activities, experiments, and simulations virtually [7]. They offer advantages in terms of access, safety, and cost-effectiveness, for they eliminate the actual need for resources and physical infrastructures. It lets learners use virtual equipment, manipulate variables, and observe results, just as they would in real-world laboratory settings [9]. Most of the platforms also include parameter change facilities, immediate feedback, and collaboration facilities for the learners to explore ideas, conduct experiments, and practice skills in a controlled environment. Added to this flexibility of use of virtual labs remotely, the learners can apply any-time, any-place experiential learning principles to nurture independent inquiry and active learning in the learning process [8].

1.11.4 Interactive Simulations in VR

A literature review was conducted to explore methods to improve interactive simulations in VR. Below are studies and some findings that outline and discuss the characteristics to improve interactive simulations in VR.

There is a study about how the learner perceives the objects, properties, and behaviors (also known as artifacts) that have been selected and included in the simulation's virtual world [24]. Building on that it could be highlighted it can be argued that the learner experience also requires a sense of immersion and empathy. Other studies show affordances in VR help users intuitively understand how to interact with the virtual environment. They also enhance realism by allowing interaction with virtual objects, much like the intuitive interaction of users with objects in the real world. This paper thus presents one important aspect of designing effective VR simulations that become user-friendly, enhancing immersion and engagement [25]. Other studies focused on the degree of learner engagement within an interactive narrative that lies in their perceived control over the avatar character. This engagement extends to the degree to which learners can make decisions that are akin to real-life practice. This characteristic is achieved through what is called a branching narrative as it provides immediate feedback to the learner, which supports further engagement and immersion [24].

1.11.5 Experiential Learning in VR

Experiential Learning is a paradigm for resolving the contradiction between how information is gathered and how it is used [11]. It is focused on learning through experience and evaluating learners in line with their previous experiences [12]. The paradigm highlights the importance of learners' participation in all learning processes and tackles the idea of how experience contributes to learning [13]. A computer-generated simulation and animation in which a human may communicate within an artificial world is VR. Furthermore, the method of learning by interaction in such a VR environment is known as experiential learning in VR. Since it includes learners explicitly in their learning process, it is classified as part of the broader field of successful learning. Virtual reality is considered helpful as a tool of pedagogy in teaching-learning, including the creative nature of the instructional learning process [14].

To understand this theme, several different research studies were reviewed to explore how virtual reality can help students enhance their experiential learning. The review of the study [15] aims to understand the role of virtual reality in experiential learning theoretically. It states that virtual reality is used in many adult occupational training situations where the actual case cannot be used for practice either due to the lack of accessibility or the risky nature of the task. An interactive learning process for learning about erosion prevention and management training army personnel is an example [16]. In addition, students' involvement in the immersion of an authentic virtual environment helps in enhancing their experiential learning. The studies found that virtual reality has many benefits for learning; it gives a first-hand experience of things and activities that are practically out of the control, it helps to practice in a controlled atmosphere while preventing real-life risks, and it improves the learner's interest and excitement while expanding the number of learning types embraced due to the game approach [15]. The review of another study [17] aimed to understand virtual reality as a supporting tool for the teaching-learning process in enhancing students' experiential learning. This study found that the virtual reality environment is formulated as a sensory-motor contact with the world, with the organ serving as the mediator in the process. It is the sensation and vision organ and the kinesthetic structure that constructs knowledge; however, immersion in a virtual environment enables one to use its ability to facilitate learning ultimately. Also, digital reality, like the physical world, allows for complete body interaction, allowing users to visualize the world by perceptual learning. The experiential aspect is one of the steps of a mechanism that contributes to the abstract interpretation of the world. The review of another study [18] aims to analyze the application of virtual reality in helping engineering students learn through experience to enhance their academic achievement. This study found that this strategy helps students experience opportunities that they would not obtain in the actual world due to various factors such as danger, high cost, and the wrong time. The virtual reality method combines imagination with reality by creating virtual worlds that reflect reality, change, and communicate with the students. Furthermore, students' success increases significantly when they use a virtual reality environment. There are a variety of virtual reality applications in the market; the majority of which can be applied in schooling and technologies to enhance students' experiential learning [18]. Another study [19] investigated an Internet-based social virtual reality device structure for building protection and education programs that enable students to engage in role-playing, dialectic learning, and social engagement. It states that the building sector is a complex world where high injury rates persist, resulting in significant construction delays in completion [20]. The intrinsic high-risk existence of project construction, minimal protective experience, and inadequate safety training, education, and awareness among construction workers and engineers are significant causes of construction accidents. However, it was noticed that modern security education programs are ineffective since they do not meet their intended markets or are not carried out on a scale that is consistent with their relevance [21]. Also, combining creative teaching with conventional classroom instruction, virtual education, and educational theories and practices significantly improves practical capacity [22]. This shows that a collaborative virtual reality framework dependent on safety management has much potential for improving learning experiences. Schools and teachers, as well as development experts, on the other hand, shared their dissatisfaction with the time-consuming development and animation of game scenarios. Thus, it found that students obtain experiential learning that would otherwise be difficult using virtual reality [19]. The review [23] aims to analyze the role of serious games as virtual reality for enhancing students' experiential learning. It states that constructivism philosophy can be applied effectively across gaming channels. The constructivism viewpoint stresses the importance of learning by experience. Active participation in a learning experience has been shown to improve information retention. One of the significances of video games would be that they enable learners to study by role-playing. Players may take on the part of some other human or entity and see the world from different eyes and test their skill and innovation. Also, experiential learning requires active exploration to acquire experience. As a result, this study reveals that virtual reality can be an effective didactic medium by putting the student at the forefront of practical learning interactions to help them learn experientially [23].

The literature review concluded that virtual reality has a significant impact on innovative design practices. The ability of VR to gain experience by participation in and constructive control of recognizing objects helps students/trainers learn, retain, and pass concepts. This improves the learner's satisfaction, inspiration, and self-efficacy, enhancing experiential learning [14].

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1.12 Review studies on user engagement and satisfaction in VR environments

1.12.1 Studies Review: Methods to Enhance User Immersion and Interaction Improving User Engagement and Satisfaction in VR Environments

- **Systematic Literature Review (SLR)**The SLR performed focuses on investigating methods for enhancing user immersion and interaction to improve user engagement and satisfaction in VR environments. The developed methodology has been suggested using three steps first proposed by Tranfield, Denyer, and Smart (2003). Three steps will, respectively, be the planning review, conducting review, and reporting and dissemination. This will enhance the transparency of an SLR process, reduce bias, and lay concrete grounds for the conclusions. Knowledge is developed on which effective approaches can be brought and developed further.

  - Findings of SLR

  The findings of SLR are as follows:

  The training in VR must be customizable to depict reality and adjustable for a range of user's needs [1]. Passive haptics in VR are the use of real physical objects that a user interacts with in the real world to create an illusion of interaction with virtual objects [2]. Another key focus, which should be emphasized in any VR design for intuitive interfaces that will guarantee immersive experiences, is understanding user needs and preferences [3]. Include intra-scenario sounds for better user immersion into virtual reality. This would make the experience more realistic [4]. Compatibility and easy access to hardware tools mean that users of virtual environments can be more deeply immersed in it anywhere and under any conditions because they will easily manage to use it. At the same time, software should be powerful for detailed scenarios and interactive object development that will develop activity and users' interaction with the virtual space. Both components are recognized for holding important positions within the virtual immersive and interactive environment [5]. There is a need for the no-distraction VR system to preserve the immersion and concentration of a user for an enhanced experience to the users [6]. High levels of immersion would be achieved by the availability of multisensory stimuli such as sounds, visuals, and haptics to create a feeling of presence whereby the user can feel present inside the virtual environment for improved user experience and engagement [7]. Access to virtual environments is developed in terms of the use of sound cues and 3D images [8]. VR storytelling enhances engagement. According to immersive storytelling, experience, and flow are increased, which increases credibility and allows user engagement more effectively [9]. Interactive interaction depends on the type and performance of hardware used to interact with visual content [10]. VR characters can appear in different virtual real-life environments to enhance interactions and engagements inside the virtual environment [11]. That is where it has been pointed out that multisensory stimulation in VR has a higher likelihood of improving immersion [12]. Color changes and arrows are provided as cognitive aids that help users perform some tasks and, therefore, can help improve user performance [13]. The integration of VR and robotics, thus forming one unique platform with some special values of the two technologies, allows new multimodal interaction strategies [14]. This becomes evident from the continuous improvements in devices and tools such as interactive gloves and eye-trackers, while the ever-expanding range of affordable devices offers an amazing set of levels of immersion, visual fidelity, and interactive capabilities of Virtual Reality to engage it with the user [15].

- **Discussion: Methods to Enhance User Immersion and Interaction Improving User Engagement and Satisfaction in VR Environments**

  The key findings of the review of studies are discussed below in segmented blocks:

  - Adaptable VR Training: The design of adaptability in VR training simply involves creating scenarios like the real world or of interest to users. The customization of training environments gives users the potential to practice skills and activities related to their specific jobs or areas of interest. By increasing user-specificity in the training environment, users can effectively learn
  - Passive Haptics: Passive haptics involve physical objects employed in correspondence with VR to provide a sense of feel and touch to users. For example, holding a real object matching a virtual tool or object that is in the VR environment offers a richer level of immersion because the user can feel the physical presence of virtual objects.

- User-Centered Design: It emphasizes the users' preferences, behaviors, and limitations. In this case, user feedback and iterative testing will shape VR experiences to better meet users' needs resulting in more intuitive interfaces and more engaging experiences.
- Scenario-Specific Sound Effects: Personalization of sounds to specific cases enhances immersion by creating realistic environments. For instance, the environmental noise of a virtual forest and the noisiness of an industrial setting contribute to one's perceived sense of immersion and improve overall engagement.
- Compatibility of Hardware and Software: Compatibility between the hardware and software parts is very critical in terms of delivering a seamless and interactive VR experience. Besides, users need to be given virtual reality access without technical barriers, which allows the users to engage in a smooth, interactive way inside a virtual environment.
- Distraction-Free Systems: Distractors within the VR system should be minimized so as not to distract or break users' immersion and attention. By minimizing extraneous elements and optimizing user interfaces, such as complex interfaces, distracting visual effects, redundancy, irrelevant audio cues, and complex controls, etc., the user can be fully engaged in the virtual environment without disruptions, allowing them to have a more immersive experience.
- Multisensory Stimulation: This is achieved through the utilization of several senses in the stimuli, including sound, visuals, and haptics. Such an experience can keep users in a virtual environment because of such sensory richness
- Accessibility Features: Some of the accessibility features such as sound cues, and accessible images. It makes this comprehensive for users with different needs. This makes navigation and interaction more comfortable and accessible to all users.
- Immersive Storytelling: Immersive storytelling methods involve captivating the attention of the user by creating interactive stories that provoke feelings and fantasy. If users are allowed to be a part of some kind of riveting story, the VR experience becomes more resounding, increasing the prospects for user engagement and satisfaction.

- Hardware:The quality and type of hardware used in interaction significantly affects user engagement in VR environments. Examples of such high-quality hardware include motion controllers and haptic feedback devices. Applying this kind of hardware increases the ability of users to interact with and become immersed in the virtual world, hence resulting in a more dynamic and engaging experience.
- VR Characters: Avatars give virtual experiences an entirely new dimension of depth and interaction, making interactions in the environment meaningful. These characters can range from guidance, companionship, or even being the virtual antagonist while increasing the level of engagement by providing context and storyline depth during the interactions.
- Multimodal Interaction Strategies: Integrating VR and robotics will facilitate innovative interaction strategies that make full use of both' potential. Using the combination of physical and virtual elements, users can interact with virtual objects in a new and more immersive way since the conventional limits are overcome, thus making the experiences more interesting and interactive.
- Advancement of Devices:Ongoing development in the field of VR devices, such as interactive gloves and eye trackers, promotes user engagement with a far more immersive and intuitive manner of interaction with virtual environments. Such innovation expands VR technology capacity, making the user experience more immersive.

The above presentation and discussion are about the findings from studies targeted at finding methods to enhance immersion and interaction in virtual environments for better user engagement.

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1.13 Explore strategies to integrate VR platforms with existing Learning Management Systems for seamless training

1.13.1 Learning Management Systems (LMS)

Learning management systems, or LMS, are software applications designed to manage, deliver, and track educational content and activities. They are widely deployed by educational institutions and corporate training alike to facilitate online learning and training programs [1]. LMS is software that deals with the administration, documentation, tracking, reporting, and delivery of training programs or educational courses, and learning and development programs. Thus, it was designed to identify the gaps in training and learning by using data analytics and reporting. Focus on online delivery but supports a range of uses become a platform for hosting online content, including courses. The purpose is to deliver and manage all types of content, including videos, courses, and documents. Include functionalities that have features like rubrics, teacher- and instructor-facilitated learning, and a discussion board.

Key features of LMS include:

- **Course Management** This enables instructors to create and manage courses, syllabi, and learning materials [1].

- **Student Management** Enables student enrollment and progress and performance tracking of students [1].
- **Content Delivery** Provides text, multimedia, and interactive presentation of various forms of content [1].
- **Assessment and Grading** Specifies the creation of quizzes, homework, assessment, grading, and feedback [1].
- **Collaboration** Allows the learners and instructors to share their thoughts and ideas through discussion forums, messaging, and group activities [1].
- **Reporting and Analytics** Reports learner performance and course effectiveness with analytics and reporting [1].

Different Types of Learning Management Systems

Learning Management Systems can be categorized according to deployment, features, and their target users as follows [1]:

- **Open-Source LMS** Freely available software that can be freely used by anyone, modified, and redistributed. Examples include Moodle, Open edX, and Sakai [1]
- **Proprietary LMS** Commercially licensed software developed and/or maintained by a company or organization. Examples are Blackboard, Canvas by Instructure, and D2L Brightbyte [1].
- **Cloud-Based LMS** Hosted on remote servers and accessed over the internet. The various LMSs listed here are scalable, are automatically updated, and the cost of the IT infrastructure is lower. Examples include the cloud version of Canvas, Google Classroom, and TalentLMS [1].
- **Mobile LMS** Those that are designed to be accessed and used on mobile devices offer a responsive design and mobile-specific feature set. Examples include Moodle Mobile and Edmodo [1].
- **Corporate LMS** Tailored towards corporate training and professional development, these include compliance training, certification, and skills development. Examples of such systems include Cornerstone OnDemand and SAP Litmos [1].

1.13.2 Strategies for Integrating VR Platforms with LMS for Seamless Training

- **Interfaces**
  - **User Interfaces (UIs)**
    - Embedded VR experiences: Embed VR modules into Moodle course pages so learners can view VR content without leaving the LMS environment. It can be done by using iframes or 'Embedded links' which launch the VR experience in either a new tab or within the LMS frame [2].

- Responsiveness: Design the VR and LMS interfaces in such a way that they become responsive. In other words, they easily can be accessed and used through desktops, tablets, and VR headsets. VR content would automatically adjust to the size and capability of the screen to preserve and guarantee continuity of the user experience.
- Intuitive navigation: Design clear paths of navigation in Moodle that would bring the learner to the VR content. Use recognizable icons, buttons, and labels that will facilitate the use and launching of VR modules by users with ease [2].
- **Administrative Interfaces**
- Content Management: The creation or reutilization of tools in Moodle will make the instructors able to easily create, upload, organize, and manage VR content. This includes features for tagging and categorizing VR modules, access permission, and versioning control.
- Tracking and Reporting Dashboards: Developing Moodle administrative dashboards that track learner progress and performance in VR modules in real-time. These would visually indicate key metrics such as time spent in VR, completion rates, and assessment scores. If possible, integrate with Moodle's current gradebook and reporting tools for comprehensive tracking [2].

- **Integration Interfaces (APIs)**

- LMS APIs: Use the Moodle Web Service API to ensure seamless communication between LMS and VR. Such APIs can facilitate automation in processes of data exchange at both ends, like enrolling users in VR modules, fetching user activity logs, and sending completion data to the LMS. This ensures that learner data is synchronized across both platforms [2].

- VR Platform API: Leverage the APIs for VR platforms to control and monitor VR content and user interactions. Further, when a platform such as ENGAGE or Labster is in use, their APIs can be used to initiate a VR session, log activities of users, and fetch performance data. These interactions can further be automated for a seamless experience [2]

- **xAPI (Experience API)**

XAPI is an e-learning software specification that enables learning content and learning systems to speak to each other in a way that's going to record and track all types of learning experiences [4]

- **Advanced Tracking**
    - Detailed Interactions: xAPI captures a wide range of interactions in VR environments. Unlike SCORM, which is limited to certain parameters for tracking purposes, xAPI can capture very detailed and complex user behaviors within the VR experience [4].
    - Contextual Data: Utilization of xAPI can capture contextual information and can provide a richer set to enable analytics. It will include information on the context of learning, the tools used, and even includes social interactions. For example, it could track not only how a learner completed a task, but how they interacted with various elements in the VR environment [4].
- **Data Storage and Analysis**
    - Learning Record Store: This is referred to as a system that would store all the xAPI statements. In the previous discussion, it has been explained that the LRS gathers data from the xAPI-enabled VR platforms and stores the data appropriately [4].
    - Analytics and Insights: It leverages the rich data capture of xAPI to derive insights into learner behavior and performance. LRS integration with Moodle analytics tools provides comprehensive reporting and a dashboard against which strategic decisions can be made to realize better value in VR training content [4]
- **Integration Strategies**
    - API Integration: This includes the setup of a VR platform to send xAPI statements to the LRS. The integration of the LRS with Moodle has to be done in such a way that fetches data from the LRS for reporting and

analysis. This, in turn, ensures real-time data exchange and tracking of the VR activities within Moodle [4].

  - Real-time Reporting: Enable real-time reporting of the VR activities within Moodle through xAPI statements, thereby tracking the progress and performance of the VR that is to be used by a learner and providing immediate feedback to the instructors [4].

- **Flexibility and Adaptability**
  - Beyond SCORM: xAPI allows for tracking a broader range of learning experiences, including informal learning and activities. This provides a more comprehensive view of learner progress and performance [4]

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1.14 Discuss data tracking, assessment, and reporting functionalities

1.14.1 Data Tracking

Data tracking is the process of collecting, recording, and analyzing information on user behavior, their interaction, or any other metric over time. This is mostly done to keep track of performance to improve services or to understand patterns and trends [1. Many types of data can be tracked; however, decision-making data in VR is probably the most interesting. Data gathered on how users make choices, navigate spaces, and interact with virtual elements in virtual reality may convey useful insight into behavior, preference, and cognitive processes, and enhance both user experience and effectiveness in general for VR applications [1].

LMSs can log decision-making data because they are easily integrated with the tracking systems of user interactions and choices. The LMS then collects this information, processes the information, and develops analyses and reports on the outputs of the user's decision-making patterns and performance [2].

1.14.2 Assessment

Assessment may be defined as the process through which a person's knowledge, skills, abilities, or performance are evaluated and measured concerning his or her proficiency or progress. These include, but are not limited to, formative assessments, which are continuous and provide feedback in the course of learning; summative assessments, which determine the overall achievement at the end of an instructional period; diagnostic assessments, which are meant to identify strengths and weaknesses that a learner has before instruction; and performance-based assessments, which engage an individual to demonstrate certain skills or competencies through practical means. Each of these has a different purpose in understanding and improving learning [6].

Procedural knowledge is relevant and applies in terms of an individual's correct performance of a task on time, as it speaks to an individual's ability to perform in a virtual environment. This kind of knowledge will enable the individual/trainer to follow specific steps and protocols, which are an essential part of certain fields that require accuracy and maintenance of standards, such as health care, engineering, and technical trades. The assessment of procedural knowledge makes a diagnosis about the lack of knowledge, gives relevant feedback to improve it, and ascertains that a trainer is theoretically knowledgeable but practically competent. Assessments focusing on procedural knowledge ensure that trainers can apply skills efficiently and lead to effective performance with quality outcomes.

Procedural knowledge assessment gauges a person's capability to understand and execute a particular order of activities that must be performed for a task. This ensures real-world application and skill competencies in terms of identification of errors and providing targeted feedback to improve performance. This will be done through simulations, step-by-step tasks, process mapping, and scenario-based assessments that monitor trainers to ensure the replication of processes to the correct procedure. Assessments are concerned with procedural knowledge to ensure that trainers not only know but can also apply their skills competently in a real-world setting [5] [6].

1.14.3 Reporting Functionalities

Reporting is the orderly review of data resulting from user performance and may come in the form of customizable dashboards to illustrate metrics, reports used to track performance over time, and detailed analytics for an in-depth look into areas like quiz results or participation levels. Reporting in an LMS is desirable in that it provides a place where all relevant information is unified, up to date, integrated with learning activities, and can provide an overall view of educational outcomes by highlighting points of strength and areas for improvement. Reporting within the LMS will entail gathering and sorting information from the user's interaction with the system. Second, reporting through the many different tools within the system provides the reporting capability; third, analysis of such reports for actionable insights helps instructors, administrators, and learners to make informed decisions in enhancing learning in the virtual environment [3] [4].

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Assessment may be defined as the process through which a person's knowledge, skills, abilities, or performance are evaluated and measured concerning his or her proficiency or progress. These include, but are not limited to, formative assessments, which are continuous and provide feedback in the course of learning; summative assessments, which determine the overall achievement at the end of an instructional period; diagnostic assessments, which are meant to identify strengths and weaknesses that a learner has before instruction; and performance-based assessments, which engage an individual to demonstrate certain skills or competencies through practical means. Each of these has a different purpose in understanding and improving learning [6].

Procedural knowledge is relevant and applies in terms of an individual's correct performance of a task on time, as it speaks to an individual's ability to perform in a virtual environment. This kind of knowledge will enable the individual/trainer to follow specific steps and protocols, which are an essential part of certain fields that require accuracy and maintenance of standards, such as health care, engineering, and technical trades. The assessment of procedural knowledge makes a diagnosis about the lack of knowledge, gives relevant feedback to improve it, and ascertains that a trainer is theoretically knowledgeable but practically competent. Assessments focusing on procedural knowledge ensure that trainers can apply skills efficiently and lead to effective performance with quality outcomes.

Procedural knowledge assessment gauges a person's capability to understand and execute a particular order of activities that must be performed for a task. This ensures real-world application and skill competencies in terms of identification of errors and providing targeted feedback to improve performance. This will be done through simulations, step-by-step tasks, process mapping, and scenario-based assessments that monitor trainers to ensure the replication of processes to the correct procedure. Assessments are concerned with procedural knowledge to ensure that trainers not only know but can also apply their skills competently in a real-world setting [5] [6].

Reporting Functionalities

Reporting is the orderly review of data resulting from user performance and may come in the form of customizable dashboards to illustrate metrics, reports used to track performance over time, and detailed analytics for an in-depth look into areas like quiz results or participation levels. Reporting in an LMS is desirable in that it provides a place where all relevant information is unified, up to date, integrated with learning activities, and can provide an overall view of educational outcomes by highlighting points of strength and areas for improvement. Reporting within the LMS will entail gathering and sorting information from the user's interaction with the system. Second, reporting through the many different tools within the system provides the reporting capability; third, analysis of such reports for actionable insights helps instructors, administrators, and learners to make informed decisions in enhancing learning in the virtual environment [3] [4].

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1.15 Living Lab Networks (Virtual/Real)

1.15.1 Living Labs and their role in fostering innovation and collaboration

Living Labs are open innovation environments that actively involve end users in the co-creation process of new services, products, and social infrastructures. According to the definition by the European Network of Living Labs (ENoLL), a Living Lab is an "open innovation environment in real-life settings, where the active involvement of end users allows for the co-creation of new services, products, and social infrastructures." This approach enables the testing and development of innovative solutions in everyday contexts, fostering direct interaction between citizens, researchers, companies, and public institutions.

The concept of Living Labs originated in the early 2000s at the Massachusetts Institute of Technology (MIT) as a methodology for research and innovation. The idea was to create a multidisciplinary and user-centered environment where innovation was driven by the community in real-life settings. This model was later adopted and promoted by the European Commission in 2010, defining Living Labs as public-private-people partnerships (PPPP) to generate open and user-centered ecosystems.

Needs and Objectives

Living Labs address various needs:

- User Involvement: They help bridge the gap between products and user expectations, making innovation more oriented towards real needs.
- Risk Reduction: By involving users from the early stages, they reduce the risks of failure and accelerate the time-to-market.
- Collaboration and Co-creation: They promote collaboration among different actors (public, private, academic, and citizens) to co-create innovative solutions.
- Real-life Experimentation: They allow for the testing and validation of products and services in real-life conditions, improving the quality of feedback and the effectiveness of solutions.

Key Characteristics

Living Labs are characterized by:

- Open Innovation: Active and constant involvement of end users in transparent and collaborative processes.
- Real-life Situations: Experimentation in everyday, non-artificial environments to obtain realistic and useful feedback.
- Co-creation: Users actively participate in all stages of the development process, from design to evaluation.
- Value Generation: Creation of services, products, and social infrastructures that meet user needs and improve quality of life.

Examples and Applications

Living Labs have been implemented in various sectors, including healthcare, smart cities, energy, mobility, social inclusion, and cultural innovation. For example, the "Apulian ICT Living Labs" project in Puglia (Italy) involved citizens, companies, and institutions to develop innovative solutions in the fields of environment, security, cultural heritage, and tourism.

Role of Living Labs in Innovation

The role of Living Labs in innovation and collaboration is crucial for several reasons:

- User Involvement: Living Labs place users at the center of the innovation process, allowing them to actively participate in the design and testing of new solutions. This user-centric approach ensures that the developed products and services truly meet the needs and expectations of end users.
- Real-life Environments: Experiments take place in real-life contexts, which allows for the collection of authentic and high-quality feedback from users. This reduces the risk of product failure in the market and accelerates the refinement process of innovative ideas.
- Multidisciplinary Collaboration: Living Labs foster collaboration among various actors, including public entities, companies, universities, research centers, and citizens. This multidisciplinary collaboration stimulates the mutual exchange of skills and ideas, creating a fertile ecosystem for innovation.
- Reduced Time-to-Market: By involving users from the early stages of the development process, Living Labs enable the quick identification and resolution of potential issues, reducing the time needed to bring a product or service to market.
- **Sustainability and Social Impact:** Living Labs promote not only technological but also social innovation, encouraging the creation of solutions that improve the quality of life and well-being of communities.

Living Labs originated as open innovation environments, initially conceived as physical spaces where users, researchers, companies, and public institutions could collaborate directly. The idea was to create a real-world context in which to test and develop new solutions, actively involving end users. With the advancement of technology and the increase in global connectivity, the possibility of creating virtual Living Labs emerged, offering a range of distinct advantages compared to their physical counterparts. Advantages and Disadvantages of Virtual Living Labs

Advantages and Disadvantages of Virtual Living Labs

Advantages:

- Accessibility and Inclusivity: Virtual networks allow for the participation of a larger number of users, regardless of their geographical location. This increases the diversity of participants and enriches the co-creation process with a wider range of perspectives and skills.
- Flexibility: They offer greater flexibility in terms of schedules and modes of participation. Users can contribute to the Living Lab activities from anywhere and at any time, using digital tools and online platforms.
- Cost Reduction: There is a reduction in costs associated with managing physical spaces, such as rent, maintenance, and logistics. This makes the creation and maintenance of Living Labs more sustainable, especially for organizations with limited resources.
- Scalability: Virtual networks can be easily scaled to include more participants and to expand the Living Lab activities to new territories and sectors.

Disadvantages:

- Limited Interaction: The lack of face-to-face interaction can reduce the quality of relationships and trust among participants.
- Less Immersive Experiences: Virtual experiences can be less engaging compared to physical ones, limiting the ability to test solutions in real-world contexts.
- Dependence on Technology: Technical problems and connectivity limitations can hinder participation and the effectiveness of activities.
- Coordination Challenges: Managing distributed participants can be complex and require advanced coordination tools.

Advantages and Disadvantages of Physical Living Labs

Advantages:

- Direct Interaction: They allow for face-to-face interaction among participants, facilitating the building of trust and effective collaboration.
- Immersive Experiences: They offer immersive experiences that allow users to test and experiment with solutions in real environments, providing more detailed and concrete feedback.
- Infrastructural Support: They can benefit from dedicated infrastructures, such as laboratories, co-working spaces, and specialized equipment, which facilitate the prototyping and experimentation of new technologies.

- Local Communities: They strengthen local communities by creating meeting and collaboration spaces that promote innovation at the territorial level, with a positive impact on the economic and social development of the involved areas.

Disadvantages:

- High Costs: Managing physical spaces involves significant costs for rent, maintenance, and logistics.
- Geographical Limitations: Participation is limited to those who can physically reach the Living Lab location, reducing the diversity of participants.
- Reduced Flexibility: Activities must be planned according to the schedules and availability of physical spaces, limiting flexibility.
- Limited Scalability: Expanding activities to new territories and sectors can be complex and costly.

Overcoming Challenges

For virtual Living Labs, it is essential to invest in robust and reliable technological infrastructures to ensure stable connectivity and effective collaboration tools. Using gamification techniques and interactive tools can make virtual experiences more engaging, while providing training and technical support to participants can help overcome technological barriers.

For physical Living Labs, it is important to seek partnerships and funding to cover the costs of managing physical spaces. Combining physical and virtual activities can broaden participation and leverage the advantages of both models. Additionally, promoting active involvement of the local community can create a sense of belonging and mutual support.

In summary, both virtual and physical Living Labs offer unique advantages and face specific challenges. The key to success is finding a balance between the two models, leveraging the strengths of each and mitigating their respective weaknesses through targeted and innovative strategies.

1.15.2 different models of Living Lab networks, including regional, national, and transnational

Living Labs represent an innovative model of co-creation and experimentation that involves end users, companies, public institutions, and research centers. These living laboratories operate in real environments to develop, test, and validate new products, services, and business models. Their structure can vary significantly, adapting to regional, national, and transnational specificities. This topic explores the different models of Living Lab networks, highlighting their distinctive characteristics and the benefits they bring.

Regional Models

Regional Living Labs are often focused on specific local needs and leverage the resources and expertise available in the region. A significant example is the Puglia Smart Lab in Italy, which promotes innovation through collaboration between citizens, businesses, and local institutions. This model is based on a quadruple helix approach, actively involving end users in the co-creation of innovative solutions. Regional Living Labs like this are essential for stimulating local innovation and responding to specific territorial needs.

National Models

At the national level, Living Labs can benefit from a larger scale and broader resources. An example is the Translational Medicine Living Lab in Italy, which brings together research institutes, companies, and clinics to improve medical care strategies. This national model allows for addressing complex challenges such as regenerative medicine and telemedicine, leveraging synergies among different actors and promoting large-scale innovation. National Living Labs are crucial for developing solutions that can be implemented across the country, improving quality of life and service efficiency.

Key Points of the Translational Medicine Living Lab:

- Collaboration Among Different Actors: The Living Lab brings together research institutes, companies, and clinics, creating synergies that allow for addressing complex challenges such as regenerative medicine and telemedicine.
- Large-Scale Innovation: Thanks to the collaboration among various actors, the Living Lab promotes large-scale innovation, developing solutions that can be implemented at the national level.
- Improving Quality of Life: The solutions developed aim to improve the quality of life and the efficiency of healthcare services, addressing complex problems with innovative approaches.

- Success Stories: Projects like RINOVATIS, which focus on tissue engineering and regenerative medicine, have been developed within the Living Lab, demonstrating the effectiveness of public-private collaboration.

The national model of Living Labs, as demonstrated by the Translational Medicine Living Lab, is crucial for developing innovative solutions that can be implemented across the country, improving quality of life and service efficiency.

Transnational Models

Transnational Living Labs represent a further evolution, facilitating collaboration beyond national borders. An example is the Alcotra Innovazione project, which is a significant example of transnational Living Labs, promoting collaboration beyond national borders. This project involves cross-border regions between Italy and France, with the aim of creating partnerships and awareness among innovation actors in the continental Alpine areas.

Key Points of the Alcotra Innovazione Project:

- Cross-Border Collaboration: The project aims to build and manage cross-border Living Labs, facilitating cooperation among different regions to address common challenges such as sustainable energy and smart mobility.
- Development Model: It uses an approach called the "Unitary Model" and an operational methodology known as the "LEADERS Approach" to design and manage communities of cross-border Living Labs.
- Achieved Results: The project has achieved significant results, including the creation of a collaboration network that transcends geographical barriers and promotes innovation at an international level.
- Integration with Pre-Commercial Procurement (PCP): The project has also explored the integration of cross-border Living Labs with innovative R&D procurement practices, gaining attention among European public authorities.

Transnational Living Labs are essential for tackling global issues and promoting innovation at an international level, creating collaboration networks that transcend geographical barriers.

References:

- Handbook on cross border collaboration and Living Labs - URENIO | Intelligent Cities – Smart Cities – Innovation Ecosystems

- [ALCOTRA INNOVAZIONE: the kick off of the four thematic working groups - CSP ICT Innovation]

Benefits and Challenges

Living Labs offer numerous benefits, including reducing the risk of new product failure, accelerating time-to-market, and creating solutions that are closer to the real needs of users. However, they also face several challenges, such as the need to coordinate multiple stakeholders and ensure the economic sustainability of initiatives. The key to success lies in the ability to create a collaborative ecosystem and maintain a flexible and adaptable approach.

Conclusion

Living Lab network models, whether regional, national, or transnational, represent a powerful tool for promoting innovation and improving quality of life. Through collaboration among users, companies, institutions, and research centers, these living laboratories can develop innovative solutions that meet the real needs of communities. Their ability to adapt to different scales and contexts makes them a key element for the future of innovation.

Examples of Successful Virtual Living Labs:

Forum Virium Helsinki (Finland):

Forum Virium Helsinki was initiated by the city of Helsinki to promote urban innovation. The goal was to create a platform that could unite companies, universities, the public sector, and Helsinki residents to develop innovative solutions for the city. This initiative was founded to respond to the growing needs for digitalization and sustainability in urban areas. Current Activities Forum Virium Helsinki focuses on various innovative projects aimed at improving urban quality of life. Some of their main activities include:

- Urban Innovation Projects: Collaborating with various partners to develop new technologies, services, and practices that can be scaled for the entire urban community.
- Experimentation and Piloting: Using Helsinki as a testing ground for new ideas, offering an open platform for companies to test their products and services.

- Support for SMEs: Providing funding opportunities and support to small and medium-sized enterprises, helping them leverage the city's resources to innovate.

Forum Virium Helsinki is a non-profit organization that operates primarily with external funding. About two-thirds of their funding comes from European Union financial instruments, making them one of the largest users of innovation funds in Finland. In 2022, they received €1.9 million in basic funding from the city of Helsinki. This funding model allows them to maintain a high level of activity and continue developing innovative projects.

Impact and Strategic Objectives

The impact of Forum Virium Helsinki's activities is monitored through semi-annual effectiveness reports. Their strategic objectives include:

- Strengthening the city of Helsinki's capacity to use data, new technologies, and digitalization.
- Helping companies use Helsinki as a testing ground.
- Being an expert, innovative, and agile organization.

Some Successful Projects of Forum Virium Helsinki

- Helsinki Region Infoshare (HRI): This project made Helsinki's city data open and accessible to the public. HRI facilitated the opening of the Ahjo document management system data, allowing citizens easy access to public information.
- Sensible 4: Another successful project is the collaboration with Sensible 4, a company developing robotic buses. This project led to the creation of new companies and jobs, demonstrating the positive impact of urban innovation.

Conclusion

Forum Virium Helsinki represents an excellent example of how cities can become living labs for innovation. Through collaboration and strategic funding, they are creating a smarter and more sustainable urban future.

References:

- [About us - European Network of Living LabsEuropean Network of Living Labs (enoll.org)]

- [The anatomy of a successful development project - Forum Virium Helsinki]

iMinds Living Labs (Belgium):

iMinds has created a virtual network of Living Labs that supports digital innovation in various sectors, including e-health, energy efficiency, and e-participation. Through collaboration between universities, companies, and end-users, iMinds has successfully developed and tested numerous digital products and services. iMinds Living Labs, now part of imec, is a Belgian initiative that has created a virtual network of Living Labs to support digital innovation in various sectors. Here is an in-depth look:

Origins and Structure

iMinds was founded by the Flemish government to stimulate ICT innovation. Subsequently, iMinds merged with imec, a world-leading research institute in the field of nanotechnology and digital technologies. iMinds Living Labs is one of imec's divisions, focused on co-creating and testing innovative solutions with direct involvement from end-users.

Innovation Sectors

iMinds Living Labs operates in various sectors, including:

- e-Health: Developing digital solutions to improve healthcare.
- Energy Efficiency: Projects aimed at optimizing energy use through smart technologies.
- e-Participation: Initiatives that promote citizen participation through digital tools.

Collaboration and Methodology

The strength of iMinds Living Labs lies in the collaboration between universities, companies, and end-users. They use a co-creation approach, where solutions are developed and tested in real environments with continuous user feedback. This method ensures that products and services are well adapted to market needs and have a higher chance of success.

Successful Projects

Some of the successful projects include:

- Proeftuinonderzoek: A project that allowed researchers and entrepreneurs to test and develop innovative solutions with their target audience.

- Digimeter: A tool that measures the adoption and use of digital technologies among citizens, providing valuable data to improve digital services.

Impact and Recognitions

iMinds Living Labs is an active member of the European Network of Living Labs (ENoLL), an international network that promotes co-creation and open innovation. Thanks to their scientifically validated methods, iMinds Living Labs has significantly contributed to digital innovation in Europe.

References:

- iMINDS (Belgium) | Europeana Space, Best Practice Network (europeana-space.eu)
- Transformative Social Innovation Theory (transitsocialinnovation.eu)
- About us - European Network of Living LabsEuropean Network of Living Labs (enoll.org)

Examples of Successful Physical Living Labs:

Green Schools Living Lab (Italy):

The Green Schools Living Lab is an initiative by the Province of Treviso aimed at transforming local schools into sustainable campuses. This project was created with the goal of promoting energy savings and environmental sustainability through the active participation of students, teachers, and school staff. The Living Lab has created a real experimentation environment where innovative solutions are tested and developed to improve the energy efficiency of school buildings. Some of the main activities include:

- Installation of Renewable Energy Systems: Using solar panels and other technologies for clean energy production.
- Energy Monitoring: Implementing monitoring systems to control and optimize energy consumption.
- Energy Teams: Forming groups of students and teachers dedicated to managing and promoting energy efficiency in schools.

The project actively involves the school community, promoting virtuous behaviors in energy use. Through competitions and educational activities, the Green Schools Living Lab has raised awareness about the importance of sustainability and helped reduce energy consumption and CO_2 emissions.

Projects and Recognitions

The Green Schools Living Lab is part of the European Network of Living Labs (ENoLL), which facilitates the exchange of ideas and best practices at the international level. Some of the successful projects include:

- TOGETHER Project: An initiative co-financed by the European Regional Development Fund to improve energy efficiency in public buildings through user involvement.
- EduFootprint Project: A project focused on the life cycle analysis of school buildings to reduce the overall environmental impact.

Conclusion

The Green Schools Living Lab represents an excellent example of how schools can become living labs for sustainable innovation. Through collaboration between students, teachers, and school staff, the project has created an educational environment that promotes sustainability and energy efficiency.

References:

- Green Schools Progetti - Treviso Scuole 2
- GREEN SCHOOLS - Provincia di Treviso | PPT - SlideShare

Living Lab Microgrid (Italy):

The Living Lab Microgrid located at the Savona Campus of the University of Genoa is an innovative and experimental infrastructure called the Smart Polygeneration Microgrid (SPM). This open laboratory was designed to test and develop smart grids and advanced energy management systems. Here are some key details:

- Origins and Objectives: The project started in 2011 with the aim of transforming the Savona Campus into a "Living Lab" for the city of the future. The SPM was created with funding of €2.4 million from the Ministry of Education, University, and Research.
- Structure and Operation: The SPM is a low-voltage three-phase intelligent microgrid that integrates the production and distribution of electrical and thermal energy. Some of its main features include:

    - Gas Microturbines: Produce electrical and thermal energy.
    - Photovoltaic Systems: Produce electrical energy.
    - Electrical Storage Systems: Store electrical energy for use when needed.
    - Cooling Systems: Cool buildings during the summer.
    - Electric Vehicle Charging Stations: Support sustainable mobility.

Collaboration and Impact

The Living Lab involves students, researchers, and companies in the co-development of sustainable energy solutions. This collaborative approach allows for the testing of new technologies in a real environment, improving energy efficiency and reducing the campus's CO_2 emissions.

References:

- La Smart Polygeneration Microgrid (SPM) | Campus universitario di Savona (unige.it)
- Università degli Studi di Genova (cluster-energia.it)

Other interesting references

- http://ec.europa.eu/information
- http://www.applus-energie.org/
- https://livinglabdays2014.files.wordpress.com/2014/09/pitch-14-green-schools-
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- https://forumvirium.fi/en/silver-project-proceeds-to-prototyping/
- https://www.pw.edu.pl/

1.15.3 common factors contributing to the success of transnational VR platforms and Living Lab networks

- **Design and performance**. The VRHDMs are rather bulky, not fashionable devices. The technical glitches are not uncommon. VR applications (whether smartphone-based or PC-based) should be faster and lighter. The set-up of the HDMs is one of the challenges for the users: unlike the mobile or computer interfaces, the interface of the VR systems may not be intuitive for the users (although the stand-alone VR systems are easier to use). The navigation inside the VR environments is uneasy on mobile devices, although it's improved on the HMDs with the usage of controllers. Easy to set up, budget mobile-based headsets require smartphones with a high display resolution (for the convenient visual experience), appropriate processing power, motion trackers, and a long-lasting battery. On the contrary, the tethered headsets are bulky and "awkward to wear," they limit users' movements due to the wired connection to PC, are dependent on the PC processor being able to render video at high speed, and, in addition, they create a safety hazard since the user may get caught and fall.
- **Rendered video quality**. Video quality is named to be one of the most significant hurdles in the VR industry. Even if the360-degree video is shot with the help of 4K Ultra HD (4096×2160 pixels) cameras, at the moment, the VR hardware and software are not able to deliver the 4K quality in VR. Nowadays, nearly every VR headset has a horizontal field of view of about 100 degrees and a resolution of around 1440×1600 pixels. The users can still see the pixels, and the text in the small font is hardly readable. For a more immersive experience, the human vision should be raised to at least 210 degrees, which will also multiply the number of pixels and the angular resolution (the number of pixels within a unit angle). The fundamental problem is that the headset with a field of view of 200 degrees and twice as much of the angular resolution will multiply the number of pixels sixteen-fold. Currently, no GPU on the market is able to process it.

- **Network speed**. The size of VR video files is another vital component. Much higher quality would be needed for a fully realistic experience than what is currently accessible in even high-end VR systems. Since mobility was one of the key reasons for the smartphones adoption, high-speed wireless connection (5G) would enable the transmission of gigabits of data "over the air interface for a large number of users… in the most radio resource efficient manner" what could contribute to the VR technology adoption. Low-latency 5G network, combined with the distributed cloud, and eye-tracking that enable foveated rendering, could impact the user experience in VR, contributing to the quality of the content without the need for wired connection to PC. 5G connection may enable VR streaming and contribute to the wireless VR adoption.
- **Degrees of freedom (DoF).** Numerous research proves that the HMDs with 6DoF provide a higher sense of presence than the ones with 3DoF. The sense of presence directly impacts the user's view and inclination of using a tool, from the point of both usefulness and ease of use.
- **Hand tracking**. VR limits the physical movement of the users. To move objects and teleport themselves in a VR environment, people use controllers. Some headset makers require external tracking devices and cameras. Facebook announced the hand tracking as a near consumer feature with the help of the built-in cameras in its Oculus Quest in 2020. It will allow users to interact in VR directly with their hands, without Oculus Touch controllers. Not only will the feature bring a new layer of interactivity, but it will also require the development of a whole gesture-interaction system.
- **Haptics**. Haptic feedback is a mode of communication that simulates the sense of touch (vibration, pressure, temperature, etc.). It deploys physical resistance and encompasses the position and movement of the human body in space. Haptic feedback has been demanded by the consumers and requested to be added to the VR experience. The start-ups HaptX or Noitom are currently developing interactive gloves. VR Electronics is developing the Teslasuit – haptic suit for VR. Both hand tracking and haptic feedback require the language to be developed - just like for smartphones and touchpads.
- **Health issues**. Some known side effects of the VR technology use include motion sickness (also called cybersickness) closely related to the latency issues; eye strain as the result of vergence-accommodation conflict, when the eye tries to focus on the pixelated objects in the distance while they are just a few centimeters away; nausea; physical discomfort such as muscle strain in the neck and shoulders as the result of prolonged use of VR; cognitive

overload and distracted attention. The long-term consequences of VR usage are also not researched extensively yet. There are concerns that regular use of VR could accelerate the development of short-sightedness (myopia). Research by specialists at Leeds University found that only 20 minutes in VR could influence the ability of children to absorb the distance to objects. It is advised that the VR users take breaks frequently to avoid nausea.

1.15.4 virtual tools, platforms, and communication channels for collaboration

Representations of ideas can be: sketches, renderings or maps. Work routines show that individual ideators represent their ideas in an "easy to access" way, meaning that Computer Aided Design or rendering software is used in a basic way. More often ideas are sketched or presented in Microsoft PowerPoint. The representation is distributed to stakeholders by e-mail for getting feedback in general, comments, further ideas, and the development of the original idea.

- Within ideation processes two perspectives can be distinguished: the individual and the group. Examples for both are stated in the following paragraphs:
- The initial moment: the occurrence of an idea by the individual. Within one to eight hours the idea is represented as a sketch or as text. Variations of the idea might be represented but not an entirely different concept. Pictures are copied into common media tools such as MS PowerPoint or MS Word.
- The representation is shared by sending it out by e-mail to recipients with an interest in the idea. They are usually well known. Their reply by e-mail occurs within one to two days. The participants do not expect feedback after two days have passed. Alternatively, feedback is gathered by phone. Feedback is usually given in an unstructured way.
- The feedback is extracted from the individual sources (text, comments to the pictures/text, phone calls) by the ideator and then summarized. After editing, the feedback is used to transform the original idea.

1.15.5 recommendations for building effective virtual Living Lab networks

Based upon the needs of the stakeholders there are some requirements that need to be fulfilled to establish living labs. First, an agreement on the common objective as well as a clear and transparent organisational structure are needed. This includes a description of roles given to certain people. Their responsibilities and duties must be well defined and distributed to the stakeholders. Secondly, conflict management and IPR guidelines are required.

Also, the following requirements should be fulfilled to ensure the success of the local SGLL.

- An open result: nobody knows exactly what the result will be, but everybody has the possibility to contribute. It also must be a participative process in which the stakeholders could bring their ideas and discuss them in an atmosphere based on mutual trust.
- A good diversity: Since one of the main purposes of the SGLL is to work on new project ideas and serious games, it is of utmost importance that the stakeholders with different backgrounds, skills and experience are involved in the process.
- Good governance: rules focused on the process rather than on the result, with a good margin of freedom for the participants.
- Transparency of the process: it's the main condition for the reciprocal trust between the stakeholders.
- An agreement on the use of specific software, tools and programming language.

Additional to these requirements on the SGLL as such, there are not that many requirements for a SGLL that are pre-requisite. However, there are some that will support collaboration easier and thus should be fulfilled. A platform and tools to facilitate connectivity: one cannot create without common spaces, tools, ways to interact, collective memory, etc. There should be a mechanism for taking care of the quality of the dialog to generate trust. Also, tools supporting creativity and the ideation process are of advantage but are not strictly necessary

Additional to the requirements that need to be fulfilled by local living labs, the virtual living lab needs to offer a collaborative working environment. There is also a need for a social network platform which represents the communications that in a local living lab takes place during the events. This will be an off-the shelf product. Also, a knowledge management system is needed to store and share information, documents, etc. It is not so important which one we use, it is more important that only one is used, and that it is traceable how knowledge evolved. To date there is hardly any experience with a virtual LL, but there is some experience with CWEs. From this we know that it is important to gather meta-information for analysis to facilitate the platform. This can be done by questionnaires, social networks, use of public data, or invasive middleware and logging events. SNA offers a lot of possibilities here. It is important, however, that the stakeholders know what has happened with their information and that the use of it is transparent and based on voluntary participation. Otherwise, it will lead to a loss of trust. Privacy issues are some of the most sensitive ones, and misuse leads to distrust. It is especially important in virtual environments that such tools are used to be able to make sure that intellectual property rights are kept.

To create a virtual substitute for a real-life living lab there is a need for a platform where all the necessary tools are merged and adjusted to work together. The tools integrated on the platform should replace the real counterparts.

Important things that need an equivalent in the virtual world are:

- Face to face meetings (aural, visual).
- Black- or whiteboards.
- Paper and pencils.
- Document sharing.
- Possibility to show things to each other.

Face-to-face meetings must be replaced with video conferences via tools like Skype. These tools are integrating both visual and aural transmissions to a distant dialogue partner. The functionality of a remote whiteboard where all participants can watch as well as to draw, write and browse documents, images or even web pages is needed. A tool which demonstrates this is Twiddla (www.twiddla.com). Twiddla also makes the need for paper and pencil unnecessary. Due to the possibility to show documents, web pages and images it also covers partially the issue of showing things to other people and the sharing of documents. To show physical objects remotely to a faraway viewer there are more or less two possibilities - either there must be a photograph of the desired object or in the case of a video conference the camera with a live video of the object. This also gives the possibility to discuss and interact with the object.

In the case of other electronic content, for example, a desktop application which cannot easily be shared, there must be a tool to remotely access to other computer screens directly through the network. There are several programs fulfilling this task - like the Remote Desktop Connection from the Windows operating system and several VNC (Virtual Network Computing) implementations, which allow the user to watch the screen on a remote computer as well as take control of it. From the point of software developers, software development tools are helpful but are not enough to develop software in different places. A tool for versioning control of software source files is obligatory. Such a tool manages the source code with all changes and all versions. Two such tools are Subversion (Subversion.apache.org) or git (gitscm.com). These tools make it possible to track changes in the source code and to add time stamp, and user information. They ensure a later recovery of deleted or corrupted files as well as managing the authorization and authentication of users. These systems are not only able to handle source code, but can also handle text documents, pictures and images, and saving and versioning of almost all sorts of files.

Bugtrackers make it possible for software developers and users to report failures in the software. These can be prioritised, sorted and organised, so that different failures and bugs can be given to specific developers and solved in a defined order. It also offers a history which makes it possible to search for equal problems.

Of similar importance is the choice of a suitable software coding environment. The choice depends on the skills and the preferences of the developer team. Typical tools that can be seen as standard are Eclipse (http://eclipse.org) and Netbeans (http://netbeans.org) - programmers' first choice for Java based development, whereas VisualStudio, Eclipse or Code:Blocks (http://www.codeblocks.org) are often the first choice for C++ development. Furthermore, some of these Integrated Development Environments (IDEs) offer the possibility of direct integration of the above-mentioned tools, like versioning control and bug tracking. This allows direct access to different functionalities that support a common use of the different systems.

To measure the success and to see if the living labs contribute to defragmentation, it is important that there is an evaluation strategy. The following criteria have proven to be important when running a sustainable Living Lab:

- Evidence of co-created values from research, development and innovation.
- Values/Services offered/provided to LL actors.
- Measures to involve users.
- Reality of usage contexts, where the LL runs its operations.
- User-centricity within the entire service process.
- Full product lifecycle support - capability & maturity.
- LL covers several entities within value-chain(s).
- Number of games developed cooperatively in the living lab.
- Availability of required technology and/or test beds.
- Evidence of expertise gained from the Living Lab operation.
- Level of own commitment to the open innovation process.
- IPR principles supporting capability and openness.
- Openness towards new partners & investors.
- Business-citizens-government partnership – strength & maturity.

- Organization of LL governance, management & operations.
- Business model for LL sustainability.
- Interest and capacity to be active in EU Innovation system.
- International networking experience and capability.
- Channels (web etc.) supporting public visibility and interaction.
- People/Positions dedicated to LL management & operations.

For the local living labs, there are not so many requirements on ICT tools. Far more it is important to establish a clear and lean structure with a transparent information flow. The main requirements are to establish a conflict management procedure, define IPR rights at an early stage and mechanisms supporting trust.

The requirements for the virtual living lab are different. Here there is no face-to-face communication, and thus it is more difficult to establish trust among the stakeholders. It is therefore a pre-requisite that knowledge and idea generation can be tracked, and that it is visible for all participants where the information is and how it is used. Furthermore, it is important to offer a toolset allowing collaborative development of games as well as to share information. A brief review of exemplary tools was presented. Finally, the evaluation criteria for judging the success or failure of the SG Living Lab were presented.

1. Evaluation & design of methodological and technical aspects of the platform for virtual living labs NET

2.1 Technical Design:

2.1.1 Hardware Requirements:

- Specify VR headsets compatible with the platform (e.g., Oculus Rift S, HTC Vive Cosmos) – BIBA, ISIM

  VR Headsets for the VR Platform This section proposes VR headsets based on the needs and requirements of the project. Their further development will be provided in Work Package 3 within T3.1. Logic Preparedness. After a discussion with project partners, according to project needs, the proposition of VR equipment and headsets will be developed in WP3.

HTC Vive Pro 2

The HTC Vive Pro 2 is a very advanced, and PC-based VR headset with extremely high resolution and the next generation of tracking. Compatible with simulations and VR interactive scenarios that require minute details, learning through immersion [1].

Key Features:

- High-Resolution Display: Boasts 2448 x 2448 pixels per eye for graphically impressive visuals within complex VR environments.
- Field of View: Up to 120-degree field of view for enhanced immersion with more spatial awareness in simulations.
- Advanced Tracking System: Requires the use of external base stations to track accurately. It finds a good fit where you have multi-user experiences.

Benefits:

For the most resource-intensive, complex VR applications like medicine, and engineering training Vive Pro 2 is well up for duty: very solid as a go-to where high levels of detail and accuracy are imperative, combined with high fidelity and solid tracking [1].

Fig. 21 HTC Vive Pro 2 [1]

Meta Quest Pro

The Meta Quest Pro is the newest addition to the mixed reality headgear that keeps bringing in both standalone and PC VR support. It shall be made versatile for a variety of learning scenarios [2].

Key Features:

- Standalone and PC VR: Operate entirely independently or plug in a PC to do complex simulations and experiences [2].
- High-Resolution Display: Includes 1800x1920 pixels per eye for bringing out high-resolution virtual environments [2].

Benefits:

Meta Quest Pro provides flexible learning environments. Capable of toggling between standalone and PC-powered modes, it can go through a wide scope of applications from casual learning to intense training sessions for educational purposes [2].

Fig. 22 Meta Quest Pro [2]

The VR platform involves support for both HTC Vive Pro 2 and Meta Quest Pro. Updates to the features of these devices have succeeded regarding compatibility and, in general, the improvement of their performance. The HTC Vive Pro 2 is for high-quality, high-fidelity, resource-hungry simulations, while the Meta Quest Pro is for versatility regarding a wide array of learning use cases. However, due to budget constraints, other suggested models include the HTC Focus Vision, HTC Focus 3, and Meta Quest 3.

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2.1.1 Software Architecture:

- **Design a modular and scalable architecture for the VR platform**

Research was conducted to design a software architecture for the VR platform and analyze various existing educational VR platforms. This provides a comprehensive overview of existing VR platforms, and the architectures used in the educational and training field.

Research on the VR Platforms

Several existing VR platforms were being analyzed; more detailed information about them is given in document T2.1 [5]. However, some of the most relevant ones are described herein:

- AltspaceVR: AltspaceVR is a collaborative virtual reality platform for social uses, with applications in education. It allows users to communicate in virtual spaces, join events, and work collaboratively in various activities. Some of the facilities provided by AltspaceVR are organizing learning and training sessions. It allows users to create and customize their virtual avatar and join other participants in virtual spaces. The platform is available on several types of VR headsets, including Oculus Quest, Oculus Rift, HTC Vive, and Windows Mixed Reality. Among others, it provides spatial audio where one can hear conversations based on how close they are to other people. It also supports events, presentations, and workshops, further making it flexible for teaching. AltspaceVR also provides an original virtual space with a virtual representation of the user, a system menu, and three-dimensional shortcut icons of the applications, further improving the virtual reality experience and simplifying operations. It mainly provides the facility of virtual environments with autonomous virtual agents. A multi-agent architecture is used to design it, which consists of different software components for their simulation and development [6] [7] [8].

- Labster Platform: Labster is a transnational VR platform that only focuses on virtual lab simulations. Labster focuses more on acquiring scientific and technical skills by learning in a virtual environment. The platform provides exposure and hands-on experience with VR experiences, including visits to virtual labs, which helps understand the practical concepts of Science and Technology. The Labster platform has a diverse range of functionality tailored to modern trends in mechatronic systems development and customization of high-performance I/O stacks.
  Labster focuses on teamwork and industrial development processes, including the mechatronic system design curriculum. Labster has developed LabStor, a modular and extensible platform for building customized I/O stacks to transcend the limitations of traditional I/O systems. The novel custom I/O stacks and stack composition allow for large performance gains that are

possible with LabStor. LabStor is an open-source, modular, user-space platform for building tailored I/O stacks that enables the development of single-purpose modules, such as I/O schedulers, to custom-optimize performance by up to 60% in various applications. Labster also integrates an overclocked laboratory platform for testing control algorithms for dynamic positioning of marine vessels. It does so through open-loop step response identification with a MOOS-based communication structure to control the platform [9]

During the research, various virtual reality platforms were identified along with their architectures. These platforms combine cloud-based, local management, service-oriented, and client-server models. Considering our project's specific requirements, a hybrid approach was followed, proposing a combination of the client-server and the service-oriented architecture, which will be described in more detail below.

Reference Architecture

- **Client Server Architecture:** The client-server model is a distributed application structure that partitions tasks or workloads between the providers of a resource or service, called servers, and service requesters, called clients. A server host runs one or more server programs, which share their resources with clients. A client does not share any of its resources, but it requests content or service from a server. Clients therefore initiate communication sessions with servers, which await incoming requests.
  The client-server characteristic describes the relationship of cooperating programs in an application. The server component provides a function or service to one or many clients, which initiate requests for such services. Servers are classified by the services they provide. For example, a web server serves web pages, and a file server serves computer files. A shared resource may be any of the server computer's software and electronic components, from programs and data to processors and storage devices. The sharing of resources of a server constitutes a service.
  Whether a computer is a client, a server, or both, is determined by the nature of the application that requires the service functions. For example, a single computer can run web server and file server software at the same time to serve different data to clients making different kinds of requests. The client software can also communicate with server software within the same computer. Communication between servers, such as synchronizing data, is sometimes called inter-server or server-to-server communication.

In general, a service is an abstraction of computer resources, and a client does not have to be concerned with how the server performs while fulfilling the request and delivering the response. The client only must understand the response based on the well-known application protocol, i.e. the content and formatting of the data for the requested service.

Clients and servers exchange messages in a request-response messaging pattern. The client sends a request, and the server returns a response. This exchange of messages is an example of inter-process communication. To communicate, the computers must have a common language, and they must follow rules so that both the client and the server know what to expect. The language and rules of communication are defined in a communications protocol. All client-server protocols operate in the application layer. The application layer protocol defines the basic patterns of the dialogue. To formalize the data exchange even further, the server may implement an application programming interface (API). The API is an abstraction layer for accessing a service. By restricting communication to a specific content format, it facilitates parsing. By abstracting access, it facilitates cross-platform data exchange.

A server may receive requests from many distinct clients in a short period. A computer can only perform a limited number of tasks at any moment and relies on a scheduling system to prioritize incoming requests from clients to accommodate them. To prevent abuse and maximize availability, server software may limit the availability to clients. Denial of service attacks are designed to exploit a server's obligation to process requests by overloading it with excessive request rates. Encryption should be applied if sensitive information is to be communicated between the client and the server [10] [11].

- **Service-Oriented Architecture (SOA):** SOA This is a design paradigm wherein the software components, called services, are designed to serve certain business functionalities. The services would communicate with each other over the network, which may use standardized protocols such as HTTP, SOAP, or REST [12].

  Components:

  - Services: The services are the independent units of functionalities, which are exposed through well-defined interfaces. For instance, services can be consumed by any client or other services as there is no dependency on any system.

- Service Registry: A directory where services are registered and can be discovered by clients or other services.
- Service Consumer: Any client or service that consumes the provided functionality of a service.

Proposed Architecture

- **Developing a VR Platform:** Developing a VR platform using a game engine like Unity. The platform will include immersive 3D environments, and scenarios, where learners can interact. The VR platform will handle immersive experiences, where users can engage with virtual environments and interactive scenarios. The platform should be accessible via web browsers or using dedicated VR headsets for a fully immersive experience.

- Integrating Moodle with VR Platform: The integration of the VR platform with Moodle insinuates user management, tracking assessment, and course enrollment. In essence, common ways through which this is done are by integrations of LTI or xAPI.
  - LTI Integration: The standard, basically known as LTI, allows the inclusion of external tools within online platforms such as Moodle. Utilizing LTI, the VR environment can relate to Moodle. If users access the VR content from Moodle, then they will be automatically authenticated using their Moodle credentials without having to log in separately.
  - xAPI Integration: It will be able to pass what the learners have interacted with inside the VR environment back into Moodle's Learning Record Store (LRS) in detail. Tracking various interactions that the learners do within the VR platform can be done accordingly.

  Learning Record Store (LRS): LRS is the data store system that acts as a repository for the learning records collected from the connected systems where the actual learning activities are conducted. It is a Software component.

- **User's Registration and Profile Management**: Even though actual learning takes place in the VR environment; all user registrations and profiles can be maintained through Moodle.
  - User Registration: Moodle allows for different types of user registration, including manual, self-registration, and more. Users who

shall be registered can thus engage with a Moodle course that would then link to the VR platform.

  - User Profiles: Profile management, including custom fields, user roles (student, teacher, etc.), and tracking, will be handled directly by Moodle. When users interact with the VR environment, Moodle can keep track of their learning history, profile updates, and activity.

- **Course Enrollment:** Moodle will manage course enrollment, and each course can include links or direct access to VR content
  - Enrollment: Once a user enrolls in a course on Moodle, the course can include modules that link to the VR platform. For instance, a lesson or module within a Moodle course might direct the learner to complete a task in VR.

- **Assessments:** Assessments can be given on the VR platform Moodle or equally on both, if needed.
  - VR-Based Assessments: In the VR environment, some assessment activities, like completing a task can be created and could track the same activity through xAPI and return results to Moodle for grading and analytics.
  - Moodle-Based Assessments: It is possible to integrate various assessment facilities present in Moodle with the VR platform. For example, after the completion of any VR experience, a Moodle quiz can be provided on the knowledge gained in VR.

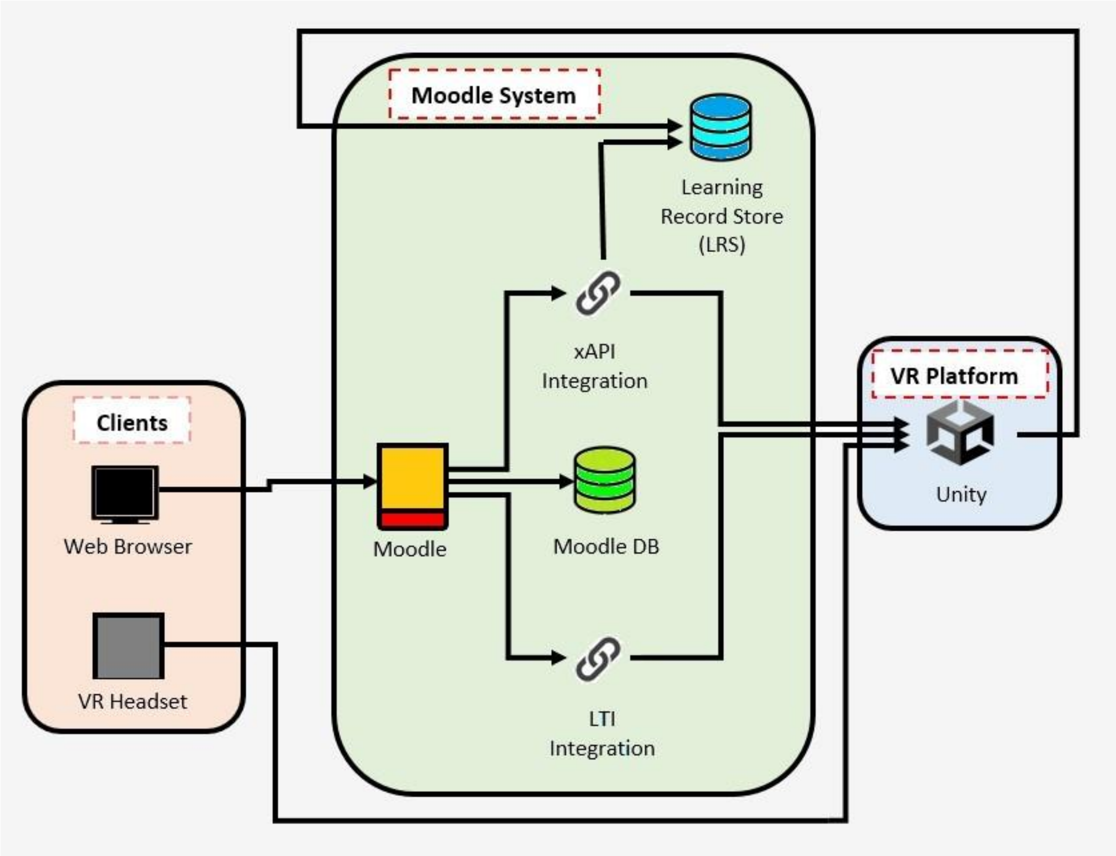

Fig. 23 Software Architecture for VR Platform

Workflow

.1 User Registration: A user registers in Moodle (manually, self-registration, or via external authentication).

.2 Course Enrollment: The user enrolls in a course that includes VR content.

.3 Accessing VR Content: The user logs into Moodle, navigates to the course, and clicks on a VR activity that links to the VR platform. Through LTI or xAPI, the user is seamlessly authenticated and can access the VR environment without needing to log in separately.

.4 Learning in VR: The user interacts with the VR environment, completing tasks, simulations, or assessments.

.5 Tracking and Assessment: The VR platform sends interaction and performance data (via xAPI) back to Moodle, which logs it under the user's profile. If assessments were completed in VR, the results are recorded in Moodle's gradebook.

.6 Moodle Analytics: Moodle provides course progress tracking, assessment results, and overall learner engagement data. Admins and teachers can analyze this data to improve learning outcomes.

Tools and Technologies to Use

- VR Development: Unity
- Moodle Customization: LTI and xAPI plugins
- Tracking & Analytics: xAPI (Experience API) with Learning Record Store (LRS)

The architecture identified has features of the Client-Server Architecture and Service-Oriented Architecture (SOA), while depending on the level and focus of abstraction.

Client-Server Architecture :

Moodle as the Server: Moodle is the central server in the environment, which plays an important role in managing the users, enrollment in courses, assessments, and tracking. Users are clients, interacting with Moodle through a web-based interface.

VR Platform as the Server: The VR platform also functions as a server, providing immersive content. The VR client, which could be a VR headset, connects to the server of the VR platform for the rendering of the virtual environment.

Clients: The clients in this architecture are the web browsers or VR devices that users use to access Moodle and the VR platform. Users authenticate via Moodle (client-server interaction) and then access the VR content through the client's connection to the VR server.

Service-Oriented Architecture (SOA):

The higher level of relevance is that to the SOA model, whereby Moodle and the VR platform are different services communicating with each other. Each service is responsible for specific functions and communicates via standardized protocols like LTI and xAPI. This makes the architecture modular and flexible.

- Moodle and the VR platform are distinct services.
- LTI and xAPI enable them to interact without being tightly coupled.
  - LTI (Learning Tools Interoperability): The standard protocol will enable the integration of Moodle and the VR platform through secured user authentication and course linking.
  - xAPI (Experience API): xAPI tracks detailed user interactions and performance in the VR environment, this will be sent to Moodle for its storing and analytics. That way, both systems can communicate with each other using one standard protocol without tight integration.

Client-Server View: Based on the interaction of the user with the system, this represents the client-server model. This allows users (clients) to interact with Moodle and the VR platform (servers) to complete their tasks.

Service-Oriented View: The backend use of LTI and xAPI interoperability between Moodle and the VR platform is the SOA model wherein services would interact and share data.

This architecture represents the hybrid approach because it inherits the client-server characteristics, where the users are clients interacting with Moodle and the VR platform acting as servers. In this architecture, SOA principles are also applied because Moodle and the VR platform are services-modular applications that interact through standard interfaces.

2.1.2 Utilize Unity 3D

- **Unity 3D Game Engine**

Unity Game Engine is the reliable choice when it comes to developing virtual reality experiences, because of its varied functionalities devoted just to the development of immersive VR worlds [1], such as:

- Unity's high-definition render pipeline (HDRP) and Universal Render Pipeline (URP) provide advanced functionality in rendering support; both enable developers to achieve reliable visual fidelity within VR environments. By supporting advanced rendering techniques like HDRP and URP, Unity can create immersive VR experiences [1].
- Unity's Shader Graph and Visual Effects Graph provides intuitive node-based interfaces to implement shaders and effects, respectively, in VR applications. Using them, for instance, dynamic particle systems, volumetric lighting, or shader-driven the most complicated visual effects can be reached to enhance a VR application with visual richness and interactivity [1].
- Unity's XR Interaction Toolkit provides the foundation necessary for the development and implication of VR interactions along with locomotion mechanics within VR applications. This toolkit gives developers a chance to enable intuitive and immersive VR interactions, as well as enhance user engagement and presence by showing hand presence and object manipulation right through teleportation and smooth locomotion in VR [1].

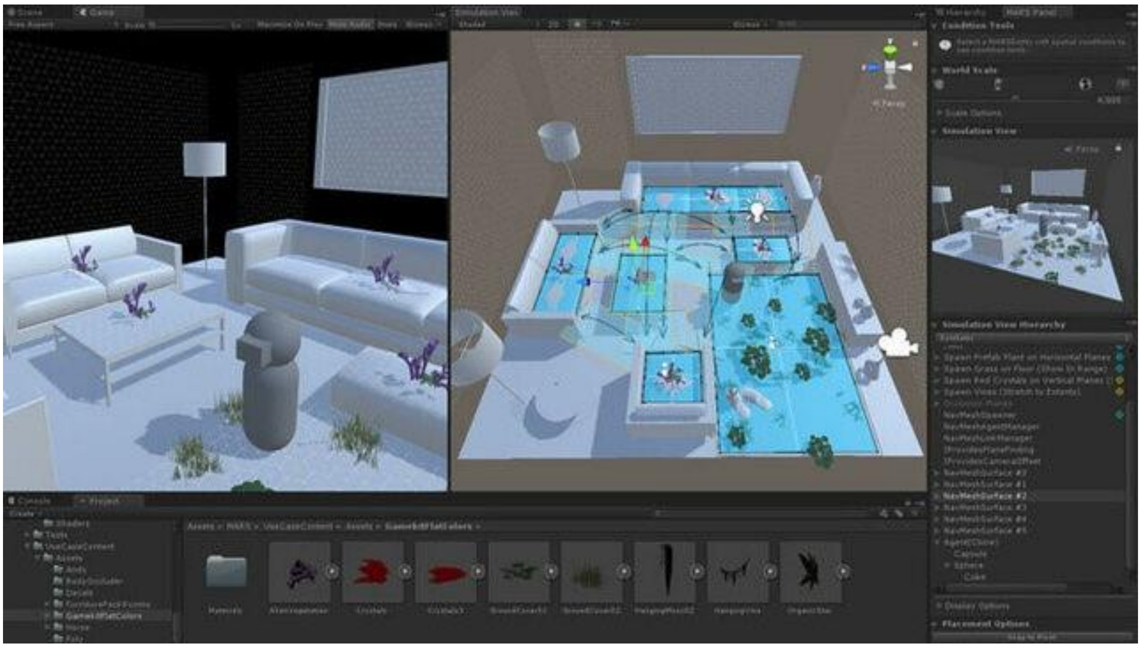

Fig. 24 Unity 3D Game Engine Development Environment [4]

- It features a physics engine that offers robust simulation capabilities to correctly model the physical interactions present within the virtual environment. It hence will enable developers to model real interactions between virtual objects and users using rigid body dynamics, collision detection, and constraints, thus allowing natural and intuitive interaction in VR experiences [1].
- Unity's multi-platform support allows developers to target many VR devices, including HMDs, standalone VR headsets, and mobile VR platforms. With built-in support for various platforms such as Oculus Rift, HTC Vive, PlayStation VR, and Oculus Quest, Unity provides development surroundings for creating VR experiences that can reach a wide variety of VR users [1].

Fig. 25 Unity Supported Platforms [1]

- Unity provides a set of performance optimization techniques to enable smooth and responsive VR experiences. Occlusion culling, level of detail systems, asynchronous reprojection, and dynamic resolution scaling are among the available techniques in Unity that can help a developer maximize frame rates, minimize latency, and optimize resource usage in VR applications [1].

- Unity's scripting APIs make it possible for developers to customize VR solutions that fit their specific requirements. From the integration of external SDKs, and custom locomotion mechanics, to AI-driven behaviors, Unity offers flexibility and control for the developer to realize their VR experience [1].

The following detail the specific reasons as to why the use of Unity is necessary in the development process for VR platforms:

- **Visualization and Interaction with 3D Models:**

Unity's advanced rendering allows designers to create complex detailed 3D models, which are necessary for the user to visualize the part that must be tested in the VR world. Its rendering engine supports several techniques of lighting and shading to achieve realistic digital models of the actual world components. Similarly, the physics engine allows the simulation to interact realistically with the models [3].

- **User-Friendly Interface Creation:**

Unity provides tools for the creation of intuitive UIs. To create an aesthetic and ergonomic interface for such interactive scenarios. Using Unity’s UI tools kit developers can create intuitive interfaces [2].

- **Real-Time Feedback and Interaction:**

Developers can build features that provide instant feedback, allowing users to make informed decisions about status quickly. Also, Unity's networking makes interactions between multiple users possible in real-time, thereby making collaboration and communication possible [3].

- **Engaging and Interactive Environment:**

Due to its strong support for VR platforms such as Oculus Rift and HTC Vive, Unity is well-suited for the development of immersive and fascinating virtual reality environments. Various intuitive interface tools facilitate the development process while strong graphics and real-time rendering account for high-quality visual performance. Its Asset Store and fully customizable scripting capabilities help in creating better and more immersive experiences in Virtual Reality [2].

- **Flexibility for Scenario Design:**

Unity provides flexible design tools for creating diverse scenes, depending on needs, using Unity modeling and scripting capabilities. Another relevant use of Unity is that its asset store gives access to a huge library of pre-framed assets and scripts, which accelerates the work of scenario design and ensures its quality [3].

- **Streamlined Development Process:**

Unity's integrated development environment streamlines the development process for the VR platform and application. Its intuitive interface and comprehensive feature set enable rapid prototyping and iteration, reducing development time and costs. Furthermore, Unity's cross-platform compatibility ensures that the VR application can be deployed to a wide range of devices, maximizing its accessibility and impact [2].

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2.1.3 Networking Infrastructure:

Managing Assets with GitLab

BIBA uses GitLab for versioning and collaboration; hence, VR content and assets - 3D models, simulations, and scenarios will be managed accordingly. GitLab will serve as the central repository that the development team will then use to store, version, and collaborate on all the files and updates related to VR.

- **Version Control:** Versioning through GitLab implies that during its development, versioning of VR modules, 3D models, and other assets are managed correspondingly.
- **Continuous Integration/Continuous Deployment (CI/CD):** GitLab CI/CD pipelines can be used to automatically deploy updates to the VR platform when changes are made to the content or assets. This will help in keeping the VR environment synchronized with the latest available versions of the developments.
- **Backup and Security:** There will be options within GitLab for the safe backup and storage of VR. The sensitive data in VR will be managed using GitLab's built-in security protocols (SSH, HTTPS) that will provide encrypted access to the content.

Cloud Hosting Solution

- **GitLab Cloud (GitLab.com)**: GitLab is itself a cloud service, hosted at GitLab.com. Users can host their repositories, manage their projects, and leverage pipelines in CI/CD without separately managing or setting up a server. This is a fully cloud-based solution whereby GitLab handles all hosting, scaling, and security concerns. The advantage of this pipeline is the repository storage of VR modules, 3D models, and other assets for easy access to such content with version control.

- Cloud hosting of the assets and VR content within GitLab will let the development teams collaborate remotely, share resources, track changes in real-time, and store all the project files securely. Utilizing the complete version control and Continuous Integration/Continuous Deployment Pipelines with GitLab will ensure seamless creation and deployment of VR assets.

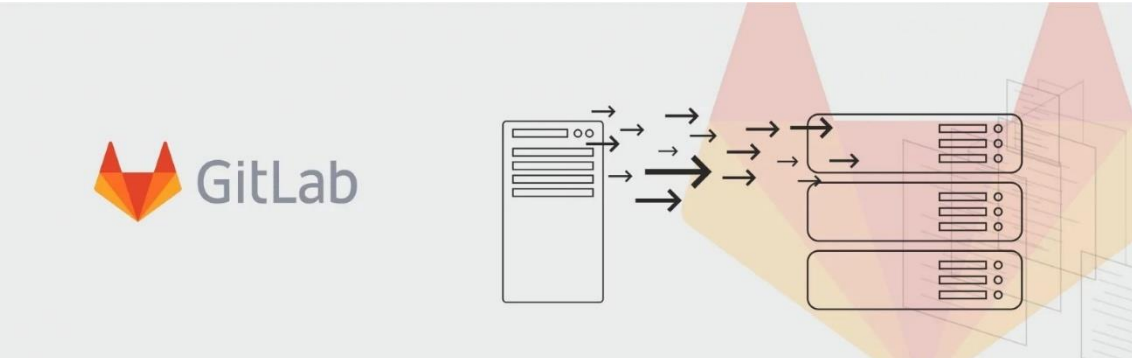

Fig. 26 GitLab for Content Hosting [1]

Minimum Broadband Requirement

- **VR and Bandwidth Streaming:** The platform should have high-speed and low-latency connectivity for seamless and smooth VR streaming. Normally, streaming VR content requires 100-300 Mbps minimum broadband speed; this will ensure that the VR simulations may remain free from buffering or lag.
- **Network Quality and Redundancy: Multiple high-quality Internet connections supported by Quality of Service (QoS)-enabled routers could prioritize traffic for VR, in contrast to other network activities.** This might be of particular importance in institutional settings where several users at any given time would access the system.

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2.1.4 User Authentication and Access Control:

User authentication and access control keeping in view the implementation of authentication and access to the VR platform, based on the alignment towards architecture, the following approach can be implemented:

Secure Login System (User/Password Authentication)

- **User Authentication: This will be provided by a secure login system.** The user authenticates with a username-password combination; the credentials will be dealt with accordingly by following the standard security protocols for encrypted communication, like HTTPS, and password storage using hashing algorithms.
- **Moodle Integration:** Moodle will maintain and make available user profiles that carry information about name, email, job title, and preferences amongst others. Using Single Sign-On (SSO), users will log in through Moodle and seamlessly access Moodle and the VR platform without requiring separate credentials. This provides a unified user authentication system.
- **Authentication Standards:** Security Assertion Markup Language - SAML and similar authentication standards can be followed to make sure that the security practice is widely accepted and provides flexibility for future integrations (living labs) when needed.

Role-Based Access Control (RBAC)

RBAC Implementation: Implementing Role-Based Access Control (RBAC) to manage user permissions. In a living lab context, different roles might include students, instructors, administrators, and possibly external users like researchers. Each role will have specific permissions:

- Students: Can log into VR and perform the training tasks.
- Instructors: Can view student progress, set up training tasks, and assess performance.
- Administrators: Full rights in Moodle and the VR platform; that implies the possibility to administrate the users, create courses, and monitor the activities.

- Living Lab Participants: It depends on the set-up and how the integration of living labs will be; controlled access can be allowed to the researchers/users of those labs for either data analysis or monitoring.

- **Permission Management:** As in Moodle, this may be performed directly through permission settings of various roles using RBAC or via the VR Platform itself. This may be achieved by allowing/denying permissions on various user actions related to accessing specific VR environments or editing scenarios among others.

- **Integration with Living Labs:** The system will integrate living labs through standardized access mechanisms. This is in consideration of the fact that standardized mechanisms of access control, such as using RBAC APIs or protocols for access, ensure that interactions are set to meet standards regarding security and access control.

2.1.5 Data Management:

User profiles

Every user has a profile page which may be reached from the user menu top right and then clicking Profile. This page contains links to further pages allowing the user to edit their profile information and preferences, view their forum/blog posts, and check any reports they have access to.

The Privacy and policies section provides links for contacting the Privacy officer, requesting data export and account deletion (new in Moodle V 3.6), along with a data retention summary page (new in Moodle V 3.6) (unless disabled by the administrator).

Viewing others's profiles

Users with permission to view the profiles of other users can view them by clicking on their name. If they click on the name of a user within a course, the course profile will be displayed and the full profile may be viewed (if allowed) by clicking the link "Full profile" in the Miscellaneous section.

Note: All users are allowed to view the full profile of users listed as course contacts in the course description.

See View profile for more information on how the profile information is displayed and Edit profile for information on updating profiles.

Site administration settings

Site policies

An administrator can force users to login for profiles and select which roles are visible in user profiles (by default teacher, non-editing teacher and student) in Administration > Site administration > Security > Site policies.

Default profile page

An administrator or manager can add additional blocks onto the default profile page for all users from Administration > Site administration > Appearance > Default profile page. Blocks can be added to the left, right or middle of the page.

* Note that this does NOT allow you to remove the following blocks, or to change the layout/order of these blocks:

- User details
- Privacy and policies
- Course Details
- Miscellaneous
- Reports
- Login activity

Clicking the button 'Reset profile for all users' will then apply these settings to the profile pages of everyone on the site.

Preventing users from customizing their profile page

By default, users can customize their public profile page and add blocks. To prevent this

Go to Administration > Site administration > Users > Permissions > Define roles

User profile capabilities

System:

- Edit own user profile
- Manage blocks on own public user profile
- Configure default page layout for public user profiles
- Update user profiles

Users:

- Edit user profile
- Manage blocks on user profile of other users
- View user full information

Course:

- View user profiles

Administrators can create new user profile categories and fields in Administration > Site administration > Users > Accounts > User profile fields.

Profile fields may be a menu of choices, text area, text input or a checkbox and may be required or not.

New profile fields will appear on each user's profile page unless "Who is this field visible to?" is set to "Not visible" in which case only the administrator can see the field. The fields can also be displayed on the signup page if "Display on signup page?" is set to "Yes" (although note that they will never be displayed if set to "Not visible").

You can set the order in which your custom profile fields appear under the associated profile category using the up/down arrows on the User profiles fields page.

To create a new profile field, select the profile field format you require from the dropdown list.

The 'Social' field allows administrators to add back social networks such as Skype ID, MSN / AIM ID which were formerly hard-coded in the user profile if required. If these were already used, they will be retained during the upgraded but converted to these social fields.

Common Settings

All new fields must be given a unique Short Name and a Name (this is displayed on the profile page). You may also choose to enter a Description for the field for your own reference.

There are also a number of configuration options common to all custom profile field types:

- Is this field required?

This option specifies whether this is a mandatory or optional field for user accounts.

- Is this field locked?

This option determines whether once information is populated in this field, it cannot be edited by the user.

- Should the data be unique?

If you need the information populated in your field to be unique across the system (such as an ID number) select Yes to this option and the profile page update will perform a validation check on the data entered.

- Display on signup page?

Depending on the authentication method in use on your Moodle site, you may have some users creating their own accounts. If you would like this custom field to appear on the registration or signup page, select Yes.

- Who is this field visible to?

Each custom field can be given one of four visibility settings:

- Visible to everyone
- Not visible
- Visible to user
- Visible to user, teachers and admins (Moodle V 3.11)

The Not visible setting would typically be set by an administrator who wants to hold private data on the users. The Visible to user setting would normally be selected for a field that holds sensitive information, while the Visible to everyone setting can be used for any type of - information.

Specific Settings

There are also a few field type Specific Settings requiring configuration around default value and size.

Important

If the site administrator bulk uploads user data via .csv file, it is essential to use the correct convention to represent the new profile field. The convention is profile field_shortname

Replace 'shortname' with the actual short name used for the new profile field e.g. dob. So the field should read something like profile_field_dob.

Also, you will need to visit Administration > Site Administration > Users > Accounts > User Profile Fields > Create new Profile Field before attempting to upload a file using it. Creating an upload file first with custom profile fields without creating the User Profile Fields first in Site Administration will result in the error profile_field_shortname is not a valid field name.

* Assessments are a function that exist on any e-learning platform

Summative assessment

Summative assessment provides a conclusive evaluation of student performance, typically quantified through grades. It serves to inform students whether they have met the required standards and passed the examination. This assessment method involves grading students based on predetermined levels of performance. In Moodle, Rubrics can be used for more detailed assessments, where specific criteria are matched with levels of achievement, and the grading with a rubric can be visually presented to the learner, together with individual feedback. Assessors assign numeric grades to each level based on how well the work fulfills the criteria. Summative assessment offers a clear snapshot of student achievement at a specific point in time.

Formative assessment

Formative assessment tends to be qualitative and involves sharing insights with students about what they need to know and where they currently stand in their learning journey. Formative assessment is closely related to feedback and feed-forward, and it should be constructive and related to the learning goals. Moodle helps facilitate meaningful communication between instructors and students through various approaches. For example, a Workshop Activity allows students to assess their own work or that of their peers, while self-assessment encourages independent reflection on progress. Within Moodle's framework, feedback is seamlessly integrated into various assessment formats, such as quizzes and assignments, allowing the instructor to offer automatic or personalized feedback tailored to individual needs. This feedback loop not only helps students learn but also provides instructors with insight into the effectiveness of their teaching methods.

Moodle's commitment to accessibility ensures equitable access to assessment tools across diverse devices.

Summative assessment tools streamline grading processes, while H5P content integration enhances learner engagement through interactive elements.

Formative assessment fosters ongoing improvement through feedback and observation, promoting student growth and autonomy.

Learning analytics offer valuable insights, empowering instructors to refine teaching strategies based on student progress and engagement.

2.1.6 Integration with Learning Management Systems (LMS):

LMS assessment integration with Moodle

Moodle offers a user-friendly interface that streamlines educators' tasks, allowing them to efficiently create, grade and manage assessments and set up diverse assessment activities that cater to unique learning preferences. The platform facilitates co-assessment and collaborative marking systems, enhancing engagement and interaction among students. Moodle's automated grading system simplifies assessment processes, while collaboration with colleagues ensures thorough evaluation, especially for open-ended questions. Moreover, educators can effortlessly collaborate in crafting exercises, building a comprehensive question bank over time.

Moodle enables a seamless transition between paper-based and digital exams, providing students with a variety of assessment options to suit their individual needs. Whether for formative or summative purposes, Moodle empowers educators to comprehensively evaluate student progress, promoting a dynamic and effective learning environment.

All learning materials will be accessible on ISIM's ONEDRIVE or from any of institution sharing devices. (Also they could be available from an file-sharing site or system).

Enable single sign-on (SSO) for easy access and course enrollment

The easiest way to make a single sign-on is to use users email and an unique access code that would be sent via user's email. In addition there could be a way to sign-on via mobile phone number and an unique user code sent via SMS .

* We don't recommend an one-time sign-on code, because it will be a little bit difficult to get recovering account if the user forgot his credentials.

2.1.7 Virtual Collaboration Tools:

- Integrate real-time communication tools for virtual meetings and discussions.

- Implement chat, voice, and video conferencing features within the VR platform.

2.1.8 Content Creation Tools:

- Provide tools for educators to create and upload VR modules - Unity, 3D models, and simulations.
- Support formats such as FBX, OBJ, and glTF for importing assets into the platform – SCORM compliant

2.1.9 User Interface (UI) and Experience (UX):

Designing an Intuitive and User-Friendly Interface for Seamless VR Navigation

The design aims at conceptualizing a system where the user will have little or no difficulty in navigating through it while interacting in the VR environment, perhaps with limited confusion, thereby increasing user experience. Other considerations focus on very particular factors such as usability, clarity, and comfort in a VR environment.

1. Key Principles of User-Friendly Design

- **Simplicity** The interface should focus on usability by displaying the relevant information and choices at the time. In addition, this will prevent complicated menus or too much information that could overwhelm a user, which is very critical to avoid in VR since it is important to be precise. This minimalist approach helps users focus on their tasks without distraction [1].
- **Consistency** Positioning menus, buttons, and icons in standard places across screens means that users can move around a system without constant reorientation. This makes it easier to use, with less learning required, since the user can anticipate the position of key elements [1].
- **Clear Visual Feedback** Any interaction of the user with the interface elements in VR should be immediately reflected by sight and hearing. For instance, buttons or options might change color or light up upon hover or selection, and soft sounds confirm the actions regarding completing tasks, etc. [1].

- **Accessibility** The interface should be made accessible for diverse users to navigate through it easily without difficulty. It also can include fonts that are easily readable and texts that scale for varied users [1] [2].

2. Key Points of User Interface Design

The following table describes some design considerations for developing an intuitive VR user interface. These features aim to ensure smooth navigation, ease of use, and customization for an optimal VR experience.

Main Menu	The main menu should be radial in appearance and directly forward in the field of view of the user, from which the user will derive many of the key features: clicking/playing interactive scenarios, reviewing progress, adjusting settings, etc. This is done for ease of interaction, whereby users can easily reach out and tap on their choice without over-movement of the head, hands, and more gestures. **Key Features:** Clearly labeled buttons that users can click using VR controllers [4].
Information Display	Enough information should be provided to the learner so that he or she can judge his or her status and make appropriate decisions [4].
Visual and Interaction Cues	In a VR setting or environment, there is much need for visual and interaction cues to help users navigate. For instance, interactive objects must be highlighted, and buttons will react on hover or click; progress indicators will show the user where they are in tasks. **Key Features:** Using glowing objects for the indication of which objects are actionable [7].
Setting Menu	The design for the settings menu should be minimalistic. In a case where the user wants to make some changes in the

	settings, such as setting volume or changing the clarity of the visuals, a small panel appears with options to "Resume," "Exit," and "Settings." This menu should not be intrusive and easily reachable. **Key Features:** Large buttons that are easily clickable with clear labels to define primary actions. Always available using a specific button on the VR controller [4].
Input Method	The input methods should be designed to be easily managed and have appropriate sensitivity and response [5].
View Layout	The visual presentation should give the learner a clear a glance view of the visually relevant information [6].
Customization	The interface should be designed in such a way as to allow the learner to customize aspects of the user interface to some degree [4].

Table. The table shows key points of User Interface (UI) design in VR

3. Considerations Specific to VR Design

- **Optimization of the Field of View** In consideration of the constraints that VR presents, some of the elements should be considered. For instance, menus, icons, and buttons should be in the natural field of view of users to avoid fatigue or motion sickness apart from discomfort. Position various elements at comfortable distances and angles to avoid extreme movements or gestures by users in visualizing interactive elements in the VR environment [8].
- **Visual Clarity and Readability** Although the resolution of some Virtual Reality headsets is not that sharp compared to conventional displays, all text and icons must be of such size and contrast to ensure that a user can

comfortably read through menus without visual fatigue while navigating the platform.

- **Key Features:** Large buttons, readable fonts with high-contrast text-to-background ratios [8].

Summary of the Design Concept

While designing an intuitive and user-friendly interface for VR; simplicity, consistency, and accessibility should be considered along with the limitations of VR environments when designing a user-friendly and accessible interface for seamless navigation in VR [2]. The easy-to-reach menus with clear visuals allow for smooth interaction of users with the platform. Visual feedback, clear task guidance, and an intuitive layout make the interface accessible to a wide range of users.

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2.1.10 Accessibility Features: to be decided

- Ensure accessibility standards compliance for users with disabilities
- Provide options for speech-to-text, screen readers, and customizable settings

2.1.11 Data Analytics and Reporting:

- Implement analytics tools to track user engagement, progress, and performance

Those could be inspired by any LMS platforms, because they have these tools for teachears.

Grades

Every course has its own Gradebook which is accessible from Course administration > Gradebook setup. Some activities such as Assignment and Quiz send grades back to this gradebook. It is also possible for teachers to enter grades directly into the gradebook.

Competencies

Competencies describe the level of understanding or proficiency of a learner in certain subject-related skills. Competency-based education (CBE), also known as

Competency-based learning or Skills-based learning, refers to systems of assessment and grading where students demonstrate these competencies.

Activity completion

If Activity completion is enabled by the administrator and in the course settings, teachers can indicate for each course item how they wish it to be registered as complete. A tick/checkmark will then appear against the activity. Students may either mark it complete manually or the item will automatically be registered as complete once a student has met the specified criteria. These may be viewing a resource, submitting an assignment, posting in a forum or other conditions. The teacher can see an overview of who has completed what in the activity completion report in Course administration > Reports > Activity completion.

Course completion

As an extension of activity completion, enabling Course completion allows for a course to be officially marked as finished, either manually or automatically according to speficied criteria. If the Course completion status block is added, students can see their progress during the course. Teachers can view the overall progress of students towards course completion from Course administration>Reports>Course completion.

Badges

Badges can be awarded either manually or using activity completion settings in a course and are a popular way to motivate students. Students may be awarded badges at different stages of the course for different levels of progress.

Course reports

A number of Course reports are available to the teacher in their course to help them track the progress of their students. In addition to the activity and course completion reports mentioned above (which are only available if these settings are enabled) there are also activity reports, participation reports and general course logs.

Analytics

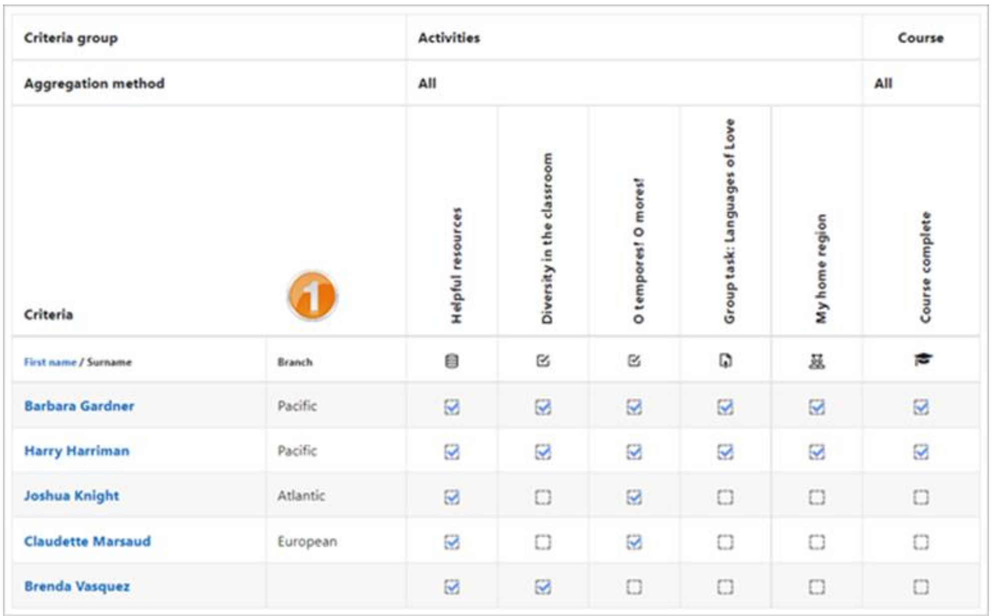
The Analytics feature provides detailed descriptive and prescriptive reports to support learners at risk.

* All those features should be available for both students and teachers.

- **Generate reports on course completion rates, assessment scores, and user feedback.**

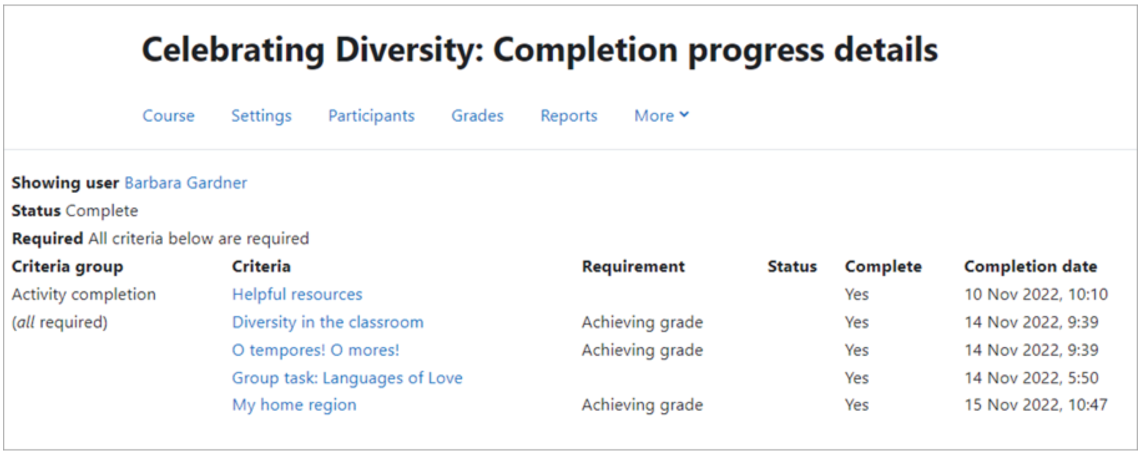
When Course completion is enabled from '**Course navigation > More > Course completion'**, the course completion report becomes available from *Course navigation > Reports.*

The course completion report can include custom profile fields, if selected from Site administration > Users > User policies > Show user identity. See example in the screenshot below:



Criteria group		Activities					Course
Aggregation method		All					All
Criteria		Helpful resources	Diversity in the classroom	O tempores! O mores!	Group task: Languages of Love	My home region	Course complete
First name / Surname	Branch						
Barbara Gardner	Pacific	☑	☑	☑	☑	☑	☑
Harry Harriman	Pacific	☑	☑	☑	☑	☑	☑
Joshua Knight	Atlantic	☑	☐	☑	☐	☐	☐
Claudette Marsaud	European	☑	☐	☑	☐	☐	☐
Brenda Vasquez		☑	☑	☐	☐	☐	☐

When viewing the completion information of a specific user, the time of completion is displayed alongside the date.



Celebrating Diversity: Completion progress details

Course Settings Participants Grades Reports More

Showing user Barbara Gardner
Status Complete
Required All criteria below are required

Criteria group	Criteria	Requirement	Status	Complete	Completion date
Activity completion	Helpful resources			Yes	10 Nov 2022, 10:10
(*all* required)	Diversity in the classroom	Achieving grade		Yes	14 Nov 2022, 9:39
	O tempores! O mores!	Achieving grade		Yes	14 Nov 2022, 9:39
	Group task: Languages of Love			Yes	14 Nov 2022, 5:50
	My home region	Achieving grade		Yes	15 Nov 2022, 10:47

Note: The course completion report is different from the Activity completion report. If you need to manually complete an activity, you should do this from the Activity completion report.

If manual self completion or manual completion by others is enabled, then those columns will appear in the course completion report. The user with the role allowed to manually complete the course on behalf of the student will be able to mark it complete in the course completion report.

2.1.12 Security and Privacy Measures:

Security and Privacy Measures refer to the strategies, protocols, and regulations implemented to safeguard sensitive data and ensure user privacy within a digital platform. These measures encompass a range of techniques, including data encryption, user authentication, and secure transmission protocols like Transport Layer Security (TLS), which protect data from unauthorized access and tampering during transmission. Effective security measures are crucial for maintaining the integrity and confidentiality of data, especially when handling personal information or sensitive research data.

In addition to technical protocols, privacy measures also involve adhering to legal frameworks such as the General Data Protection Regulation (GDPR). These regulations ensure that user data is collected, stored, and processed transparently and securely. Compliance with GDPR gives users control over their personal data, providing them with rights to access, correct, or delete their information, thereby fostering trust and accountability in the platform.

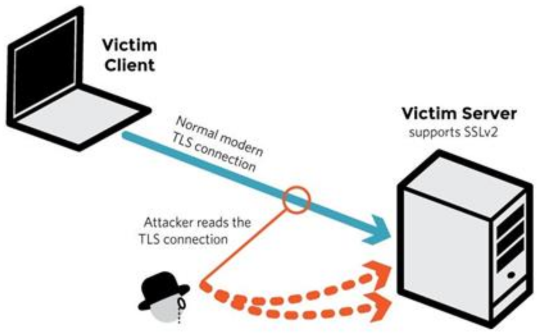
Transport Layer Security (TLS) ensures the secure transmission of data across the platform. By encrypting data in transit, TLS prevents unauthorized access, tampering, and eavesdropping. All communication between users and the virtual living lab platform must use TLS to protect sensitive information like login credentials, personal data, and experimental results.

Transport Layer Security (TLS) is an essential protocol for ensuring that data transmitted between users and the virtual living labs platform remains confidential and secure. TLS encrypts the data during transmission, making it unreadable to unauthorized third parties who may attempt to intercept it. This encryption is vital for protecting sensitive information such as login credentials, personal data, experimental data, and system communications.

TLS works by creating a secure, encrypted tunnel between the client (user's device) and the server (the platform). This is achieved through a handshake process, where both parties authenticate each other and agree on an encryption method before data transfer begins.

Example of TLS in Action:

Imagine a researcher logging into the virtual living lab to access experimental data. Without TLS encryption, a hacker could potentially intercept the data, gaining access to sensitive research results or user credentials. However, with TLS in place, even if the data were intercepted, it would be unreadable due to the encryption, ensuring that the researcher's information remains protected.



Key features of TLS encryption include:

- **Data Integrity**: Guarantees the data is not altered during transmission.
- **Authentication**: Verifies the identity of the communicating parties.
- **Confidentiality**: Ensures that data is only accessible by authorized entities.

Most web browsers display a padlock icon in the address bar when TLS is active, signaling that the communication is secure. Implementing TLS is a fundamental security measure for safeguarding data in transit within virtual living labs and other online platforms.

Comply with General Data Protection Regulation (GDPR) for user data protection.

To protect users' personal data, the platform must adhere to the General Data Protection Regulation (GDPR). Compliance with GDPR ensures that users' rights to privacy are maintained and that their personal information is processed legally and transparently.

The General Data Protection Regulation (GDPR) is a legal framework designed to protect the privacy of individuals within the European Union (EU). For platforms like virtual living labs, GDPR compliance is not just a legal requirement but also an ethical responsibility to ensure that users' personal data is handled securely and transparently.

Core principles for GDPR compliance include:

1. **Lawfulness, Fairness, and Transparency:** Personal data must be processed in a legal, fair, and transparent manner. Users should be informed about how their data is used.
2. **Purpose Limitation:** Data should only be collected for specified, legitimate purposes and not processed in a way that is incompatible with those purposes.
3. **Data Minimization:** Only the data necessary for the specific purpose should be collected and processed.
4. **Accuracy:** Personal data must be accurate and kept up to date. Inaccurate data should be corrected or deleted.
5. **Storage Limitation:** Data should only be stored for as long as necessary for the purposes it was collected for.

6. **Integrity and Confidentiality:** Personal data must be processed securely to prevent unauthorized access, loss, or damage.
7. **Accountability:** Organizations must be able to demonstrate compliance with these principles and are responsible for ensuring data protection.

Example of GDPR Compliance:

Suppose a user participates in a virtual lab experiment. The platform must inform the user about the type of data being collected (e.g., experiment participation, location, and browsing habits), why it is collected, and how it will be used. Additionally, the user must provide explicit consent to these terms. If the user later decides they no longer want their data stored, they can exercise their "right to be forgotten" and request that all personal data related to them be permanently deleted from the platform.

By complying with GDPR, the platform ensures:

- **Transparency**: Users know exactly what data is being collected and for what purpose.
- **Control**: Users can manage their data, choosing what is shared and what should be deleted.
- **Accountability**: The platform takes full responsibility for the proper handling and protection of personal data.

Incorporating GDPR compliance and TLS protocols strengthens user trust and ensures that the platform operates securely and ethically, in line with global privacy standards.

2.2 Technical Requirements & Data Entry:

2.2.1 User Profiles:

Registration processes must be automated mainly by Moodle itself. Since Moodle already handles the user's name, email, organization, and job title, this should be transmitted to the VR platform when the user first accesses the platform via LTI or xAPI. In this sense, registration for the VR Platform is not needed.

- **Moodle**: Moodle will be the prime user's registration system. In Moodle, multiple user registration methods are allowed.

- **Profile Capture:**
  - Name: Full name of the user. Full name would be captured at the time of user registration.
  - Email: Email would be captured uniquely for each user purpose of authentication and communication.
  - Organization and Job Title: The Organisation and Job titles can be captured at the time of registration in Moodle. In Moodle, there is an option to add an extra custom profile field.
- **LTI Integration:** This is an integration through which the profile information of users who have registered on Moodle can be shared with the VR Platform via LTI. By sharing this information, one will get details such as names and emails. In this way, Single Sign-On capabilities would also be ensured; hence, the users will log in once and reach the VR environment without entering their credentials again and again.
- **Centralized User Management:** The user information is stored in Moodle. Once the user logs on to the VR platform, it will show the updates on a profile, for example, changes in job title, and organization via LTI.

VR Training Topics

- Users can choose their preferred VR training themes at the time of registration, or at any time via profile management in Moodle.
- Moodle's Course Management System allows users to enroll in a variety of courses that are associated with VR. A user, upon getting enrolled into a particular course, xAPI will track user activity within the VR platform.

Course Enrollment

- Moodle centralizes course enrollment. The moment the user enrolls for a course containing VR content, Moodle, using LTI or xAPI, links the user to the VR platform.
- When the user accesses a VR session via Moodle, their preferences (i.e., courses they have enrolled in) are used to provide personalized VR training experiences.

Notifications

- Moodle can manage notification preferences, including email updates on the availability of new VR content, course completions, and assessment grades.
- Users can adjust their notification preferences directly in Moodle, whereby notifications are customizable based on course activity or performance in the VR platform.

2.2.2 Course Materials:

VR modules for liquid penetrant testing with interactive simulations and scenarios

Technical Approach

The VR modules will simulate the whole process of liquid penetrant testing, ranging from preparation to application/inspection phases. Each user will interact with the tools and equipment to accomplish every step in the process in a virtual environment. The basic steps involved are applying the penetrants and identifying defects. Such modules will be designed using software that supports Virtual Reality development, such as Unity. These will subsequently be integrated into Moodle via LTI once they are developed. User interactions and performance are then followed via xAPI thereafter and logged on the Moodle LRS for further analytics. In addition to the VR modules, 3D models of essential equipment, parts, and defects will be created to enhance the learning experience.

These will be models for enabling the user to interact with virtual tools used in liquid penetrant testing. The users can be allowed to view defective models including cracks and welding faults in a virtual environment and practice their identification there. Such models need to provide hands-on practice by enabling the user to manipulate and inspect the parts as if performing tests. As with VR modules, the interactions of users with 3D models will be tracked with xAPI. The data will be synchronized with Moodle to ensure tracking of progress and measurement of learning outcomes. Integrating these interactive VR modules and 3D models will provide immersive learning; and interaction while ensuring performance data by all users are tracked for further analysis.

3D models of equipment

Technical Approach

The technical approach is to design and import new or existing 3D models of typical equipment and parts with built-in defects in liquid penetrant testing. For example, on the equipment side, the design will create or adapt 3D models of instruments like spray bottles, brushes, cleaning materials, and more from existing Unity assets since some commonly tested parts include metal surfaces, industrial components, and pipes. These, apart from the ones mentioned above, are defects that can be deemed to be detected in a normal fashion by liquid penetrant testing: cracks, leakages, or weld defects; hence designed as 3D models. These will later be integrated into the virtual environment to provide interactive learning whereby a user can manipulate, inspect, and interact with these objects. For instance, zoom in for a closer view of the surface defects or rotate the parts to practice how to conduct the inspection techniques properly. xAPI would track interactions of users in how they interact with the 3D models, showing the learner's progress, including the time spent inspecting parts or even success at identifying defects. This data will be synced with Moodle, allowing for monitoring and analysis of training effectiveness. Similarly, for the VR modules focused on liquid penetrant testing, interactive scenarios will be developed. These modules will be integrated with Moodle through LTI for seamless access, while xAPI will track user progress and performance.

2.2.3 Assessment and Progress Tracking:

- Quizzes, tests, and practical assessments for skill evaluation.

Quizzes and Tests

- The quizzes should feature multiple-choice, true/false, and scenario-based questions.
  - The questions could look like
    - "**Question 1**: "What is the primary purpose of liquid penetrant testing?"
      - A) To measure thickness
      - B) To detect surface-breaking defects
      - C) To assess material properties
      - D) To evaluate corrosion"

If the user selects B, show feedback: "Correct! Liquid penetrant testing is used to detect surface-breaking defects" and a progress bar on top should indicate user's advancement.

There should be a cloud database to store user profiles and progress data, ensuring that all updates are synced in real time as well as API endpoints for:

- Submitting quiz results.
- Updating user profiles.
- Fetching user progress and badges.

The system should be adaptive, adjusting every subsequent question based on user performance.

After a quiz, if a user scores below a certain threshold (e.g., 70%), the system could recommend:

- "You may benefit from reviewing the 'Penetrant Application Techniques' module before retaking the quiz."

Provide immediate feedback and adjust future assessments based on user responses.

Example: If a user consistently answers questions about "Defect Identification" correctly, the system could increase the complexity of those questions or introduce different topics.

Users must demonstrate proficiency in foundational topics before moving on to advanced concepts, such as: Completing the "Basics of Liquid Penetrant Testing" module and scoring at least 80% on the respective quiz before accessing more advanced topics. Users should spend less time on topics they already understand and more time on areas where they need improvement.

A checklist showing modules like "Module 1: Basics of Liquid Penetrant Testing" with a green checkmark if completed.

Award a badge for completing the first module, labelled "Beginner Tester", "Proficient Tester", "Advanced Tester" etc.

The environment should also include progress reports, like: "You have completed 4 out of 10 modules", "Your average quiz score is 85%", "You scored 4 out of 5 in your last practical assessment" etc.

The environment could optionally include some **gamification elements**, like leaderboards (Top Users: "1. User A - 95% average score; 2. User B - 90% average score" & update the leaderboard every time a quiz is completed).

- Tracking of completed modules, achievements, and earned badges.

4. **Collaborative Tools and Communication**:
   - Virtual classrooms for live lectures, workshops, and expert sessions.
   - Discussion forums, chat rooms, and messaging for peer interaction
5. **Feedback and Surveys**:
   - Surveys for course feedback, satisfaction ratings, and improvement suggestions.
   - Ratings and reviews for VR modules, instructors, and overall platform experience.
6. **Networking and Events**:
   - Profiles of industry experts, trainers, and guest speakers for networking.
   - Event calendar with details of workshops, conferences, and webinars.
7. **Resource Library**:
   - Repository of educational materials, research papers, and best practices in NDT.
   - Access to industry reports, case studies, and latest developments in the field.
8. **Administrative Controls**:
   - Dashboard for platform administrators to manage users, courses, and content.
   - Content moderation tools for reviewing and approving user-generated content.

2.3 Data Entry into Transnational VR Platform:

2.3.1 User Registration

- **New users create profiles with personal and professional information**
  - **Integration with Moodle:**
    - In the event of a new user signing up via Moodle, he/she is creating a profile that shall store personal and professional information such as name, e-mail, organization, job title, and role.
    - The same shall be stored in Moodle, which shall act as a master user database.
- **Seamless Data Transfer to the VR Platform:**
  - When a user creates an account in Moodle, using LTI his or her profile data securely enters the VR Platform. The advantage of this will be that users need only once to go through a registration process via Moodle and can access their data directly from the VR environment.
  - The very first time a user enters the VR platform; the user's information will be automatically pulled from Moodle. This would avoid double data entry and maintain consistency between Moodle and the VR Platform.
- **Profile Creation in the VR Platform:**
  - The VR platform shall receive and store user profile data through LTI. This would include Name, Email organization, and job title.
  - Profile Synchronization: If a change has been made to the Moodle information of the user it will instantly update that change on the LTI connection in the VR platform.

Specify training preferences, areas of interest, and notification settings

Managing Preferences in Moodle

Users can create their preferences during the user registration or by using the Moodle profile settings on

- **Choice of VR training topics:** Users identify areas of interest that they want to train.
- **Field of Interest:** Users can choose areas of interest.

- **Notification settings:** Users shall have choices of what kinds of notifications they will get, which may include: a) Upcoming Training Sessions Scheduled; b) New VR content made available; c) Assessments are completed

Course Enrollment in Moodle

- Enrolment into courses based on training preferences on Moodle would therefore allow the user to have access to VR-based courses.
- LTI Integration: Upon enrolment, Moodle would transfer the relevant course information to the VR platform via LTI so that the right content is provided to the user in the VR environment.

Customized VR Experience

- It uses the user preference passed from Moodle to make this experience customized in the VR platform. As an example, if a user shows that they are interested in engineering simulations, the VR platform then may underline related training scenarios or modules when the user logs in.

2.3.2 Course Enrollment:

- Users browse available VR modules and enroll in desired courses
- Track progress, completion status, and earned certifications within user profiles

2.3.3 Assessments and Quizzes:

- Users complete quizzes, tests, and practical assessments for skill evaluation.
- Receive immediate feedback on performance and access detailed results.

2.3.4 Collaboration and Communication:

- Participate in virtual classrooms, live lectures, and expert sessions.
- Engage in discussions, group projects

3. Evaluation & design of methodological and technical aspects of the VR application for PT NDT method

The project aims to create a transnational virtual reality platform to support training in non-destructive testing (NDT), with a particular emphasis on penetrant testing (PT). The goal is to develop an infrastructure that combines physical laboratories and virtual reality (VR) simulations to offer both practical and remote training.

The ambition is to build a network of Living Labs that connects physical laboratories in each partner country (Romania, Spain, Germany, Italy, and Portugal, with references being ISIM, CESOL, IPUNTO, BIBA, WALTER TOSTO, IIS, and EWF), so that the VR simulation platform can be used transnationally. The Living Labs, both virtual and real, must enable practical experimentation and real-time collaboration between students and trainers.

1. **Objective:** Provide NDT training with advanced technologies, particularly focusing on the simulation of PT tests through virtual reality, while leveraging a network of Living Labs to facilitate practical experimentation, real-time collaboration, and the sharing of best practices across partner countries.
2. **Scale:** The network will cover at least one laboratory in Romania, Spain, Germany and Italy, to have a sufficiently branched network, linking the infrastructures into a coherent and scalable system. This will allow for the flexible and interoperable management of growing training and technical needs.

1. **Physical Laboratories:**

The network of existing physical laboratories in the partner countries is the practical foundation for the project's success. IIS, ISIM and CESOL are already equipped to perform NDT tests and can serve as central nodes, while the other partner facilities need to be mapped to ensure adequate transnational coverage. The goal is to have equipped physical laboratories in each country, allowing both practical training experiences and the sharing of best practices internationally, standardizing operating procedures according to recognized standards such as ASTM and ASME. Necessary Resources are:

- **NDT Equipment:** Machinery and tools for performing penetrant tests, such as immersion tanks, UV lamps, and detection systems.
- **Training Spaces:** Classrooms and laboratories equipped to host workshops and practical sessions.
- **Qualified Personnel:** Instructors and technicians with experience in NDT testing and training.
- **Educational Materials:** Manuals, operating guides, and consumables for the tests.
- **Support Infrastructure:** Ventilation systems, safety, and waste management to ensure a safe and compliant working environment.

In Italy, IIS, thanks to its established facilities and expertise, can serve as a hub for NDT training. Its advanced equipment can host practical workshops for students and technicians, providing immersive on-site training. Strategically, IIS could take on the role of facilitator for integration between national and international laboratories, also leveraging collaborations such as the one with the TICASS consortium, to promote innovation and environmental sustainability in the sector. Similar models can be replicated in other partner countries of the project. Established knowledge and skills in NDT training also belong to CESOL, ISIM, and IPUNTO. The laboratories and/or training rooms of all these players can be strategically important to foster the development of a network of hubs that collaborate and interact closely despite significant geographical distances.

2. **Virtual Platform**

The VR platform represents the project’s fundamental digital element, enabling advanced simulations of NDT tests with penetrant liquids. Through this platform, users can perform exercises in a highly realistic, replicable, and safe virtual environment, overcoming geographical barriers. The platform must be able to simulate not only the techniques but also the operational details of NDT procedures. For these reasons, the following resources will be indispensable:

- **Hardware:** VR headsets, controllers, high-performance computers to support advanced graphics and real-time simulation.

- **Software:** Simulation programs that accurately replicate NDT tests, including modules for procedure management and result analysis.
- **Internet Connection:** High-speed lines to ensure real-time collaboration between different laboratories and users.
- **Technical Support:** IT personnel for the maintenance and updating of equipment and software.
- **Digital Educational Materials:** Tutorials, demonstration videos, and documentation accessible through the VR platform.

The use of a VR platform combined with the establishment of a transnational Living Lab (LL) can prove to be a powerful tool for training and innovation. Virtual reality (VR) allows the creation of immersive learning environments that simulate real situations, particularly useful for practical training, where users can experience complex scenarios in a safe and controlled environment. A transnational Living Lab facilitates collaboration between different institutions and countries, promoting the exchange of knowledge and skills that can lead to innovative solutions and shared best practices. Virtual platforms make training accessible to a wider audience, regardless of their geographical location, thus reaching remote or disadvantaged communities. Additionally, virtual training can be easily adapted to the specific needs of users, with content personalized for different levels of competence and learning styles.

The combination of VR and LL can accelerate the innovation process, allowing new ideas to be tested and refined in a virtual environment before being implemented in the real world. Users can acquire practical and theoretical skills more effectively thanks to the interactivity and immersion offered by VR, leading to a more qualified and prepared workforce. Virtual training can reduce the costs associated with traditional training, such as travel, accommodation, and physical materials, while a transnational LL can share resources and infrastructure, optimizing the use of available resources. VR platforms can provide immediate feedback to users, allowing them to correct mistakes and improve their performance in real-time. Finally, the use of virtual platforms reduces the environmental impact associated with traditional training, such as the use of paper and CO_2 emissions from travel.

3.1 required equipment for PT NDT experiments

3.1.1 Hardware and Equipment: -

Penetrant Testing (PT), a widely used Nondestructive Testing (NDT) method, requires specific equipment to ensure accurate results. Below is a list of the essential equipment:

1. Penetrant Materials:

- Penetrant: A liquid that is applied to the surface of the material. It can be either visible (dye penetrant) or fluorescent.
- Cleaner/Remover: Used to clean the test surface before the test and to remove excess penetrant after the dwell time.
- Developer: A fine white powder applied after the penetrant removal to draw out the penetrant from defects for easier visibility.

2. Inspection Booths/Stations:

- Inspection Booth: Enclosed space or station to control environmental factors like light and cleanliness. It is often used for testing parts under controlled lighting conditions, especially for fluorescent penetrants.

3. Lighting Systems:

- UV/Black Light Lamp: Required for inspections using fluorescent penetrants. The intensity must be 1000 μW/cm² and white light less than 20 lux.
- White Light: Necessary for visible dye penetrants. The required intensity is more than 500 lux.

4. Cleaners/Degreasers:

- Solvent-based or water-based cleaners for pre- and post-cleaning the surface to ensure contaminants like oil or grease do not interfere with the test results.

5. Penetrant Application Equipment:

- - Spray Guns or Aerosol Cans: Used to apply penetrant and developer evenly on the test surface.
- - Dipping Tanks: For submerging parts in penetrant for large-scale or batch testing.

6. Dwell and Drying Equipment:

- Dwell Tanks: For controlled penetration time.
- Oven/Drying Cabinet: Used to dry the surface after the cleaner or penetranis removed. The surface piece temperature must be between 10º to 50°C.

7. Inspection Accessories:

- Timer: To accurately measure dwell time, ensuring proper penetration.
- Thermometers: To monitor the temperature of penetrant materials, as extreme temperatures can affect the test's effectiveness.

8. Cleaning/Water Rinse Station (for water-washable penetrants):

- A rinse station with controlled water pressure is used to wash off excess penetrant from the part after the dwell period.

9. Magnifying Glass/Low Power Microscopes:

- For a more detailed view of fine indications (especially for critical parts).

10. Safety Equipment:

- Gloves, Goggles, and Respirators: For protection from chemicals during the testing process.
- Ventilation System: To remove hazardous fumes from penetrants and solvents, especially in enclosed inspection areas.

11. Calibration Blocks/Standards:

- Reference Test Panels: Used to verify system performance, ensuring the penetrant testing process works as expected.
- These items ensure a comprehensive and controlled Penetrant Testing process.

Overview of Required Equipment for PT NDT Experiments (VR)

The equipment needed for a PT NDT is presented above. What follows is a short description of how these main pieces of equipment will be realized in the VR:

1. **Penetrant Materials:**

These are to be modeled as dyed and fluorescent liquids. The tools also come with cleaning, removal, and developer applications.

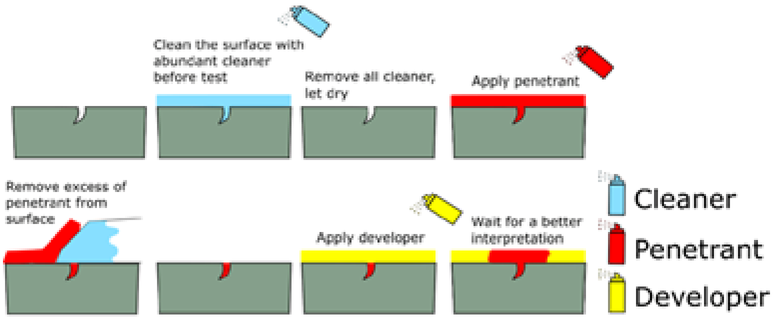


Fig. 27 Reference [1]

2. **Inspection Booths:**

In the interactive scenario design, there will be consideration of controls for lighting in the booths.

3. **Lighting Systems:**

White Light: Must be equal to or more than 500 lux for a final inspection.

4. **Cleaners/Degreasers:**

The VR models of solvent-based or water-based cleaners will be designed to pre- and post-clean the surface to make sure the test results are not interfered with by contaminants such as oil or grease.

5. **Penetrant Application Equipment:**

Models for both spray guns and dipping tank applicators will be designed to apply the penetrants and conduct the tests.

6. **Water Rinse Station:**

A rinse station/feature will be designed to allow users to wash off excess penetrant.

7. **Magnifying Glass/Low Power Microscopes:**

Virtual tools allow zooming into areas for detailed inspection.

References

i. OnestopNDT. (2024, April 10). Exploring dye penetration testing. https://www.onestopndt.com/ndt-articles/dye-penetration-testing.

To ensure the availability of penetrant materials, cleaning agents, and inspection tools for a Penetrant Testing (PT) setup, follow these steps:

1. Inventory Management:

- Stock Penetrant Materials: Keep an inventory of various types of penetrants (fluorescent and visible) to match the needs of different testing scenarios.
- Ensure Adequate Cleaner/Remover: Stock up on solvent-based and water-based cleaners based on the types of materials being tested.
- Supply of Developer: Maintain sufficient quantities of dry, non-aqueous, or water-based developers.

2. Supplier Coordination

- Establish Reliable Suppliers: Develop relationships with multiple suppliers to ensure consistent access to high-quality penetrant materials, cleaning agents, and tools.
- Create Reordering Protocols: Implement automatic reordering triggers when supplies fall below a minimum threshold to avoid shortages.

3. Inspection Tools and Equipment

- Maintain and Calibrate UV/Black Light and White Light: Ensure that sufficient lighting equipment is available and regularly calibrated for inspections.
- Monitor Expiry Dates of Consumables: Regularly check the expiration dates on penetrant, cleaner, and developer containers. Store them under proper conditions to prolong shelf life.

4. Routine Equipment Maintenance

- Check and Maintain Application Tools: Periodically check spray guns, aerosol cans, and dipping tanks for wear and tear.
- Inspect and Clean Drying Ovens and Rinse Stations: Regular maintenance ensures these systems operate correctly, preventing testing delays.

5. Organized Storage

- Categorize Materials: Store different types of penetrants, cleaners, and developers separately in labeled, well-organized containers to ensure easy access.
- Safety and Compliance: Ensure all chemicals and materials are stored following safety regulations and Material Safety Data Sheets (MSDS) requirements.

By keeping a well-managed inventory, maintaining reliable supplier connections, and regularly inspecting and maintaining equipment, you can ensure the continuous availability of all penetrant testing materials and tools.

3. **Virtual Lab Environment Creation**:

- Design 3D models of lab setups, equipment, and workstations for virtual simulation.
- Include accurate representations of inspection booths, part fixtures, and defect specimens.

4. **Simulation Parameters and Settings**:

- Define parameters for penetrant application methods (e.g., immersion, spray, brush).

Non-destructive liquid penetrant testing (PT) is widely used for detecting surface defects such as cracks, porosity, and other discontinuities in non-porous materials. The process involves applying a liquid penetrant to the surface of a test object, allowing it to seep into surface-breaking flaws. The excess penetrant is then removed, and a developer is applied to draw out the penetrant from the flaws, making them visible under inspection conditions (typically with UV light for fluorescent penetrants or visible light for dye penetrants).

Different application methods can be used depending on the nature of the part being inspected and the size and shape of the defect. Below are the primary methods of applying penetrants in LPT, along with their parameters:

1. Immersion Method

- **Description**: The test object is immersed in a tank filled with liquid penetrant for a specific period. This allows the penetrant to seep into any surface flaws by capillary action.
- **Parameters**:
- **Penetrant dwell time**: This is the time the object remains in contact with the penetrant, usually ranging from 5 to 60 minutes, depending on the material and the flaw size. It is not necessary to submerge the specimen during all penetrant dwell time.
- **Penetrant type**: Can be either fluorescent or dye-based, depending on the inspection requirements.
- **Temperature**: The temperature of the penetrant and the part should be within the recommended range (10ºC-50ºC) to ensure proper viscosity.

- **Part cleanliness**: The part must be thoroughly cleaned to remove any contaminants before immersion, as dirt, oils, or debris can block the penetrant from entering surface flaws.
- **Advantages**: Suitable for parts with complex geometries or high volumes of small parts.
- **Disadvantages**: Requires a large amount of penetrant and is not practical for very large components.

2. Spraying Method

- **Description**: Penetrant is applied to the test object using a spray nozzle or aerosol. This method is used when immersion is impractical or for localized inspections.

- **Parameters**:

- Spray pressure and distance: The pressure of the spray should be sufficient to cover the surface without removing or displacing the penetrant too quickly. The typical distance is around 15-30 cm from the surface.
- Application uniformity: It is essential to ensure an even and complete coverage to avoid missed defects.
- Penetrant dwell time: After application, the penetrant is allowed to sit on the surface for the required dwell time.
- Environmental conditions: Humidity, temperature, and airflow can affect penetrant performance, especially for solvent-based sprays.

Advantages: Allows for controlled application and is ideal for large or irregularly shaped parts that cannot be immersed.

Disadvantages: Potential for overspray, waste, or incomplete coverage on complex geometries.

3. Brushing Method

Description: The penetrant is applied by brushing it onto the surface. This is often used for small areas, parts with intricate details, or when only a specific part of the component needs inspection.

Parameters:

- Brush type: Use soft brushes that do not scratch or damage the surface. The brush should also not leave residues that could block penetrant entry.

- Penetrant viscosity: The consistency of the penetrant needs to be thick enough to stay on the surface but thin enough to seep into cracks.
- Dwell time*: Brushed-on penetrants may require slightly longer dwell times than immersion or spray methods because the coating tends to be thicker.

Advantages: Simple and cost-effective, especially for spot inspections or areas that are hard to reach with other methods.

Disadvantages: Time-consuming for large surfaces and may result in uneven coverage if not applied properly.

4. Flowing/Pouring Method

Description: Penetrant is poured or allowed to flow over the part's surface, often used for horizontal surfaces or when it is not feasible to immerse the part.

Parameters:

- Flow rate: The flow should be slow and steady to ensure proper coverage and penetration without causing turbulence that might prevent the penetrant from settling into flaws.
- Penetrant recovery: Excess penetrant should be collected and recycled, if possible, which requires proper containment around the part.
- Dwell time: This method generally uses the standard dwell times for penetrant application, depending on the material and defect type.

Advantages: Useful for large, flat, or horizontal surfaces where immersion or spraying is difficult.

Disadvantages: Can be wasteful if not properly controlled, and it may be hard to achieve even coverage on irregular surfaces.

5. Dipping Method

Description: Similar to immersion method but, used for smaller parts that can be dipped into a container of penetrant manually. This method is often used for batch testing small components.

Parameters:

- Penetrant volume: The container must have enough penetrant to submerge the part completely.
- Dwell time: Standard dwell times apply, with parts dipped for a few minutes and then left to allow full penetration.
- Part preparation: As with other methods, parts must be clean before dipping.

Advantages: Simple and quick for small parts; no need for expensive equipment.

Disadvantages: Limited to small parts and may not work well for complex geometries.

6. Roller Application Method

- Description: A roller saturated with penetrant is used to apply the liquid onto large or flat surfaces. This is an alternative to spraying and brushing.

Parameters:

- Roller material: The roller must be compatible with the penetrant type and should be soft enough not to damage the surface.
- Roller coverage: Ensure the roller is adequately saturated and the application is even.
- Dwell time: Standard dwell times apply, though this method may require reapplication if the initial coverage is uneven.

Advantages: Good for large flat surfaces where immersion or spray application is inefficient.

Disadvantages: Roller may not work well for curved or highly detailed surfaces.

7. Penetrant Injection (for Specific Applications)

Description: In cases of sealed cavities or very fine cracks, the penetrant may be injected using a syringe or pressurized system.

Parameters:

- Injection pressure: Should be controlled to prevent forcing penetrant too deep or missing shallow defects.
- Dwell time: Varies based on the method of injection and the size of the flaw.

Advantages: Very effective for pinpointing localized defects in specific areas.

Disadvantages: Not practical for large surfaces, and specialized equipment may be required.

Summary of Key Parameters Across All Methods:

- Penetrant Type: Either visible dye penetrants (for white light inspection) or fluorescent penetrants (for UV light inspection).
- Dwell Time: Varies based on the material, penetrant, and defect type (between 5-60 minutes).
- Surface Preparation: Proper cleaning before application is essential to remove oils, rust, and contaminants that can block penetrant entry.
- Removal Method: Penetrants are removed either with water, solvent, or emulsifiers depending on the penetrant type.
- Developer Application: After excess penetrant is removed, a developer is applied to draw penetrant from flaws to the surface for easier detection.
- Inspection Conditions: Use UV or visible light depending on penetrant type and environment, ensuring good visibility for flaw detection.

These methods are selected based on the material, geometry, size of the part, and the defect types being inspected.

  - Set variables such as dwell time, temperature, and agitation for accurate simulation.

In non-destructive liquid penetrant testing (PT), achieving accurate and consistent results requires careful control of several key variables. These variables influence the penetrant's ability to detect surface-breaking defects and ensure the test's sensitivity and repeatability. The most critical variables include dwell time, temperature, and agitation. Here is a detailed explanation of these variables, including other relevant factors for simulating an accurate PT process:

1. Dwell Time

Dwell time refers to the amount of time the penetrant is allowed to remain on the surface of the test object to penetrate any flaws.

Proper dwell time ensures that the penetrant has sufficient time to enter surface defects through capillary action. Too short a dwell time might result in incomplete penetration, while too long may cause the penetrant to dry out or make removal more difficult.

Key Factors:

- Material of the Test Object: Porous or rough surfaces may require a longer dwell time to ensure full penetration into surface defects.

- Type of Defects: Smaller, tighter cracks may need a longer dwell time compared to wider, more open defects.
- Penetrant Type: Different penetrants (e.g., water-washable, solvent-removable, post-emulsifiable) may require different dwell times, must be between 5 and 60 minutes.
- Part Geometry: Complex shapes or areas with multiple surfaces may require adjusting the dwell time to ensure uniform penetrant coverage.
- Recommended Dwell Times:
- Fine cracks: 20-60 minutes
- Larger or shallow defects: 5-20 minutes
- Temperature conditions: normaly range is between 10ºC-50ºC. Extreme cold or heat can alter dwell time (increase in colder environments).

2. Temperature

The temperature of both the test surface and the penetrant during the testing process. Temperature affects the viscosity, the speed of capillary action, evaporation rate of the penetrant, and developer performance.

Key Factors:

- Optimal Temperature Range: The recommended temperature range for most penetrants is 10ºC-50°C. Outside this range, the penetrant's effectiveness can be reduced due to changes in viscosity or excessive evaporation.
- Low Temperatures: Penetrant viscosity increases in cold temperatures, reducing its ability to flow into defects. Therefore, dwell time may need to be extended.
- High Temperatures: At higher temperatures, penetrants become less viscous and may evaporate faster, reducing the dwell time and possibly causing drying before adequate penetration. This can also lead to the breakdown of certain chemicals in the penetrant.
- Part Preconditioning: For parts with temperatures outside the optimal range (either too cold or too hot), preconditioning to bring them into the acceptable range is essential for accurate testing.

3. Agitation

Movement or stirring of the penetrant to ensure uniform contact with the test surface during immersion or dipping methods.

Agitation enhances the penetrant's ability to contact all surfaces uniformly and can improve penetration into defects, especially for complex geometries.

Key Factors:

- Type of Agitation: Common methods include mechanical stirring, circulation pumps, or manual shaking of small parts in the penetrant bath.
- Agitation Frequency: Over-agitation can introduce air bubbles or cause splashing, which may result in incomplete or uneven coverage. Gentle but consistent agitation is typically recommended.
- Effect on Penetration: For smaller or tighter defects, agitation can help drive the penetrant into surface cracks, improving defect visibility.
- Application Method: In immersion techniques, agitation helps to ensure the penetrant reaches all surfaces. In spraying or brushing methods, agitation is generally unnecessary or minimal.

4. Penetrant Viscosity

- Definition: The thickness or fluidity of the penetrant, which affects how easily it flows into surface defects.
- Importance: Viscosity directly affects the penetrant's ability to enter fine cracks and other surface discontinuities.

Key Factors:

- Temperature-Related Viscosity Changes: As temperature increases, viscosity decreases, making it easier for the penetrant to flow into defects but also increasing evaporation risk. Lower temperatures increase viscosity, requiring more dwell time.
- Penetrant Type: Thicker, higher-viscosity penetrants may be better suited for larger defects, while lower-viscosity penetrants are more effective for detecting finer flaws.
- Material Surface: Rough or porous surfaces may require thicker penetrants to ensure adequate coverage without running off too quickly.

5. Surface Preparation

The process of cleaning the test surface before applying the penetrant.

Any contaminants (e.g., oils, dirt, rust, or previous coatings) can prevent the penetrant from entering surface defects, leading to missed indications.

Key Factors:

- Surface Condition: Surfaces must be free of contaminants, and pre-cleaning methods such as solvent wiping, abrasive cleaning, or ultrasonic cleaning may be used depending on the material and application.

- Post-Cleaning Inspection: After cleaning, it's essential to verify that no residues remain that could block the penetrant. Ultrasonics or UV light can be used to detect residues.

6. Penetrant Application Method

The technique used to apply the penetrant to the test surface (immersion, spraying, brushing, pouring, etc.). The application method affects how well the penetrant covers the surface and penetrates defects.

Key Factors:

- Uniformity of Application: Regardless of the method, even application is critical to ensure that all surface defects are exposed to the penetrant.
- Surface Coverage: Ensure complete coverage, especially in complex geometry or areas with difficult access.

7. Penetrant Removal

The process of removing excess penetrant after the dwell time has elapsed.

Proper removal ensures that only penetrant trapped in defects remains for detection while avoiding excessive removal that could also remove penetrant from shallow defects.

Key Factors:

- Water-Washable Penetrants: Require careful rinsing to avoid washing penetrant out of defects. Use controlled water pressure and temperature.
- Solvent-Removable Penetrants: Require solvents to remove the excess penetrant. Avoid overuse of the solvent to prevent removing penetrant from the defects.
- Post-Emulsifiable Penetrants: These require an emulsifier to be applied before water washing. Emulsification time is critical to avoid premature or incomplete removal of excess penetrant.

8. Developer Application

After removing excess penetrant, a developer is applied to draw penetrant from defects and create visible indications.

The developer helps bring the penetrant to the surface, forming a contrast against the background for easier detection.

Key Factors:

- Developer Type: Dry powder, water-soluble, or solvent-based developers are used depending on the penetrant system and the testing environment.
- Developer Dwell Time: Allow time for the developer to draw penetrant from the defects, typically 10-30 minutes.
- Environmental Conditions: Humidity, temperature, and air currents can affect the performance of the developer.

9. Inspection Conditions

The lighting and inspection conditions under which the test object is examined for defects. Proper lighting is essential for detecting indications.

Key Factors:

- Lighting Type: For fluorescent penetrants, UV-A light (365 nm wavelength) is used. For visible dye penetrants, white light is required.
- Light Intensity: Adequate light intensity (typically 1,000 μW/cm² at least of UV light and less 20 lux of white light, for fluorescent penetrants and 500 lux at least of white light for visible dye penetrants, is critical to ensure proper visibility of indications.
- Ambient Conditions: Dark environments are necessary for fluorescent penetrant inspections to prevent interference from other light sources.

Summary of Key Variables:

- Dwell Time: 5-60 minutes, depending on material, defect size, and penetrant type.
- Temperature: 10ºC-50°C; avoid extreme temperatures to prevent viscosity changes.
- Agitation: Gentle, consistent movement for immersion methods to ensure even coverage.
- Viscosity: Affects penetration time; lower viscosity penetrants are suitable for fine cracks.
- Surface Preparation: Clean surfaces are critical for accurate results.
- Penetrant Application: Uniform coverage with methods such as spraying, immersion, or brushing.
- Penetrant Removal: Controlled process to avoid removing penetrant from defects.
- Developer Application: Time and technique for drawing penetrant from defects into visible indications.
- Inspection Conditions: Proper lighting for detecting indications (UV for fluorescent, white light for visible dye).

Careful control and monitoring of these variables ensure the accuracy and reliability of the liquid penetrant testing process.

3.1.2 Data Collection and Analysis:

Capturing detailed data throughout the PT process is essential for ensuring the accuracy, traceability, and reproducibility of inspection procedures. Here's an overview of how data is captured during the PT process, emphasizing both inspection procedures and defect identification.

1. Pre-Inspection Documentation

- Before conducting the PT process, relevant data about the material and inspection conditions must be documented. This includes:
- Component Information: Details about the component being tested (e.g., material type, size, shape, and surface finish).
- Inspection Standards: Reference to applicable codes and standards (e.g. ISO 3452-1 to 6) that govern the inspection.
- Inspection Environment: Temperature, humidity, and lighting conditions during the test.
- Penetrant Type: Specific penetrant formulation used (visible dye, fluorescent, water-washable, solvent-removable, etc.).
- Surface Preparation Method: Methods used for cleaning or preparing the surface (e.g., chemical cleaning, grit blasting).

2. Data Captured During the LPT Procedure

During the PT process, a variety of data points are collected to monitor and record the inspection step-by-step:

- **Penetrant Application Data**:

  - Penetrant Dwell Time: The time that the penetrant is allowed to sit on the surface after application. This is crucial for ensuring penetration into surface discontinuities.
  - Penetrant Application Method: Whether the penetrant was applied by spraying, brushing, or dipping.
  - Penetrant Removal Method: How excess penetrant was removed (water-rinse, solvent wipe, or post-emulsification). The pressure and time for rinsing, in case of water-washable penetrants, is also recorded.

- **Developer Application Data**:

- Developer Type: The type of developer used (dry powder, aqueous, solvent-based).
- Application Method: How the developer was applied (spraying, dipping, immersion).
- Developer Dwell Time: Time allowed for the developer to sit on the part, allowing any trapped penetrant to be drawn to the surface.

- **Inspection Timing**:

- Post-Developer Inspection Time: Time allowed after developer application before the inspection is carried out. This timing is critical for optimizing defect visibility.

3. Defect Identification Data Capture

During the inspection phase, where defects become visible under specific conditions (e.g., visible dye under white light, fluorescent penetrant under UV light), the following defect-related data is captured:

- **Defect Location**: Precise location of any observed defects relative to the part's dimensions and geometry. This may be captured visually, through images, or by using a digital system like coordinates or referencing a part drawing.

- **Defect Size**: Measurement of the defect's dimensions (length, width) using appropriate tools such as a caliper or microscope, where necessary.

- **Defect Type**: Classification of the defect, such as:

- Cracks (linear indications)
- Porosity (round, grouped indications)
- Lack of fusion
- Corrosion pitting
- Seams

- **Indication Type**: Whether the observed indications are relevant (true defects) or non-relevant (caused by contamination, geometry-related false positives).

- **Severity of Defect**: Assessment of the defect's potential impact on the component's integrity, determined through classification codes (e.g., minor, moderate, or critical) based on applicable standards.

4. Data Recording and Reporting

- Accurate documentation is essential for traceability and further analysis. The following types of data are generally recorded:

- Visual Documentation: Photographic evidence or video recordings of defect indications, especially for critical defects.
- Inspection Results: The outcome of the inspection (pass, fail, or further investigation required). Detailed notes on which parts were rejected or passed based on defect criteria.

- Inspector Information: The name, certification level, and signature of the inspector conducting the test.
- Inspection Report: The full report containing all procedural steps, recorded data, observed defects, and any conclusions. Reports are typically stored electronically for easy retrieval and compliance purposes.

5. Advanced Data Capture Techniques

Advanced data capture systems are increasingly integrated into modern LPT practices to improve accuracy and traceability:

- Digital Imaging: High-resolution cameras and image processing software are used to capture and analyze defect images, providing digital records of the surface condition.
- Data Logging Systems: Automated systems that log dwell times, pressure values, temperature, and other key parameters throughout the process.
- AI and Machine Learning: Emerging technologies that assist in identifying defects by comparing visual patterns against a database of known defect profiles.

6. Post-Inspection Analysis

After the inspection is completed, additional analysis and data review are often carried out:

- Defect Characterization: Further classification and analysis of defects, potentially using other NDT methods (e.g., ultrasonic testing) to assess the depth and severity.
- Statistical Analysis: For large volumes of inspections, statistical data may be analyzed to identify trends in defect occurrence, which can be useful for predictive maintenance.
- Corrective Actions: Information on any corrective actions that were taken or recommended based on defect findings, such as reworking or repairing parts.

Conclusion

Data capture in liquid penetrant testing is a critical part of ensuring the accuracy, repeatability, and reliability of the inspection process. It involves documenting the entire process from pre-inspection setup to defect identification and reporting. Advances in digital tools, imaging systems, and data logging are improving the quality and consistency of PT data capture, making it easier to trace defects and meet regulatory or industry standards.

3.1.3 Analyze results for accuracy, sensitivity, false indications, and defect sizing. -

In Penetrant Testing (PT), the accurate collection and analysis of data are vital for determining the presence and characteristics of surface defects. Key factors to consider include the accuracy of the test, the sensitivity of the inspection to small defects, the identification of false indications, and the sizing of actual defects. Below is a detailed explanation of how data is collected and analyzed for these aspects.

1. Data Collection in PT

Data collection during the LPT process involves capturing information throughout each step of the inspection procedure. This includes pre-inspection, penetrant application, inspection, and post-inspection steps.

a. Pre-Inspection Data Collection

- Surface Condition: Information about the surface preparation of the test object, including cleaning methods (e.g., chemical cleaning, abrasive blasting), which influences defect visibility.
- Environmental Conditions: Temperature, humidity, and lighting conditions are recorded, as they can affect the penetrant's performance and test sensitivity.
- Component Information: Material type, geometry, and any pre-existing information about potential areas of interest (e.g., weld joints, high-stress zones).

b. Penetrant Application Data Collection

- Penetrant Type and Manufacturer: Specific penetrant used, along with its batch number and expiration date, ensuring traceability.
- Dwell Time: The time during which the penetrant is allowed to seep into surface flaws. Accurate timing is critical for sensitivity.

- Penetrant Removal Method: The method used to remove excess penetrant (water, solvent, or emulsifier) is recorded, as improper removal can lead to false indications.

c. Developer Application Data Collection

- Developer Type: Whether a dry, wet, or non-aqueous developer was used.
- Developer Dwell Time: The time allowed for the developer to draw the penetrant back to the surface and enhance defect visibility.

d. Inspection and Defect Identification

- Visual Data Capture: Inspectors observe the surface under white light (for visible dyes) or UV light (for fluorescent dyes). High-resolution cameras may be used to capture images of defect indications.
- Defect Size Estimation: Defects are sized visually or using tools like magnifying lenses, calipers, or image analysis software.
- Indication Characteristics: The inspector records information on the size, shape, location, and brightness (in case of fluorescent penetrants) of the indications.

2. Data Analysis for Accuracy, Sensitivity, False Indications, and Defect Sizing

Once data is collected, it is analyzed to ensure the reliability of the results. The main goals of analysis are to assess accuracy, ensure sensitivity to small defects, distinguish between false indications and real defects, and accurately determine defect size.

a. Accuracy Analysis

Accuracy in PT involves comparing the detected defects against known standards and actual conditions.

- Calibration: Equipment, such as UV lights and timing devices, is calibrated to ensure consistent performance. Data on calibration status is reviewed as part of the accuracy assessment.
- Inspector Skill Level: Analysis may include reviewing the inspector's qualification (Level I, II, or III) and prior performance history. Experienced inspectors are more likely to achieve accurate results.
- Defect Confirmation: Critical indications are often re-inspected or compared with results from other NDT methods (e.g., magnetic particle testing or ultrasonic testing) to confirm the accuracy of the defect findings.

- Review of Test Conditions: Analyzing whether environmental factors (e.g., incorrect lighting or temperature) could have influenced the accuracy of the inspection.

b. Sensitivity Analysis

Sensitivity refers to the LPT’s ability to detect small or fine defects.

- Penetrant Sensitivity Level: Penetrants are graded by sensitivity, with fluorescent penetrants typically being more sensitive than visible dye penetrants. Data on the sensitivity level used is compared with the expected defect size.
- Dwell Time Review: Data on dwell time is analyzed to ensure it was adequate for the expected defect size. Short dwell times may reduce sensitivity, while excessively long times can cause issues such as bleed-out.
- Developer Performance: Data on the type and performance of the developer is analyzed to ensure it sufficiently enhanced defect visibility, especially for fine or tight cracks.
- Defect Size vs. Sensitivity: A comparison is made between the smallest defect detected and the known capabilities of the chosen penetrant and developer system to ensure it meets the sensitivity requirements.

c. False Indications Analysis

False indications are non-relevant markings that appear during PT, which are not true defects. These can arise from surface roughness, improper cleaning, or penetrant entrapment in non-defect-related areas.

- Surface Preparation Data: Improper cleaning or poor surface preparation can lead to false indications. Data is analyzed to check whether appropriate cleaning methods were used.
- Indication Characteristics: The characteristics of the indications are carefully reviewed. Non-relevant indications often have irregular shapes, are located in non-critical areas, or do not correspond to known stress areas on the part.
- Indication Remediation: Data may be reanalyzed after suspect indications are cleaned and re-inspected to determine whether they were false positives.
- Surface Geometry and Contaminants: Geometry-related indications (e.g., at edges or joints) and contaminants that can mimic defects are identified through post-inspection analysis.

d. Defect Sizing and Analysis

Sizing defects accurately is crucial for determining their impact on part integrity.

- Visual Inspection Data: Defect sizes are initially estimated visually, often using a reference scale or by comparing them to known standards. This data is cross-verified with other measurement tools.
- Tool-Assisted Measurement: Defects can be measured using digital calipers, microscopes, or imaging software. Data from these tools is used to provide precise defect dimensions (length, width, depth, etc.).
- Defect Growth Patterns: By comparing defect data from multiple inspections (for parts inspected periodically), analysis can track the growth of a defect over time, assisting in predicting part lifespan or identifying areas needing repair.
- Indication Brightness and Size Correlation: For fluorescent penetrants, brightness levels of indications are sometimes used as a proxy for defect depth and volume. More intense fluorescence can indicate deeper or wider defects.

3. Advanced Data Analysis Tools

To improve data analysis and reduce human error, several advanced tools can be employed:

- Digital Image Processing: Software can enhance captured images to help in sizing defects, eliminating false indications, and improving the overall sensitivity of the inspection.
- Statistical Process Control (SPC): Statistical methods can be used to analyze historical data on defect occurrence, allowing trends to be identified, such as recurring defects in particular areas or components.
- Artificial Intelligence (AI) and Machine Learning (ML): AI-based systems can analyze large datasets of PT results to detect patterns, identify false positives, and improve defect sizing accuracy. ML algorithms can be trained to differentiate between false indications and real defects more effectively than traditional methods.

4. Reporting and Documentation

Once data has been collected and analyzed, a comprehensive report is generated. This includes:

- Inspection Summary: Details of all identified defects, including their type, size, and location.
- Indication Classification: A breakdown of relevant and non-relevant indications.
- Inspector Notes: Additional observations, including whether the part passed or failed inspection criteria.

- Corrective Action Suggestions: If defects exceed acceptable limits, recommendations for repairs or further testing may be included.

Conclusion

Data collection and analysis in Liquid Penetrant Testing play a critical role in ensuring the reliability of inspection results. Key areas of focus include maximizing sensitivity to detect small defects, minimizing false indications, and accurately sizing true defects. With the use of advanced tools such as image processing software and AI, the precision and reliability of PT can be further enhanced.

3.2 Quality Assurance and Standards:

To ensure the success of the project and the quality of simulations for non-destructive testing (NDT) with penetrant testing (PT), it is necessary to adhere to internationally recognized ISO and EN standards. Compliance with these standards is essential to maintain process integrity and ensure that simulation results are considered valid and reliable.

- **Compliance with ISO and EN Standards for PT Testin**g : The entire project must operate in accordance with regulations such as ISO 3452-1 to 6, which establishes general principles for penetrant testing, and EN 13445-5 and 6 Boiler and Pressure Vessel Code which covers the requirements for non-destructive testing. This means that every test, whether physical or simulated, must follow these standards to ensure that the methodologies used are consistent with industry-accepted practices. This is crucial for the Living Labs to conduct simulations that reflect real operating conditions.

  PT simulations must accurately replicate the conditions required to test material quality, from surface preparation to defect detection, maintaining consistency with the procedures outlined by ISO and EN standards.

- **Verification of Consistency Between Simulations and ISO and EN Standards:** It is imperative that the results obtained from VR simulations are comparable to those of physical tests, according to the criteria established by ISO and EN standards. This requires continuous and detailed data verification to ensure that defects identified in simulations are consistent with those detected in real tests. The simulation platform must reproduce key parameters such as the viscosity of the penetrant liquid, exposure time, and detection techniques to ensure results conform to normative expectations. Through this verification process, it will be possible to improve the accuracy of simulations and ensure they are accepted as training and certification tools in international industrial contexts.

- **International Approach Based on ISO and EN Standard**s: Adherence to ISO and EN standards provides a solid regulatory framework for the entire project, ensuring that all training and testing activities are standardized. This guarantees that the results are recognized and accepted in the various participating countries, promoting the replicability of the model on a global scale. The use of virtual simulations will also reduce costs and material waste, contributing to a more sustainable approach without compromising training quality.

Furthermore, collaboration with consortia operating at the national level (such as TICASS in the Italian context) that promote technological innovation, and sustainability can significantly contribute to the project's success. The resources and expertise developed within these consortia can be used to strengthen the project's infrastructure, ensuring that ISO and EN standards are effectively implemented. The integration between physical laboratories and VR platforms, combined with transnational collaboration, will support the quality and reliability of training in all the home countries of the project partners.

User Interaction and Control:

To ensure a comprehensive and interactive training experience, it is essential to implement advanced user controls that allow the adjustment of key parameters within penetrant testing (PT) simulations. These include the ability to modify:

- **Virtual Environment Lighting:** Adjusting brightness simulates different working conditions, such as the use of natural or artificial light. This is crucial for replicating real situations, as lighting affects the operator's ability to detect defects, especially when using fluorescent penetrants that require UV light.
- **Environment Temperature:** Allow users to adjust the virtual environment temperature to simulate different operating conditions. Temperature can influence the viscosity of the penetrant liquid and the evaporation rate of the solvent, thereby altering the test's effectiveness. Simulating temperature variables enables operators to understand how thermal conditions can impact NDT test results.

- **Surface Roughness of the Workpiece:** Modifying the roughness of the surfaces to be tested allows for the simulation of different surfaces. Greater roughness can retain more penetrant and make it more difficult to remove excess liquid, thus affecting the results. Simulating this variable enables operators to learn how different material conditions impact the tests.
- **Adjustment of Operational Times:**
  - **Penetration Time**: Allowing users to adjust this parameter helps study how shorter or longer times affect the test's effectiveness. Too short a time does not allow the penetrant to properly fill the defects, while excessive times can overly saturate the surface.
  - **Detection Time:** A detection time that is too short does not allow the penetrant to emerge from the defects, while too long a time can make the defect less visible, simulating the effects of suboptimal operational times.
  - **Inspection Time:** Adjusting this time allows testing scenarios where the inspection is performed too quickly or too slowly. This is particularly useful for evaluating operational efficiency and accuracy during the defect identification process.

These controls not only enhance the interactivity and customization of the simulation experience but also offer the opportunity to experiment with variables that can significantly affect NDT test results. Training users on how each variable impacts the process ensures greater awareness and preparedness in facing real practical situations. Simulations must comply with ISO and EN standards to ensure the quality and reliability of the tests.

A virtual laboratory must offer a highly immersive experience, accurately replicating the physical inspection process as an operator would in a real context. It is essential to provide users with tools that can be manipulated precisely, creating the illusion of interacting with physical objects. This translates into the need to use virtual versions of the most commonly employed tools during NDT inspections, such as penetrant spray cans and detectors. The virtual penetrant spray can should allow the operator to spray the liquid onto the test object with natural and intuitive gestures, just as they would in the real world. The hand movement and pressure of the spray can should be faithfully replicated, offering a highly realistic experience that enables operators to acquire practical skills during the simulation. Once the penetrant liquid is applied, the system should display the fluid's behavior based on the material characteristics, simulating how the liquid spreads into the defects of the piece being examined.

- **Realistic Interaction and Total Immersion**

This attention to detailed tool manipulation goes beyond the technical aspect of the test, creating an extremely engaging and realistic experience. The importance of this advanced simulation lies in allowing the operator to perform every step of the NDT process interactively: spraying, observing the results, and adjusting their approach based on errors or successes, as they would in a physical environment.

Adding visual and tactile feedback, such as the virtual resistance of the tools or the accurate reproduction of material surface changes, makes the interaction extremely truthful. For example, the operator could adjust the roughness of the virtual piece's surface, influencing how the penetrant liquid behaves and allowing them to observe the differences between a smooth and a rough surface. This type of variable provides practical depth to learning, making it possible to simulate a wide range of operational scenarios.

- **Benefits for Training and Research**

Integrating this interactive capability into the virtual laboratory not only makes the experience more realistic but also provides a safe environment where technicians and operators can experiment without the risk of damaging expensive equipment or materials. Additionally, direct interaction with virtual tools and objects allows for the refinement of operational skills in a repeatable manner tailored to specific training needs.

The use of real-time manipulable tools in a virtual context also allows for testing different operational variables, such as changing light and visibility, without interrupting the process. This type of total control over the environment ensures that users can simulate scenarios that faithfully reproduce the difficulties encountered during physical inspections, leading to a greater understanding and awareness of the NDT process.

Ultimately, providing operators with the ability to use virtual tools with realistic behaviors ensures that the virtual laboratory is not just a theoretical support but a powerful training tool capable of transferring high-level practical and technical skills.

3.3 Recordkeeping and Reporting:

Effective recordkeeping and reporting are crucial for managing and analyzing data generated within virtual living labs. The ability to accurately store, retrieve, and analyze simulation data, experiment logs, and user performance metrics provides a foundation for evaluating both system effectiveness and user progression.

The critical role of recordkeeping and reporting in virtual living labs explores the importance of secure data storage, efficient data retrieval and analysis, and robust reporting mechanisms in enabling researchers to effectively manage and analyze experimental data, simulation logs, and user performance metrics. By implementing these practices, researchers can gain valuable insights into system performance, user behavior, and research outcomes, ultimately contributing to the success of virtual living lab initiatives. These aspects are detailed in the following sections:

- Data Storage
- Centralized Database: Implement a centralized database to store all experiment data, simulation logs, and user performance metrics. This ensures data consistency and facilitates easy retrieval and analysis.
- Data Retention Policy: Establish a data retention policy that outlines how long different types of data will be stored, based on factors like regulatory requirements and research needs.
- Data Backup and Recovery: Implement robust data backup and recovery procedures to prevent data loss in case of system failures or disasters.
- Data Retrieval and Analysis
- Data Querying Tools: Provide tools for querying and filtering data based on specific criteria, such as experiment parameters, user IDs, or timeframes.
- Data Visualization Tools: Implement data visualization tools to generate charts, graphs, and other visual representations of the data, facilitating easier analysis and interpretation.
- Statistical Analysis Tools: Integrate statistical analysis tools to perform statistical tests, calculate correlations, and identify trends within the data.
- Reporting
- Automated Reporting: Develop automated reporting tools to generate regular reports on key performance indicators (KPIs), such as user engagement, experiment success rates, and system performance.
- Customizable Reports: Allow researchers to create customized reports tailored to their specific research questions and needs.
- Data Export: Enable researchers to export data in various formats, such as CSV, JSON, or XML, for further analysis using external tools.

3.4.1 Storing Simulation Data, Experiment Logs, and User Performance Metrics

The platform must employ a robust, scalable storage system capable of handling large volumes of data. This includes not only storing raw simulation data but also detailed logs from experiments, system interactions, and individual user performance metrics. The data must be structured in a way that allows easy retrieval for further analysis while maintaining data integrity and security.

To effectively store simulation data, experiment logs, and user performance metrics, your platform should consider the following key components:

Storage System Choices

- Database Solutions:
  - Relational Databases (e.g., PostgreSQL, MySQL): Great for structured data and complex queries.
  - NoSQL Databases (e.g., MongoDB, Cassandra): Suitable for unstructured data and scalable horizontally.
  - Time-Series Databases (e.g., InfluxDB): Ideal for handling time-stamped data like experiment logs and performance metrics.
- Data Lakes: For storing large volumes of raw data in its native format. Technologies like Amazon S3 or Hadoop can be utilized.
- Cloud Storage Solutions: Use cloud services like AWS, Azure, or Google Cloud for scalable and flexible storage options.

Data Structuring

- Schemas: Establish clear data schemas that define the structure of your data (e.g., tables for experiments, logs, metrics).
- Indexing: Implement indexing for faster query performance, especially for frequently accessed data.
- Data Formatting: Use JSON, CSV, or Parquet for easy serialization and deserialization of data.

Data Integrity and Security

- Access Control: Implement role-based access controls (RBAC) to restrict data access based on user roles.

- Encryption: Utilize encryption for data at rest and in transit to safeguard sensitive information.
- Backup and Recovery: Establish regular backup schedules and disaster recovery plans to protect against data loss.

Data Retrieval and Analysis

- **APIs**: Develop RESTful APIs for easy data access and manipulation by clients and analytics tools.
- **Data Warehousing**: Consider a data warehouse (e.g., Snowflake, BigQuery) for large-scale analytics, enabling complex queries and reporting.
- **Data Visualization**: Integrate with visualization tools (e.g., Tableau, Power BI) to provide insights into the data collected.

Scalability

- Ensure the chosen solutions can scale horizontally as data volume increases, allowing the system to grow with demand.

Monitoring and Maintenance

- Implement monitoring solutions to track data integrity, performance, and database health.
- Regularly update and maintain the storage infrastructure to handle new requirements and technologies.

A **NoSQL database** could be a suitable solution, given its ability to handle unstructured or semi-structured data commonly produced in simulations and experiments. The system should support features like:

- **Automatic data versioning** to track updates and changes in experiment setups.
- **Time-stamping** to record when specific data points are logged, facilitating chronological analysis of user interactions or system performance over time.
- **Data indexing** for faster queries and efficient report generation.

Moreover, a modular approach to data storage could allow for **segmentation** based on data types (e.g., user performance versus experimental logs), improving both data management and retrieval efficiency.

- Generate reports on user proficiency, skill development, and areas for improvement.

A core aspect of recordkeeping is the ability to generate meaningful reports. These reports should synthesize the raw data collected into actionable insights about user proficiency, skill development, and areas where users need improvement.

This can be achieved using **automated reporting tools** integrated into the platform, capable of:

- Aggregating user metrics such as task completion time, error rates, and overall success rates.
- Highlighting **trends in skill acquisition** over time, which could be visualized using data visualization tools like **heatmaps** or **progress curves**.
- Comparing user performance against predefined benchmarks to identify areas of strength and those needing improvement.

An example of this might be an analysis of a user's proficiency in a technical task within the lab. The system would generate a report identifying key performance metrics (e.g., time to complete a task, accuracy of execution), then cross-reference these metrics with baseline values to highlight skill improvement or the need for further training.

To enhance recordkeeping and provide actionable insights into user proficiency and skill development, the platform should incorporate robust reporting tools. These tools not only help in synthesizing raw data but also enable constructive feedback that can drive user growth and improvement. Here's how to achieve effective report generation:

Automated Reporting Tools

- **Integration**: Develop or integrate automated reporting tools that can pull data from various user metrics and activity logs without requiring manual intervention.
- **Scheduled Reports**: Implement the ability to schedule reports (daily, weekly, monthly) to track ongoing user performance trends consistently.

Data Aggregation

- **User Metrics Collection**: Collect relevant metrics, including:
  - **Task Completion Time**: Measure the time taken by users to complete specific tasks within the lab.

- **Error Rates**: Track the frequency of errors made during task execution.
- **Overall Success Rates**: Calculate the percentage of tasks completed successfully versus those that encountered issues.

Trend Analysis and Visualization

- **Skill Acquisition Over Time**: Implement algorithms to analyze trends in skill acquisition, which will help in understanding user progress:
  - **Heatmaps**: Use heatmaps to visualize user activity and proficiency levels over time, indicating which skills are improving and which require more attention.
  - **Progress Curves**: Develop progress curves that display individual user growth trajectories, allowing both users and educators to visualize improvements and stalling areas.

Benchmark Comparison

- **Predefined Benchmarks**: Establish standardized benchmarks based on domain-specific performance indicators, which could include industry standards or expert-defined thresholds.
- **Comparative Analysis**: Generate reports that compare individual user performance against these benchmarks, highlighting:
  - **Strengths**: Areas where the user exceeds proficiency benchmarks.
  - **Improvement Opportunities**: Skills where performance lags behind expected values, suggesting possible areas for remedial training or focused practice.

Example Report Workflow

- **Skill Proficiency Analysis**:
  - **Data Gathering**: The system collects metrics such as:
    - Time to complete specific technical tasks
    - Accuracy of execution (e.g., percentage of errors)
  - **Performance Evaluation**:
    - Compare collected metrics against baseline values established from previous users’ performances or industry standards.

- ○ **Report Generation**:
  - Create a report summarizing findings, including:
  - Key performance indicators (KPIs) like average completion time, error percentage, and overall success rate.
  - Visual charts (heatmaps, bar charts) showcasing the progression of skills over designated time frames.
  - Recommendations for further training paths or advanced tasks based on areas needing improvement.

User Feedback and Iterative Improvement

- Incorporate feedback mechanisms within the reports. Users could rate the usefulness of the insights, providing valuable qualitative data to improve future report iterations.
- Enable users to set personal goals based on report findings, facilitating a continuous improvement mindset.

3.1.4 Network Connectivity:

- ○ Enable remote access to virtual labs for distributed training and collaboration.

The platform must provide remote access to facilitate **distributed training** and **collaborative experimentation**. A distributed architecture would allow researchers, students, and collaborators to engage with the virtual lab from various geographical locations without compromising performance or data integrity.

To implement this:

- **Cloud infrastructure** can be used for the virtual lab environment that will be hosted on a cloud platform, such as AWS, Azure, or GCP. This provides scalability, high availability, and the ability to dynamically allocate resources based on demand.
- **Load balancing mechanisms** should be employed to distribute traffic and resource use efficiently across multiple virtual lab instances. This ensures optimal performance regardless of user location and prevents bottlenecks.
- The platform should implement **real-time synchronization** of experiment data to prevent any desynchronization issues that could arise due to multiple users accessing the same virtual environment simultaneously.

In a remote collaboration scenario, multiple users could work on the same simulation, with each participant able to view and modify parameters in real-time. Tools like **multi-user virtual desktops** or **remote desktop protocols (RDPs)** could enhance this experience, providing a seamless interface for both control and monitoring.

Design Considerations

- Security: Implement robust authentication and authorization mechanisms to control access to the virtual labs and ensure data integrity.
- Performance: Optimize network communication and data synchronization to minimize latency and maintain responsiveness.
- User Interface: Design an intuitive and user-friendly interface that supports collaboration and real-time interaction.
- Scalability: Ensure the platform can scale to accommodate a growing number of users and experiments.
- **Cost-effectiveness:** Utilize cloud resources efficiently to optimize costs without compromising performance or functionality.

Implementation

- Cloud Platform: Choose a cloud provider based on factors like cost, scalability, and available services.
- Virtualization Software: Select a suitable virtualization software, such as VMware or KVM, to create and manage virtual lab instances.
- Load Balancer: Implement a load balancer using tools like HAProxy or NGINX.
- Data Synchronization: Choose a distributed database or message queue technology, such as Apache Kafka or RabbitMQ, for real-time data synchronization.
- Multi-user Access: Utilize multi-user virtual desktop solutions or RDPs to enable collaborative access.
- Security: Implement authentication and authorization mechanisms using tools like LDAP or OAuth.
- Performance Optimization: Monitor and optimize network communication and data synchronization to minimize latency.

Implement secure VPN connections for external users and researchers.

Ensuring the security of external users accessing the platform is paramount, especially when handling sensitive experimental data or intellectual property. Virtual Private Networks (VPNs) provide a solution for secure remote access, ensuring that data transferred between external users and the platform is encrypted and protected from potential cyber threats.

Key elements of VPN implementation should include:

- End-to-end encryption: All data passing through the VPN tunnel must be encrypted using strong encryption protocols like AES-256 to prevent unauthorized access or data leaks.
- Multi-factor authentication (MFA): External users should be required to use MFA, combining passwords with additional verification steps (e.g., one-time passwords or biometric authentication) to enhance security.
- Access control policies: The platform should define role-based access controls (RBAC) to ensure that users can only access resources relevant to their role or task. For example, a researcher might have full access to specific experimental modules but limited access to other parts of the platform.

By implementing secure VPN connections, external users can confidently engage with the platform without compromising the confidentiality or integrity of the data. This is particularly important for researchers handling sensitive or proprietary information.

Design Considerations

- VPN Protocol: Choose a secure VPN protocol, such as OpenVPN or WireGuard, that offers strong encryption and authentication mechanisms.
- Authentication: Implement two-factor authentication (2FA) to enhance security and prevent unauthorized access.
- Access Control: Configure granular access controls to restrict access to specific resources based on user roles and permissions.
- Logging and Monitoring: Implement comprehensive logging and monitoring of VPN connections to detect and respond to suspicious activity.
- Client Software: Provide easy-to-use VPN client software for different operating systems and devices.
- Network Segmentation: Segment the virtual lab network to isolate external users from critical internal resources.

- Data Encryption: Ensure all data transferred over the VPN connection is encrypted using strong algorithms.
- Vulnerability Management: Regularly update VPN software and firmware to address vulnerabilities and security patches.

Implementation

- VPN Server: Deploy a VPN server on the cloud platform or on-premises, depending on your security requirements.
- Client Software: Distribute VPN client software to external users and provide instructions for installation and configuration.
- Authentication: Configure 2FA using methods like SMS, authenticator apps, or hardware tokens.
- Access Control: Define access control policies based on user roles and permissions.
- Logging and Monitoring: Set up centralized logging and monitoring systems to track VPN activity.
- Network Segmentation: Implement network segmentation using firewalls and VLANs to isolate external users.
- Data Encryption: Ensure all data transferred over the VPN is encrypted using AES-256 or higher.
- Vulnerability Management: Establish a regular patching and update schedule for VPN software and firmware.

3.1.5 Integration with VR Platform:

This will include the incorporation of PT-NDT simulations into the VR platform in a structured, modular approach.

Development of the VR platform shall be realized in Unity which will develop an immersive interactive environment within which the learners can interact with realistic PT scenarios. Integration with Moodle provides for efficient user management, progress tracking, and course enrollment. This will ensure single sign-on as the users, through LTI integration, will log in with the credentials of Moodle into the VR platform. Besides that, xAPI will track user performance within a VR environment as completed tasks or assessments and return this information to Moodle for analytics and performance evaluation. The VR platform will also have the capability to support collaboration via Living Labs, which enables users in different geographic locations to work together which will promote international training and collaboration in research that can help improve coordination. Integration of PT-NDT simulations in this framework provides a flexible interactive data-driven VR platform to the learners.

The integration of PT-NDT simulations within the VR platform should be in a structured, standards-compliant, and modular manner.

1. Development Environment & PT-NDT Simulation: The development of the VR platform will be in Unity. It will simulate critical parts of the PT-NDT process, such as applying fluids with penetrants, time lapses between them, checking under UV light, among others. The system will be developed in line ISO 3452-1 to 6, such that the simulations can be immersive and relevant to the industrial practices as possible. Following these standards, there is a defined appropriate procedure and requirements on materials of penetrants, testing techniques, and inspection practices in PT-NDT; hence, the simulation would be developed for practical training.
2. Integration of Moodle with VR Platform: Integration with Moodle provides for efficient user management, progress tracking, and course enrollment. This will ensure single sign-on as the users, through LTI integration, will log in with the credentials of Moodle into the VR platform. Besides that, xAPI will track user performance within a VR environment as completed tasks or assessments and return this information to Moodle for analytics and performance evaluation.
3. Living Labs and Collaborative Integration: The VR platform will also have the capability to support collaboration via Living Labs, allowing users to be in distant geographical locations, collaborating in development fostering an international training and research collaboration that improves coordination. The Living Labs network should foster: real-time interaction, simulation, real life open-innovation ecosystem, user-centred and co-creative design, participative process based on mutual trust, good diversity, governance; rules focused on the process rather than on the result, with a good margin of freedom for the attendees, transparency of the process, agreement on the use of specific software, tools and programming language and data exchange

across various international research groups and training centers. It shall have high-speed network infrastructure so that real-time communication and interaction with the platform are expediently possible, ensuring tracking performance and data synchronization across various locations in an efficient manner.

4. Compliance and Standards: PT-NDT simulations integrated within the VR architecture will be fully compliant with ISO standards. Whereas following the standard of networking, multi-user environments can easily be allowed to seamlessly synchronize data in collaboration scenarios. In addition, the VR platform should be aligned with all regulations under GDPR, which therefore means any kind of user data that might be processed through Moodle and the VR platform will be securely handled in confidence for privacy and security reasons.
5. Integration Strategy: To perform more refined integrations, the VR platform will employ modular components, where different modules of simulation are independently developed but are seamlessly integrated with the platform.

3.5.1 Real-Time Collaboration Features:

To promote collaboration and learning within the context of the European project aimed at improving training in non-destructive testing (NDT) with liquid penetrants, the system must allow multiple users to connect simultaneously to the virtual laboratory and work together on experiments and simulations. This could include research groups interacting in real-time to share data and analyses. The multi-user functionality is particularly useful for international projects or training classes, allowing students and researchers from different parts of the world to collaborate without geographical barriers. Additionally, this simultaneous access capability can facilitate the immediate sharing of results and observations, improving the efficiency and quality of group work.

- **Concrete examples of use:**
  - International research projects: Research groups in different partner countries such as BIBA, ISIM, IIS, CESOL, IPUNTO, Walter Tosto, and EWF can work together on complex experiments, sharing data and analyses in real-time.
  - Training classes: Students from various universities and training institutes can participate in practical lessons and collaborate on projects, enhancing learning through direct interaction.

- Workshops and seminars: Organize virtual workshops where industry experts can demonstrate advanced techniques and answer participants' questions in real-time

- **Benefits:**
  - Collaboration without barriers: Overcome geographical and temporal limitations, allowing continuous and smooth collaboration.
  - Immediate sharing: Facilitate the sharing of results and observations, improving the quality of group work and accelerating the learning process.

  - Implement chat, voice, or video conferencing tools for communication during simulations.

Communication functionalities, such as chat, audio, and video, are essential for coordinating teamwork in a virtual environment. Users should be able to discuss their observations and make decisions in real-time, thus enhancing the collaborative experience in the Living Lab. This type of integration fosters an experience like that of a physical laboratory, with the advantage of remote interaction.

- **Communication tools**
  - **Chat:** Allows users to quickly exchange textual information, links, and documents during simulations.
  - **Voice calls:** Facilitate immediate and detailed discussions, enabling quick problem-solving and decision-making.
  - **Video conferences:** Allow presenting results, sharing screens, and receiving visual feedback, improving group understanding and cohesion.

Concrete examples of use:

- **Group discussions:** During a complex simulation, team members can use chat to quickly exchange information, voice calls to discuss strategies, and video conferences to present results and receive immediate feedback.
- **Review sessions**: Organize review sessions where users can present their progress and receive suggestions and corrections in real-time.
- **Technical support:** Provide immediate assistance to users encountering technical or operational difficulties during simulations.

- **Benefits:**
  - **Effective coordination**: Improve team coordination, making the learning and research process more dynamic and interactive.
  - **Immersive experience:** Create a virtual work environment that faithfully replicates the interaction and collaboration of a physical laboratory.