



VIOLET

AR/VR International Welding Engineer Qualification



D2.3 Report on I/EWE Needs and Training



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1. Executive summary

The purpose of this document is to provide evidence-based information to support the development of innovative, learner-centred training solutions and the future integration of digital learning approaches into the I/EWE qualification framework. The report identifies the areas where XR technologies can provide the highest educational value while considering both the opportunities and limitations of their implementation in welding education and industrial training.

The analysis, based on feedback collected from welding engineers, trainers, and industry representatives across the project consortium, highlights a strong interest in the use of XR technologies for improving welding training. Although the current level of XR adoption remains limited, the majority of respondents recognise the potential of VR/AR/AI-based solutions to enhance learning effectiveness, safety, and accessibility.

The main findings indicate that XR technologies are particularly relevant for supporting theoretical, analytical, and procedural learning activities, such as welding process simulation, parameter setting, real-time feedback on welding techniques, defect identification, WPS/PQR optimisation, and visualisation of complex metallurgical phenomena. Industry representatives and technical experts consider these applications highly valuable for improving understanding and preparing learners before practical training on real equipment.

At the same time, the analysis confirms that XR solutions should complement rather than replace hands-on training. Practical experience with real welding equipment, including sensory feedback and workplace conditions, remains essential for the development of psychomotor skills and professional certification. A blended learning approach, combining digital XR-based activities with traditional practical training, is therefore considered the most suitable model.

The report concludes that XR technologies can contribute significantly to the modernisation of I/EWE training by increasing flexibility, improving learning efficiency, and supporting the digital transformation of welding education. The identified training priorities and recommendations will provide a foundation for the development of future XR-based learning materials, scenarios, and training frameworks within the VIOLET project.

2. Introduction

This report presents the results of the needs analysis carried out within the VIOLET project to identify the current level of awareness, training needs, and expectations regarding the use of Extended Reality (XR) technologies in the education and training of International/European Welding Engineers (I/EWE).

The analysis is based on questionnaire responses collected from welding engineers, trainers, and industry representatives across the project consortium. The findings provide valuable evidence on the current challenges, digital skills gaps, and priorities for integrating innovative learning technologies into vocational education and training.

The main objective of this report is to support the design of modern, learner-centred training solutions by identifying the areas where XR technologies can bring the greatest educational value. The results will guide the development of digital learning materials, practical XR training scenarios, and recommendations for updating the I/EWE qualification in line with the evolving needs of industry and the digital transformation of vocational education.

This report provides the foundation for the subsequent activities of the VIOLET project by ensuring that the proposed training framework is evidence-based, relevant, and aligned with technological developments and labour market requirements.

2.1. Background and context

The manufacturing and welding sectors are undergoing significant transformations driven by digitalisation, automation, and the increasing adoption of Industry 4.0 and Industry 5.0 approaches. These changes are creating new requirements for professional skills, including the ability to use digital technologies within industrial processes and training environments.

At the same time, vocational education and training systems face the challenge of adapting existing learning approaches to meet the needs of modern industry. Welding engineers, trainers, and technical professionals require updated training methods that combine theoretical knowledge with practical experience and digital competences.

Extended Reality (XR), including Virtual Reality (VR) and Augmented Reality (AR), represents an emerging opportunity to enhance technical education and professional training. These technologies enable immersive learning experiences, realistic simulation of industrial scenarios, and safe practice environments for developing complex technical skills.

Within this context, the VIOLET project addresses the need to explore and integrate XR-based solutions into the education and training pathway of International/European Welding Engineers (I/EWE). The project aims to support innovation in vocational education by developing training approaches that are aligned with technological developments, industry expectations, and future skills requirements.

2.2. Objectives

The VIOLET project aims to provide a framework for modernising the I/EWE qualification by developing online training materials and digital tools, contributing to the improvement of the quality, accessibility, and attractiveness of vocational education and training in the welding sector.

This report is based on the collection and analysis of questionnaire data, which helps identify the knowledge, skills, and training needs required for the effective use of XR technologies.

2.3. Methodology

In the initial phase, 2 questionnaires were developed: one targeting engineers from the manufacturing sector and another targeting industry stakeholders. To collect the information required for developing the framework for the modernisation of the I/EWE qualification, all project partners identified target groups consisting of training providers and welding companies that could participate in the surveys. This was done to establish a database of engineers and representatives from the industrial sector who would take part in the two questionnaires.

Subsequently, the partner responsible for the surveys (ASR) drafted the questionnaire items, which were then reviewed and evaluated by all project partners. After the final versions of the questionnaires had been agreed upon, they were distributed to the industrial companies and engineers designated by each partner.

Based on the analysis of the survey responses, we identified the stakeholders' interests, objectives, availability, and expectations regarding the training methodology.

In addition, to gain a comprehensive understanding of the existing framework, a desk-based document analysis was carried out, and the main findings were summarised. Finally, the most relevant results and conclusions achieved within this project deliverable are presented.

2.4. Characterisation of the target group

Based on the partners' proposed list of industrial companies and engineers, questionnaires were distributed through social media and through the network list of each partner. distributed via social media and through the network list of each partner. We received 121 answers from

engineers and 44 from the industrial sector. The characterisation of the target group involved in the questionnaires can be seen in the charts below, where the position/role of the participants (Figure 1), country (Figure 2), and years of experience are indicated (Figure 3)

3. Survey results and Analysis

3.1. Survey results from the Engineer questionnaire

3.1.1. Section A: Profile

Role of participants:

Conclusion (Figure 1): A total of 121 participants completed the survey. The majority were International Welding Engineers (IWE) (42.9% of respondents), followed by Engineers (33.3% of respondents). The remaining participants included Other professional roles (12.2% of respondents), IWE Instructors (4.1% of respondents), Examiners (4.1% of respondents), and Course Coordinators (3.4% of respondents). This distribution demonstrates that the survey primarily captured the perspectives of professionals directly involved in welding engineering, while also incorporating valuable input from training and assessment specialists.

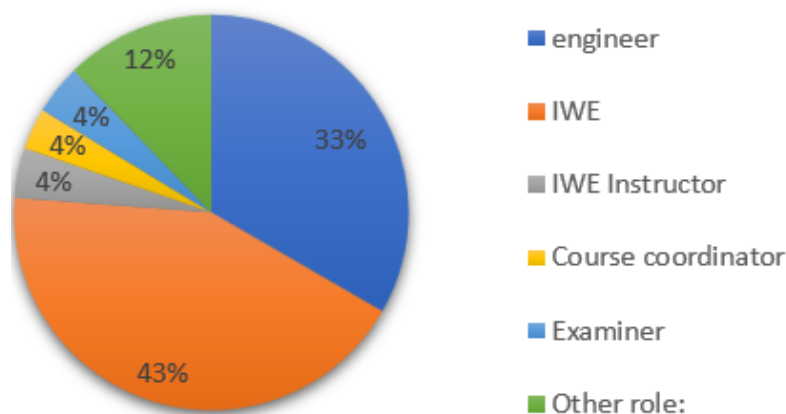


Figure 1. Role of participants

Residence country of participants

Conclusion (Figure 2): A total of 1 participant from 11 countries completed the survey. The highest participation was from Romania (48.6%), followed by Portugal and Poland (each 14.4%), Turkey and Slovenia (each 7.2%), the Netherlands (2.7%), Germany (1.8%), and Belgium, Ireland, France, and Hungary (each 0.9%). The results demonstrate broad international participation, providing a solid basis for the development of the modernized I/IWE qualification framework.

■ Romania ■ Portugal ■ Belgium ■ Ireland ■ Hungary ■ Turkey ■ Slovenia ■ Netherland ■ Germany ■ France ■ Poland

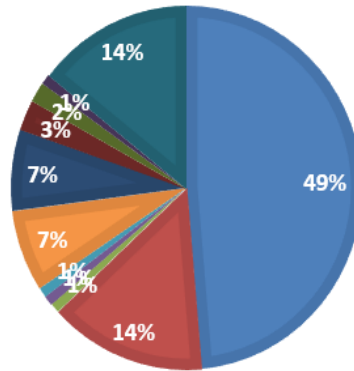


Figure 2. Residence country of participants

Experience in welding:

Conclusion (Figure 3): Of the 121 respondents, 37.7% had more than 10 years of welding experience, 36.0% had less than 5 years, and 26.3% had 5–10 years. This distribution reflects a balanced mix of experienced and early-career professionals.

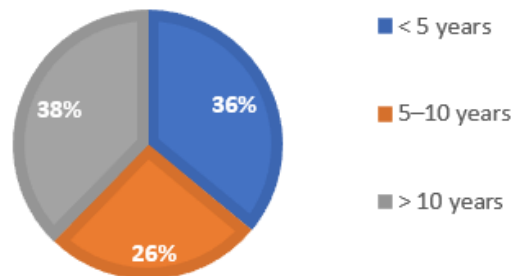


Figure 3. Experience in welding

3.1.2. Section B: Digital technologies:

Use of VR/AR/AI in training

Conclusion (Figure 4): Of the 121 respondents, 62.0% had not used VR/AR/AI in training, while 38.0% had previous experience with these technologies. The results indicate that the use of VR/AR/AI in training is still limited, highlighting the potential for wider adoption in welding education.

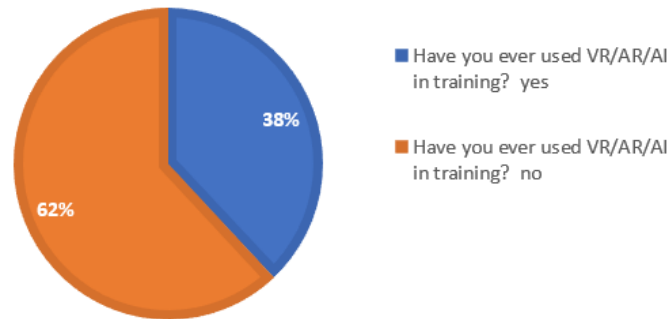


Figure 4. Use of VR/AR/AI in training

Perceived Risks of Using Digital Tools in IWE Training:

Conclusion (Figure 5): The results indicate that the most significant perceived risks of XR implementation in IWE training are the lack of trainers' digital skills (27.9%) and the time required to become familiar with XR tools (25.0%), while low trainee acceptance (18.0%), technological overload (16.9%), and other concerns (12.2%) were considered less significant.

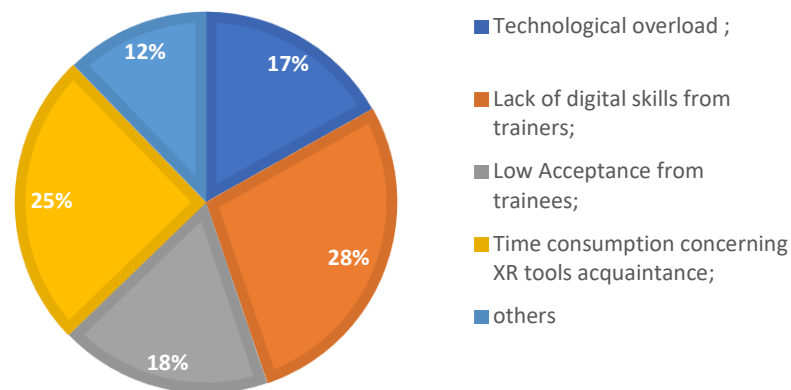


Figure 5. Perceived Risks of Using Digital Tools in IWE Training

3.1.3. Section C: Welding and cutting processes:

Utility of AR / VR simulation for practising MMA/MIG-MAG/TIG processes - welding positions and metal pool control (according to: IAB-089 – "Welding Simulating Systems")

Conclusion (Figure 6): The results indicate a highly positive perception of AR/VR simulation for practising MMA/MIG-MAG/TIG welding processes. More than half of the respondents rated its utility as Good (54.6%), while 26.9% considered it Excellent. Only 3.4% rated it as Poor or Not

useful, suggesting broad acceptance of AR/VR simulation as an effective training tool for welding positions and metal pool control.

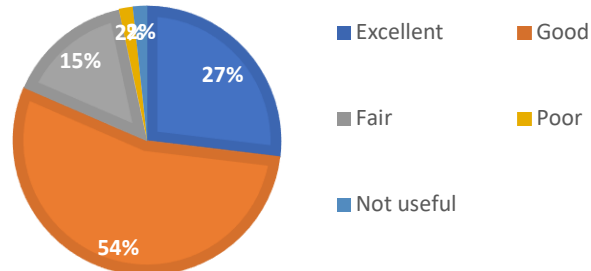


Figure 6. Utility of VR simulations for MMA/MIG-MAG/TIG

Perceived Benefits of AR/VR for Training on setting parameters (current/voltage/gas flow) on Real Equipment

Conclusions (Figure 7): The results show strong support for the use of AR/VR in training on parameter setting for real welding equipment. Most respondents believed AR/VR would improve training significantly (53.3%) or moderately (36.7%), while only 9.2% expected a slight improvement and 0.8% saw no benefit. These findings indicate broad confidence in AR/VR as an effective tool for enhancing practical welding training.

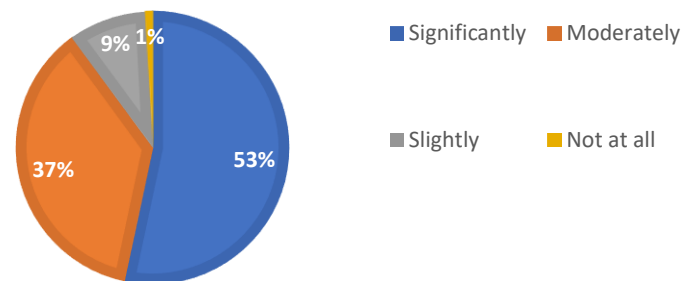


Figure 7. Perceived benefits of AR/VR for Training on setting parameters

Perceived Usefulness of AR/VR/AI for providing Real-Time Feedback on deviation (travel speed, torch angle)

Conclusions (Figure 8): The results provide strong support for the use of AR/VR/AI to provide real-time feedback on welding deviations. Most respondents rated this functionality as Very Useful (59.5%) or Essential (23.1%), while 14.9% considered it Useful and only 2.5% rated it as Somewhat

Useful. Overall, the findings highlight the high perceived value of intelligent real-time feedback for improving welding training and performance.

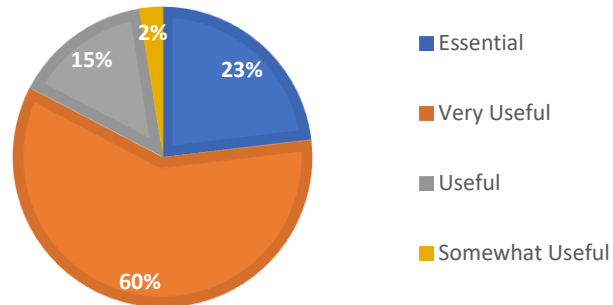


Figure 8. Perceived usefulness of AR/VR/AI for Real-Time Feedback

Perceived Relevance of VR/AR for Cutting Process Training (plasma, oxygas, laser) for demonstrating and cutting paths

Conclusions (Figure 9): The results indicate that VR/AR is widely regarded as a valuable tool for demonstrating safety procedures and cutting paths in plasma, oxygas, and laser cutting processes. Most respondents rated it as Relevant (55.4%) or Highly Relevant (35.5%), while only 0.8% considered it Irrelevant, confirming strong support for integrating VR/AR into cutting process training.

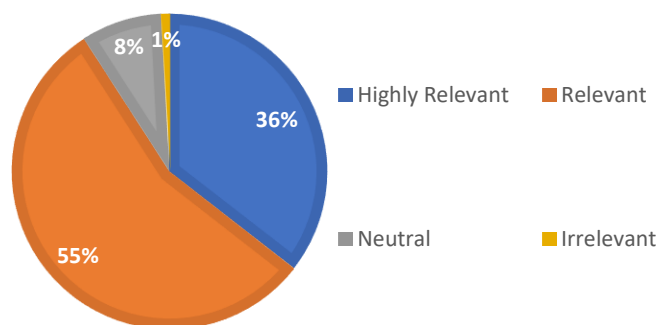


Figure 9. Relevance of VR/AR for Cutting Process Training

Perceived the most significant limitations of VR/AR/AI Technologies

Conclusions (Figure 10): The main challenges associated with XR implementation are the lack of physical "feel" (44.8%) and high initial investment costs (30.4%). Other concerns, including the complexity of digital content creation (12.8%), time required to master XR tools (7.2%), and

technological overload (4.0%), were reported less frequently. Overall, the findings suggest that technical realism and implementation costs are the primary barriers to wider XR adoption.

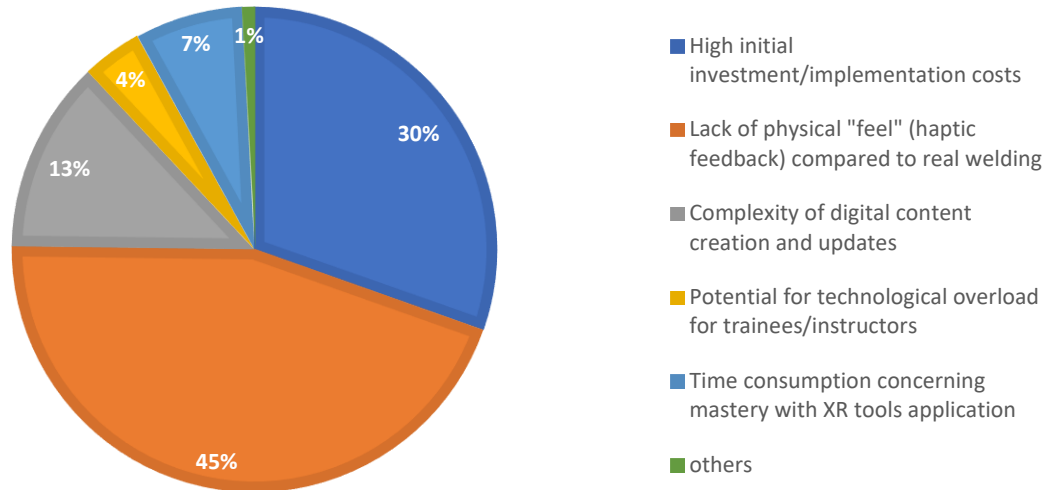


Figure 10. Perceived Limitations of VR/AR/AI Technologies

Perceived primary benefits of VR/AR/AI Technologies

Conclusions (Figure 11): The results indicate that the primary anticipated benefit of XR technologies is faster learning (31.7%), followed by improved safety (28.5%) and waste reduction (24.4%). Real-time feedback (15.4%) was selected less frequently, suggesting that respondents primarily value XR technologies for enhancing learning efficiency and training outcomes

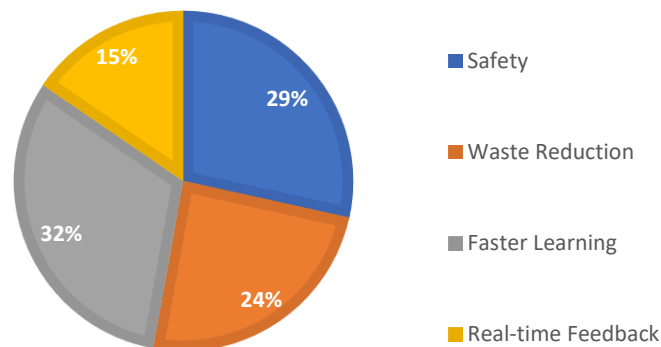


Figure 11. Perceived primary benefits of VR/AR/AI Technologies

3.1.4. Section D: Materials and their behaviour when welding

Perceived Value of VR/AR model highlighting HAZ(ZIT) transformations, distortions, and residual stress increase for understanding Metallurgical Phenomena

Conclusions (Figure 12): The results indicate that 54.5% of respondents believe that a VR/AR model would significantly improve the understanding of metallurgical phenomena, while 41.3% consider it a good support for theoretical classes. Only 2.5% perceive a minimal impact, and 1.7% believe that traditional methods are sufficient.

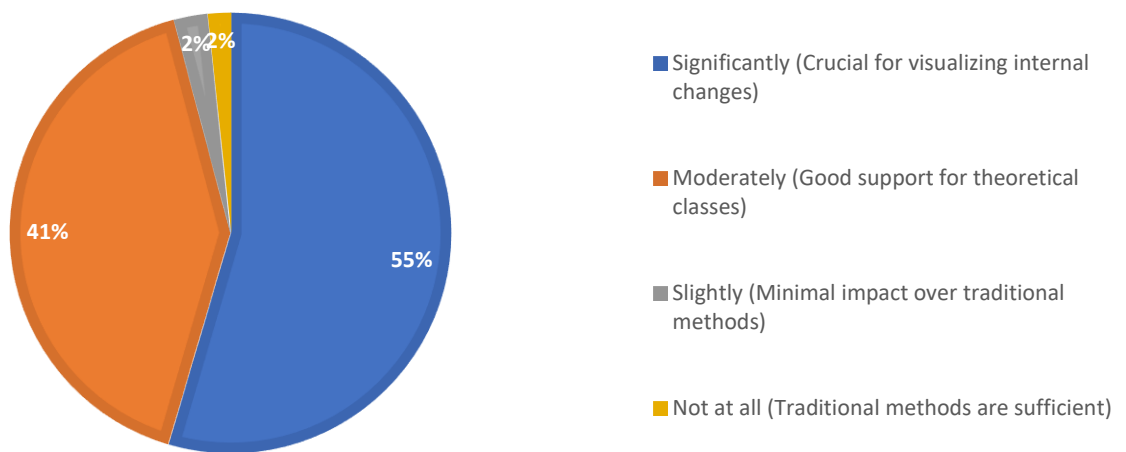


Figure 12. Perceived Value of VR/AR for Understanding Metallurgical Phenomena

Perceived Usefulness of AR/VR/AI for predicting hardness, cold or hot cracking risk, and preheating/PH, OWHT(TTPS)

Conclusions (Figure 13): The results indicate that most respondents perceive AR/VR/AI as valuable for technical review according to ISO 14731, with 42.1% considering these technologies very useful and 25.6% rating them as essential. A further 26.4% find them useful for preliminary calculations, while only 5.0% perceive limited practical value and 0.8% consider them not useful.

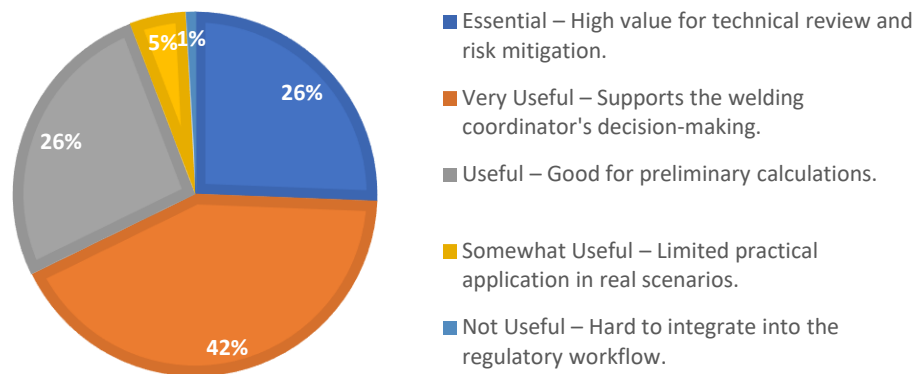


Figure 13. Perceived Usefulness of AR/VR/AI for Predicting Welding Parameters

Perceived Value of VR/AR for Understanding the Influence of Filler Materials and Shielding Gases on the microstructure

Conclusion (Figure 14): The results indicate that 62.0% of respondents believe that VR/AR can support the understanding of the influence of filler materials and shielding gases on the microstructure. In comparison, 35.5% believe it can provide partial support. Only 2.5% consider that VR/AR does not contribute to this understanding

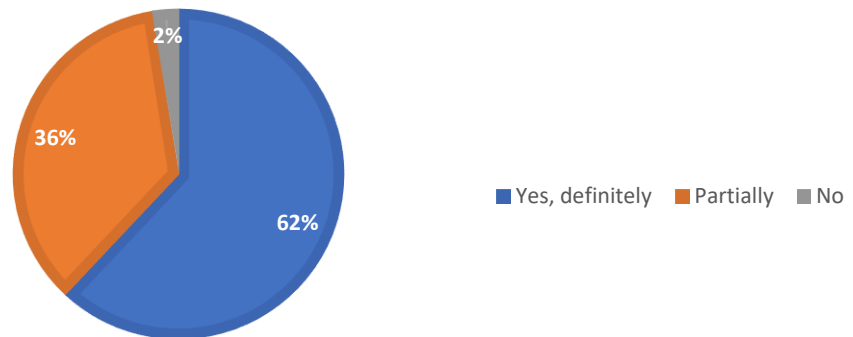


Figure 14. Value of VR/AR for Understanding the Influence of Filler Materials and Shielding Gases on the microstructure

Preferred Simulations for deep learning for learning material behaviour in Welding

Conclusion (Figure 15): The results indicate that the most valuable simulation for deep learning of material behaviour in welding is Phase Transformations and CCT Diagrams (47.4%), followed by Cracking Phenomena (36.8%). In contrast, Solidification Mechanism (8.3%) and Post-Weld Heat Treatment (7.5%) are considered less important by respondents

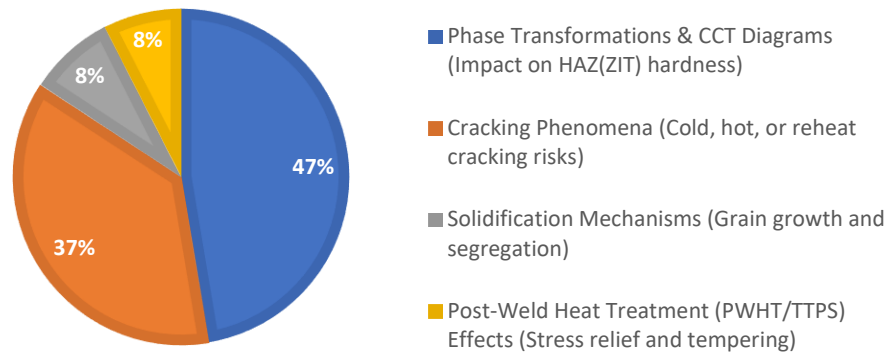


Figure 15. Preferred Simulations for deep learning for learning material behaviour in welding

3.1.5. Section E: Design of welded structures:

Perceived Benefits of 3D/VR/AR Visualization of joints and weld accessibility include improved design for Manufacturability and reduced distortions

Conclusion (Figure 16): The results indicate that 52.9% of respondents believe that 3D/VR/AR visualisation of joints and weld accessibility would significantly improve design for manufacturability and reduce distortion, while 41.3% consider it moderately beneficial. Only 5.8% perceive a slight improvement, indicating strong overall support for the use of these technologies in welding design and manufacturing.

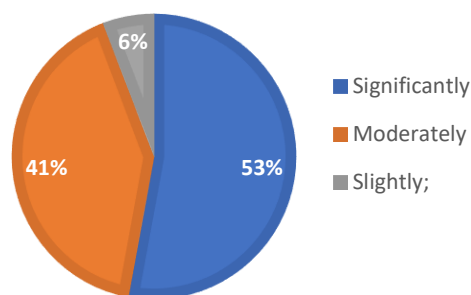


Figure 16. Perceived Benefits of 3D/VR/AR Visualisation for design for manufacturability

Perceived Utility of AR/VR for overlapping welded joints and Welded Sequence directly on the part to avoid limitations and deformations

Conclusion (Figure 17): The results indicate that most respondents consider AR/VR highly beneficial for visualising welded joints and welding sequences, with 52.9% rating these technologies as very useful and 24.0% as extremely useful. Additionally, 22.3% consider them useful, while only 0.8% perceive them as only somewhat useful, demonstrating strong support for the application of AR/VR to improve weld planning and reduce manufacturing limitations and deformations.

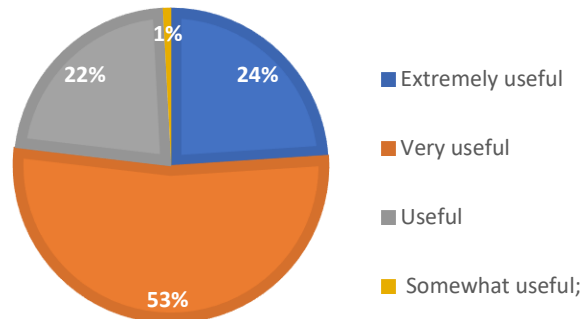


Figure 17. Perceived Utility of AR/VR for Weld Sequence Planning and Joint Accessibility

Perceived Appropriateness using AR/VR/AI for Design Optimisation (e.g., positioning of joints, thickness, beads) based on experimental data

Conclusion (Figure 18): The results indicate that respondents strongly support the use of AR/VR/AI for welding design optimisation based on experimental data, with 47.9% considering it appropriate and 42.1% highly appropriate. Only 9.1% expressed a neutral opinion, while just 0.8% considered these technologies inappropriate.

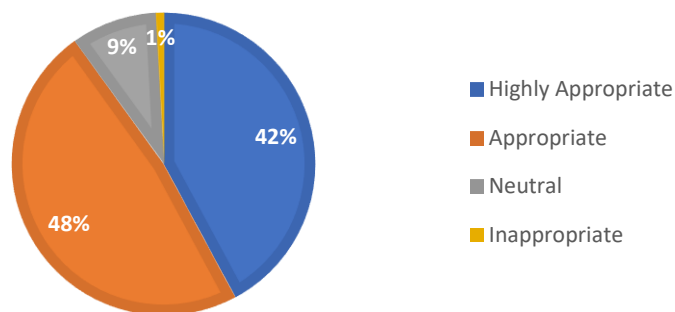


Figure 18. Perceived Appropriateness of AR/VR/AI for Design Optimisation

Essential Digital Functionalities most essential for Welded Structure Design

Conclusion (Figure 19): The results indicate that thermomechanical simulations are considered the most essential digital functionality for welded structure design, accounting for 51.1% of responses. WPS libraries integration was selected by 30.5% of respondents, while 18.4% identified normative checks automation as the most important functionality.

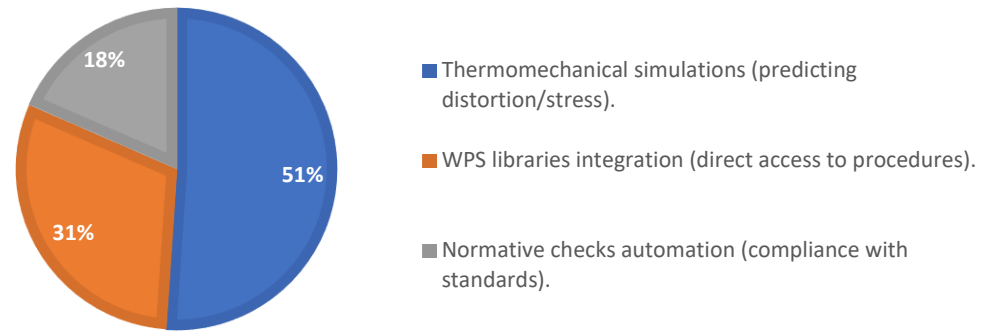


Figure 19. Essential Digital Functionalities for Welded Structure Design

3.1.6. Section F: Manufacturing Problems of Welded Structures

Perceived Usefulness of AR/VR for simulating the Manufacturing Flow (assembly-welding-NDT) to identify bottlenecks and risk areas

Conclusion (Figure 20): The results indicate strong support for the use of AR/VR in simulating the manufacturing flow (assembly → welding → NDT), with 45.0% of respondents rating its usefulness as high and 36.7% as very high. A further 16.7% considered it moderately useful, while only 1.7% perceived little or no value, highlighting the potential of AR/VR to identify production bottlenecks and risk areas

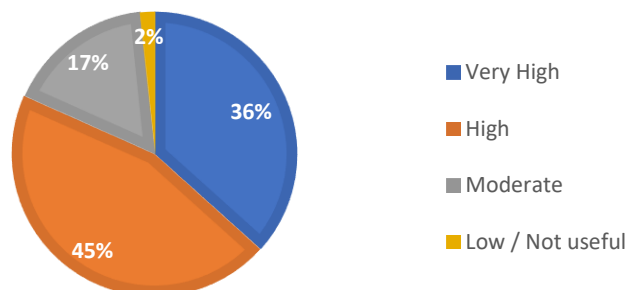


Figure 20. Perceived Usefulness of AR/VR for Manufacturing Flow Simulation

Perceived Efficiency of AR/VR in Reducing Assembly Errors (alignment, joint setup) before arcing

Conclusion (Figure 21): The results indicate that respondents perceive AR/VR as highly effective in reducing assembly errors before arcing, with 38.3% rating its efficiency as much and 35.8% as significant. Additionally, 25.0% consider it moderately effective, while only 0.8% perceive a slight benefit, demonstrating strong confidence in the use of AR/VR for improving assembly alignment and joint setup.

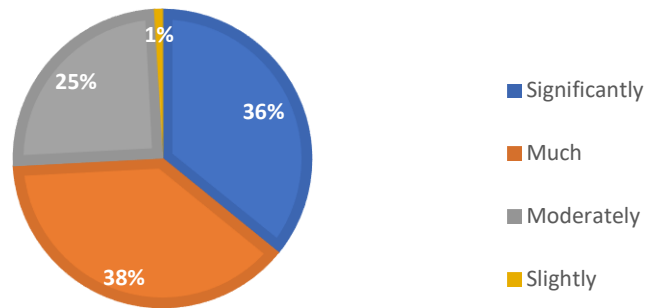


Figure 21. Perceived Efficiency of AR/VR in Reducing Assembly Errors

Perceived Real-Time Utility of AR/VR/AI for identifying non-conformity (e.g., out-of-tolerance parameters) to prevent repairs

Conclusion (Figure 22): The results indicate that respondents strongly support the use of AR/VR/AI for real-time identification of non-conformities, with 47.9% rating these technologies as very useful and 34.5% as extremely useful. Only 16.8% considered them useful, while just 0.8% perceived them as not useful.

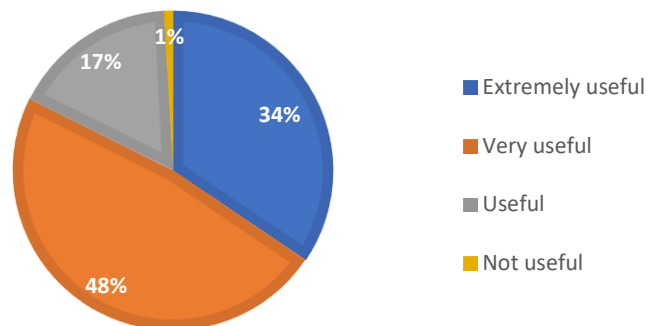


Figure 22. Perceived Utility of AR/VR/AI for Real-Time Non-Conformity Detection

Perceived Contribution of VR/AR/AI to ISO 3834 Compliance for pre/during/post-weld inspection and traceability of materials and consumables

Conclusion (Figure 23): The results indicate that 43.8% of respondents believe VR/AR/AI moderately facilitates compliance with ISO 3834 requirements, while 39.7% perceive a significant contribution. Only 14.9% reported a slight contribution, and 1.7% considered that these technologies do not facilitate compliance at all.

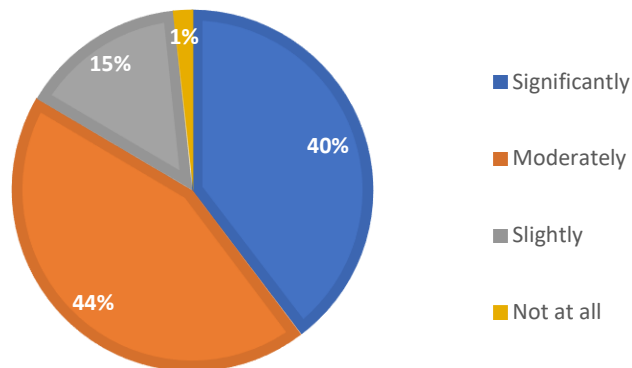


Figure 23. Perceived Contribution of VR/AR/AI to ISO 3834 Compliance

Essential Elements to include in an Ideal Virtual Workshop for Professional Training

Conclusion (Figure 24): The results indicate that real-time physics simulation of the weld pool is considered the most essential element of an ideal virtual workshop (68.6%), followed by equipment setup simulation (26.4%), while safety hazard scenarios were selected by only 5.0% of respondents.

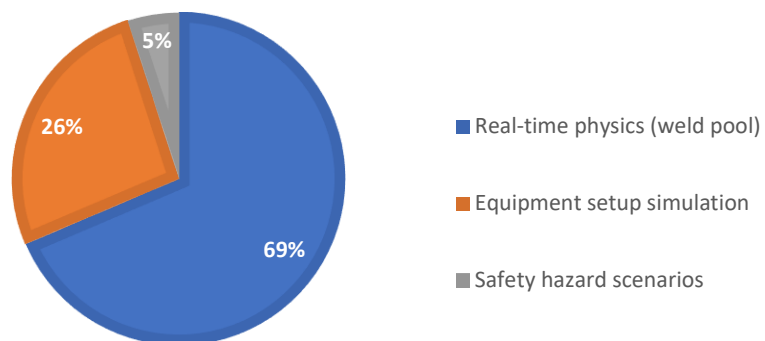


Figure 24. Essential Elements of an Ideal Virtual Workshop for Professional Training

Perceived Usefulness of VR/AR for Real-Time Defect Detection (e.g., porosity, undercut) during the processes

Conclusion (Figure 25): The results indicate strong support for VR/AR tools that provide real-time defect alerts during welding, with 51.2% of respondents considering them essential and 43.0% useful. Only 4.1% rated them as somewhat useful, while 1.7% considered them not useful.

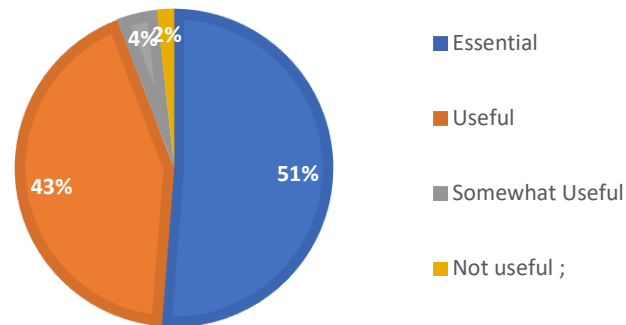


Figure 25. Perceived Usefulness of VR/AR for Real-Time Defect Detection

Perceived usefulness of using VR/AR to Simulate Weld Calculations (e.g., cooling rates, heat input) to improve the PQR and WPS development process

Conclusion (Figure 26): The results indicate strong support for using VR/AR to simulate weld calculations for PQR and WPS development, with 47.5% of respondents rating it as highly useful and 45.0% as useful. Only 5.0% considered it somewhat useful, while 2.5% found it not useful.

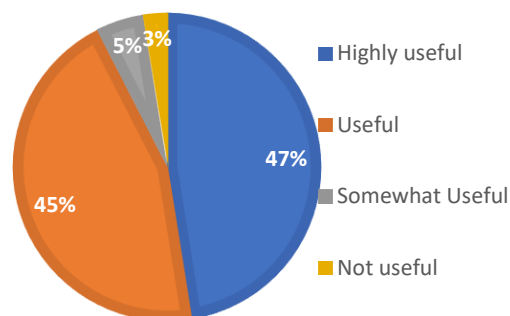


Figure 26. Perceived Usefulness of VR/AR for Simulating Weld Calculations

Preferred VR/AR Laboratory Exercises for Professional Training

Conclusion (Figure 27): The results indicate that Visual Inspection was the most preferred VR/AR laboratory exercise (35.3%), followed by Repair Management (21.8%), Virtual Auditing (21.4%), and Procedure Validation (20.7%). Only 0.8% of respondents selected other types of exercises.

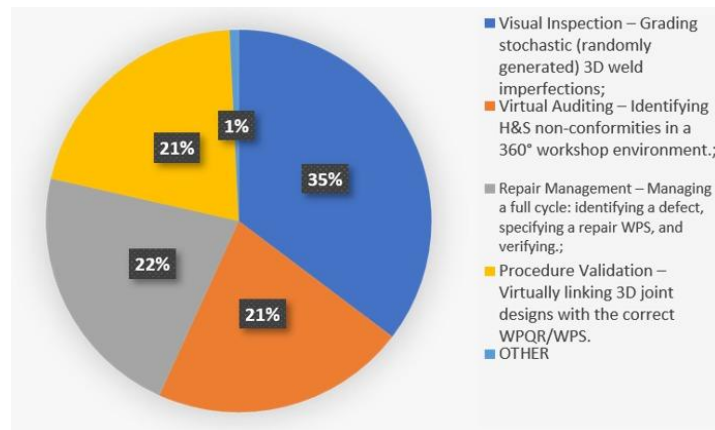


Figure 27. Preferred VR/AR Laboratory Exercises for Professional Training

3.1.7. Section G: XR Benefit Validation Strategic Training Scope

Technical review (ISO 14731) perceived Usefulness of AR/VR to check Torch Accessibility in complex 3D geometries before production

Conclusion (Figure 28): The results indicate strong support for using AR/VR to assess torch accessibility during the ISO 14731 technical review, with 45.5% of respondents rating it as highly valuable and 31.4% considering it strategically important. Only 19.0% perceived moderate value, while 4.1% considered it to have no value.

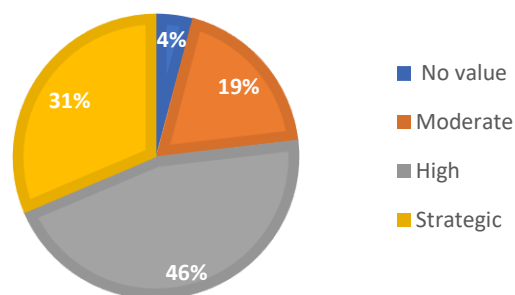


Figure 28. Perceived Usefulness of AR/VR for Torch Accessibility Assessment

Perceived Usefulness of AR/VR for Material and Consumable selection against digital certificates

Conclusion (Figure 29): The results indicate strong support for using AR/VR to virtually validate materials and consumables against digital certificates, with 49.2% of respondents rating it as highly valuable and 26.7% as strategically important. Only 20.0% perceived moderate value, while 4.2% considered it to have no value.

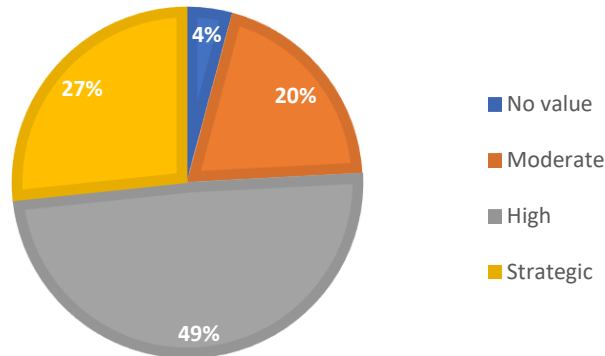


Figure 29. Perceived Usefulness of AR/VR for Material and Consumable Validation

Perceived Usefulness of 3D Weld Imperfection Simulation for Inspection and testing of welded joints

Conclusion (Figure 30): The results indicate strong support for using randomly generated 3D weld imperfections in NDT/DT training, with 45.5% of respondents rating this approach as highly valuable and 30.6% as strategically important. Only 21.5% perceived moderate value, while 2.5% considered it to have no value.

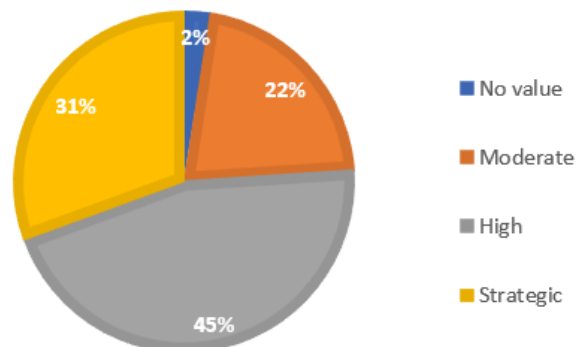


Figure 30. Perceived Usefulness of 3D Weld Imperfection Simulation for Weld Inspection

Perceived Usefulness of AR/VR for Training in Non-Conformity Management, Corrective Actions, and Repair Cycle Management, from Defect to Resolution

Conclusion (Figure 31): The results indicate strong support for using AR/VR to manage the repair cycle, with 44.2% of respondents rating it as highly valuable and 35.8% as strategically important. Only 17.5% perceived moderate value, while 2.5% considered it to have no value.

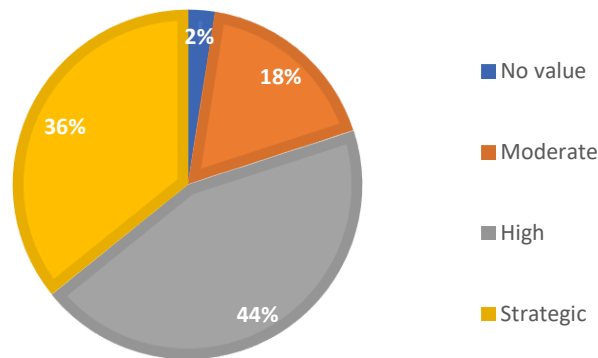


Figure 31. Perceived Usefulness of AR/VR for Repair Cycle Management

Perceived Usefulness of XR to assess and monitor the performance levels for Welding Personnel

Conclusion (Figure 32): The results indicate positive perceptions of XR for welding personnel qualification, with 40.5% of respondents rating it as highly valuable and 24.0% as strategically important. Meanwhile, 29.8% perceived moderate value, and only 5.8% considered it to have no value.

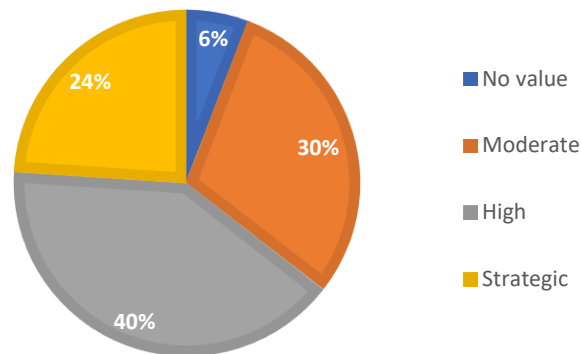


Figure 32. Perceived Usefulness of XR for Welding Personnel Qualification

Perceived Usefulness of XR for Heat Treatment (PWHT) Visualisation: cooling rates and preheating requirements to prevent cracking

Conclusion (Figure 33): The results indicate strong support for using XR to visualise PWHT, cooling rates, and preheating requirements, with 51.7% of respondents rating it as highly valuable and 30.0% as strategically important. Only 17.5% perceived moderate value, while just 0.8% considered it to have no value.

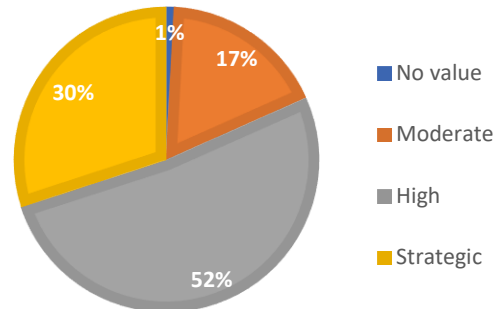


Figure 33. Perceived Usefulness of XR for PWHT Visualisation

Perceived Usefulness of XR for Virtual Auditing: identifying safety and environmental non-conformities in a 360 virtual workshop audit.

Conclusion (Figure 34): The results indicate strong support for using XR in virtual auditing, with 43.0% of respondents rating it as highly valuable and 25.6% as strategically important. Meanwhile, 28.1% perceived moderate value, and only 3.3% considered it to have no value.

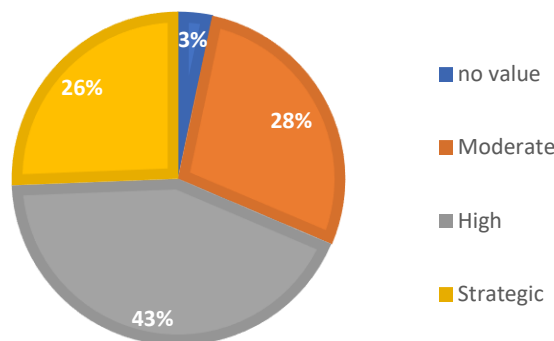


Figure 34. Perceived Usefulness of XR for Virtual Auditing

Perceived Usefulness of XR for determination of welding procedures (WPS/PQR)

Conclusion (Figure 35): The results indicate strong support for using XR in WPS/PQR development, with 50.4% of respondents rating it as highly valuable and 30.3% as strategically important. Only 16.8% perceived moderate value, while 2.5% considered it to have no value.

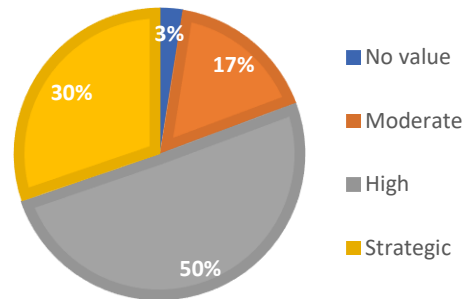


Figure 35. Perceived Usefulness of XR for WPS/PQR Development

Perceived Usefulness of XR for Weld Defect Data Collection

Conclusion (Figure 36): The results indicate very strong support for using XR to collect weld defect data, with 49.6% of respondents rating it as strategically important and 39.7% as highly valuable. Only 9.9% perceived moderate value, while just 0.8% considered it to have no value.

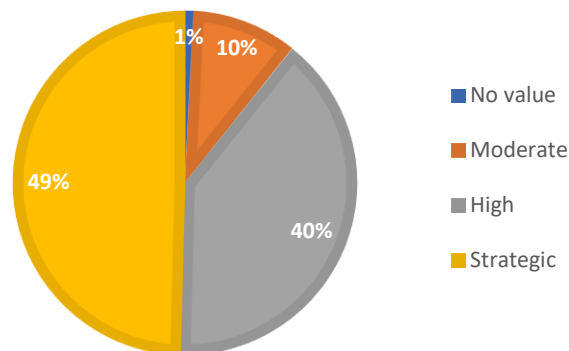


Figure 36. Perceived Usefulness of XR for Weld Defect Data Collection

Perceived Usefulness of XR for Heat Input Monitoring in welding processes

Conclusion (Figure 37): The results indicate strong support for using XR to monitor heat input in welding processes, with 48.8% of respondents rating it as highly valuable and 34.7% as

strategically important. Only 14.9% perceived moderate value, while just 1.7% considered it to have no value.

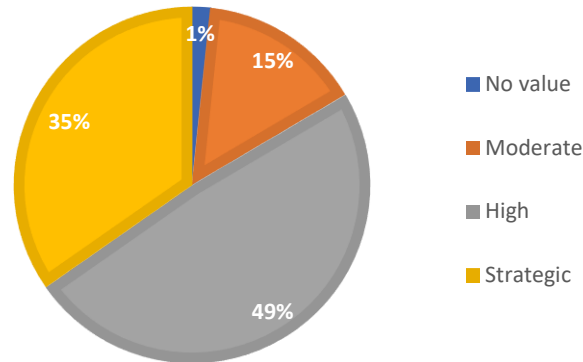


Figure 37. Perceived Usefulness of XR for Heat Input Monitoring

Perceived Usefulness of XR for Welded Joint Design

Conclusion (Figure 38): The results indicate that XR technologies are considered highly valuable for the design of welded joints, with 48.8% of respondents rating their value as High and 32.2% as Strategic. Only 18.2% perceived a Moderate value, while 0.8% saw No value, demonstrating strong confidence in the potential of XR for supporting welded joint design.

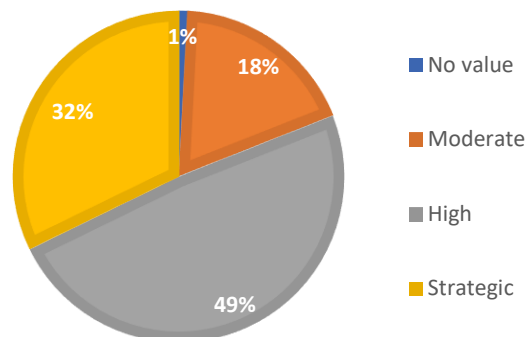


Figure 38. Perceived Usefulness of XR for Welded Joint Design

Additional comments

Regarding welding and cutting processes:

- A very good idea that deserves to be implemented!

- I believe that, for a person to decide whether they would enjoy welding in practice truly, it is essential to experience the real feedback involved—such as noise, smell, light, and other physical

sensations. This is why hands-on practice remains strongly supported and necessary in any field of activity, as it helps a person determine whether they genuinely want to learn specific welding processes, work as a welder, assemble components, and engage with the complexity of the profession according to their own motivation and willingness to learn. Welding is a special process and one of the most important in metal fabrication. While we can learn almost anything—mathematics, languages, physics, occupational safety, and so on—with the help of AI and Virtual Reality, physical skills require a physical approach; otherwise, we cannot train the brain to perform certain movements simply by observing them.

- These technologies are excellent tools for accelerated learning, standardisation, and safety, but they cannot replace the practical, sensory experience required for the certification and performance of a professional welder.

- "As a technical and pedagogical conclusion regarding the integration of XR technologies into IWE (International Welding Engineer) training, it is essential to view these tools not as a universal solution or a "silver bullet," but as a competence catalyst. The following additional arguments and technical justifications support the previous assessments, particularly about welding and cutting processes:

- 1. Process-by-process justification (MMA vs. MIG/MAG vs. TIG). For the MMA process (111): The importance of XR is critical for mastering three-dimensional movement. The trainee must perform two movements simultaneously: linear travel along the joint and progressive electrode advancement toward the weld pool as the electrode is consumed. The simulator is ideal for isolating and mastering this fine coordination. For the MIG/MAG process (135): The correlation between wire feed speed (vs) and arc voltage (U) determines the transfer mode (short-circuit, spray, globular). XR makes it possible to graphically visualise the operating window (WPS) in which these variables work optimally, giving the future engineer an intuitive understanding of arc stability. For the TIG process (141): Although its usefulness is moderate due to tactile complexity, XR eliminates one of the costliest beginner mistakes: touching the tungsten electrode to the weld pool or the filler rod, an action that in real practice immediately contaminates the weld and requires work to stop so that the electrode can be reground.*
- 2. Cutting processes (oxygen, plasma, laser) Although the focus is often on welding, IWE training also includes thermal cutting technologies. In this case, VR/AR simulation is extremely useful for oxygen cutting: providing a visual understanding of the preheating flame (neutral, carburising, or oxidising flame) and of nozzle-to-plate distance control to prevent backfire/flashback, which is a major safety risk in real-world practice. Plasma cutting maintaining the correct torch angle to achieve a perpendicular cut without excessive dross formation.*
- 3. The economic and sustainability argument from the perspective of an IWE programme manager: beyond learning speed, the ecological and financial arguments are irrefutable. One hour of virtual welding means: zero welding fume and gas emissions (reducing workshop ventilation and filtration costs); zero consumption of expensive shielding gases (argon, helium mixtures) and filler metals (high-alloy steels, aluminium); zero waste (Test plates cut and welded only to be discarded as scrap). Final thought: technologies enhanced by AI shift the training burden from the area of "physical trial and error"—where trainees waste materials to understand a concept—to the area of "preliminary cognitive analysis." When the trainee eventually enters the real workshop, they are no longer a*

confused beginner, but an informed operator who uses the welding booth only to calibrate the physical feel that technology still cannot replicate."

Additional comments

Provide specific technical insights regarding materials behaviour, especially concerning ISO standards

XR/AI technologies can enhance welding engineering training by helping learners understand metallurgical phenomena, welding parameters, and ISO requirements through simulation and visualisation. However, they should be used as complementary educational tools, not as substitutes for real testing and practical experience.

VR/AR and AI technologies are valuable tools for training and preliminary analysis, but they cannot replace real tests and the technical expertise required by ISO standards. They should be used as decision-support tools, not as substitutes or replacements for qualification and verification processes.

Additional comments:

How VR/AR/AI can optimise the design of welded structures:

- *Simulation of welded joints under extreme conditions, such as narrow gap, misalignment, wide gap, etc.*
- *VR/AR and AI can optimise the design of welded structures by enabling the early identification of limitations, the visualisation of access conditions and welding sequences, and the reduction of distortions through simulations, data-driven recommendations, training, and access to databases.*
- *The combined application of Virtual Reality (VR) for ergonomic assessment, accessibility analysis, and full-scale geometric visualisation, Augmented Reality (AR) for real-time execution guidance and error prevention, and Artificial Intelligence (AI) for predictive metallurgical analysis, structural optimisation, and intelligent decision support fundamentally transforms the role of the International Welding Engineer (IWE). Rather than serving solely as a designer of welded joints, the IWE becomes a lifecycle manager of welded structures, capable of ensuring compliance with international standards, improving structural performance and safety, reducing manufacturing defects and distortion, and achieving substantial economic optimisation throughout the entire design, fabrication, and maintenance process.*

3.1.8 Final Comments from the Engineers' Questionnaire

- *It is a very good idea that deserves to be implemented!*
- *I am available to collaborate on optimising teaching methods and working with VR and AI.*

- *I believe that every IWE should have an overall view of the projects they are involved in and should maintain flexibility in their relationships with the welding foreman and the welders.*
- *Greater emphasis should be placed on the preparation of WPS, qualification files, approval files, and the learning of essential variables. In addition to knowing how to calculate preheating temperature and perform other technical calculations, a welding engineer should also know how to prepare a qualification file, an authorisation renewal file, and a welding procedure qualification file. At present, the course/examination is based mainly on the mechanical memorisation of information. Practical training is essential, and VR technology could significantly support the learning process.*
- *The integration of XR into I/EWE qualification enhances training quality by simulating access conditions, welding sequences, and associated risks, while providing a safe and controlled environment for technical analysis, competence assessment, and the understanding of thermal phenomena without the consumption of logistical resources, materials, or energy.*
- *I did train at TWI, and it has a very well-structured ONLINE training that helps the student learn better and faster.*
- *The combined implementation of VR, AR, AI, Digital Twins, predictive simulations, and intelligent data analytics fundamentally transforms the education and professional role of the International/European Welding Engineer. Rather than functioning solely as a specialist responsible for welding procedures and documentation, the modern IWE/EWE becomes a digital lifecycle manager of welded structures, capable of integrating design optimisation, process simulation, quality assurance, traceability, predictive maintenance, and risk management into a unified digital workflow.*
- *Rather than functioning solely as a specialist responsible for welding procedures and documentation, the modern IWE/EWE becomes a digital lifecycle manager of welded structures, capable of integrating design optimisation, process simulation, quality assurance, traceability, predictive maintenance, and risk management into a unified digital workflow.*
- *By aligning advanced digital technologies with international standards—including ISO 14731, ISO 3834, ISO 15614-1, ISO 13920, ISO 9606, EN 1090, Eurocode 3, and the IIW/IAB training guidelines—future welding engineers will be better equipped to improve structural performance, enhance safety, reduce production costs, accelerate qualification processes, and support the digital transformation of the welding industry within the framework of Industry 4.0 and beyond. By aligning advanced digital technologies with international standards—including ISO 14731, ISO 3834, ISO 15614-1, ISO 13920, ISO 9606, EN 1090, Eurocode 3, and the IIW/IAB training guidelines—future welding engineers will be better equipped to improve structural performance, enhance safety, reduce production costs, accelerate qualification processes, and support the digital transformation of the welding industry within the framework of Industry 4.0 and beyond. By aligning advanced digital technologies with international standards—including ISO 14731, ISO 3834, ISO 15614-1, ISO 13920, ISO 9606, EN 1090, Eurocode 3, and the IIW/IAB training guidelines—future welding engineers will be better equipped to improve structural performance, enhance safety, reduce*

production costs, accelerate qualification processes, and support the digital transformation of the welding industry within the framework of Industry 4.0 and beyond.

- *I think that the application of AR/VR/MR may still be in the introduction phase, but it is important to look for adequate areas.*
- *I'll contact you to understand if there are any possibilities to collaborate with the consortium project.*
- *If a welder hasn't been burned and choked on smoke, he's not a real welder.*
- *Simulators may be integrated into the IWE/IWT/IWS curriculum, but only as a supplementary teaching method, not as a substitute for the mandatory requirements set out in IAB-252r5*
- *A combination of traditional/practical activities and the new IWE/IWT qualification system is recommended.*
- *XR integration will become essential for the training of welding engineers, as it enables accessibility validation, WPS/WPQR optimisation, and real-time digital quality monitoring. In the short term, XR accelerates learning; in the medium term, it will standardise competence assessment; and in the long term, it will connect training with ISO requirements and digital workflows in the factory.*

3.2. Survey results from the Industry Stakeholder questionnaire

Age of respondents

Conclusion (Figure 39): The respondents were evenly distributed by age, with 51.2% aged over 40 and 48.8% under 40, ensuring a balanced representation of both experienced and younger professionals.

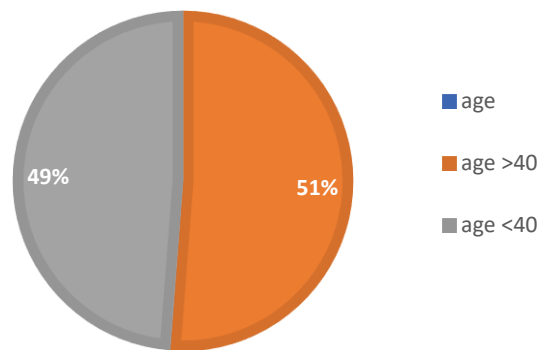


Figure 39. Age of respondents

Welding experience

Conclusion (Figure 40): The respondents had a well-balanced level of welding experience, with 49 % having 5–20 years of experience, while 25.5% had more than 20 years and 25.5% had less than 5 years, ensuring representation across different experience levels.

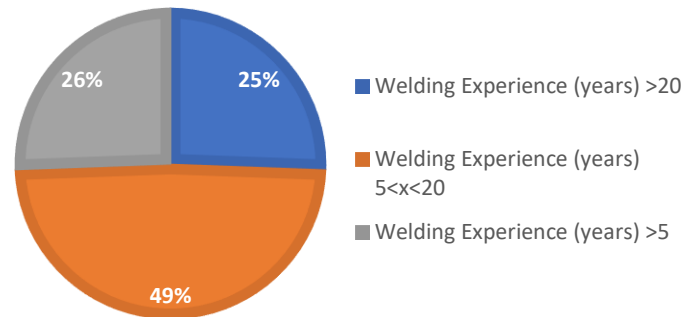


Figure 40. Welding experience

Current role

Conclusion (Figure 41): The respondents represent a diverse range of professional roles, with Engineers (46.5%) and Welding Engineers (14.0%) forming most of the sample. This distribution indicates that the survey primarily reflects the perspectives of technical professionals while also incorporating insights from managerial and academic positions.

Count of Current role:

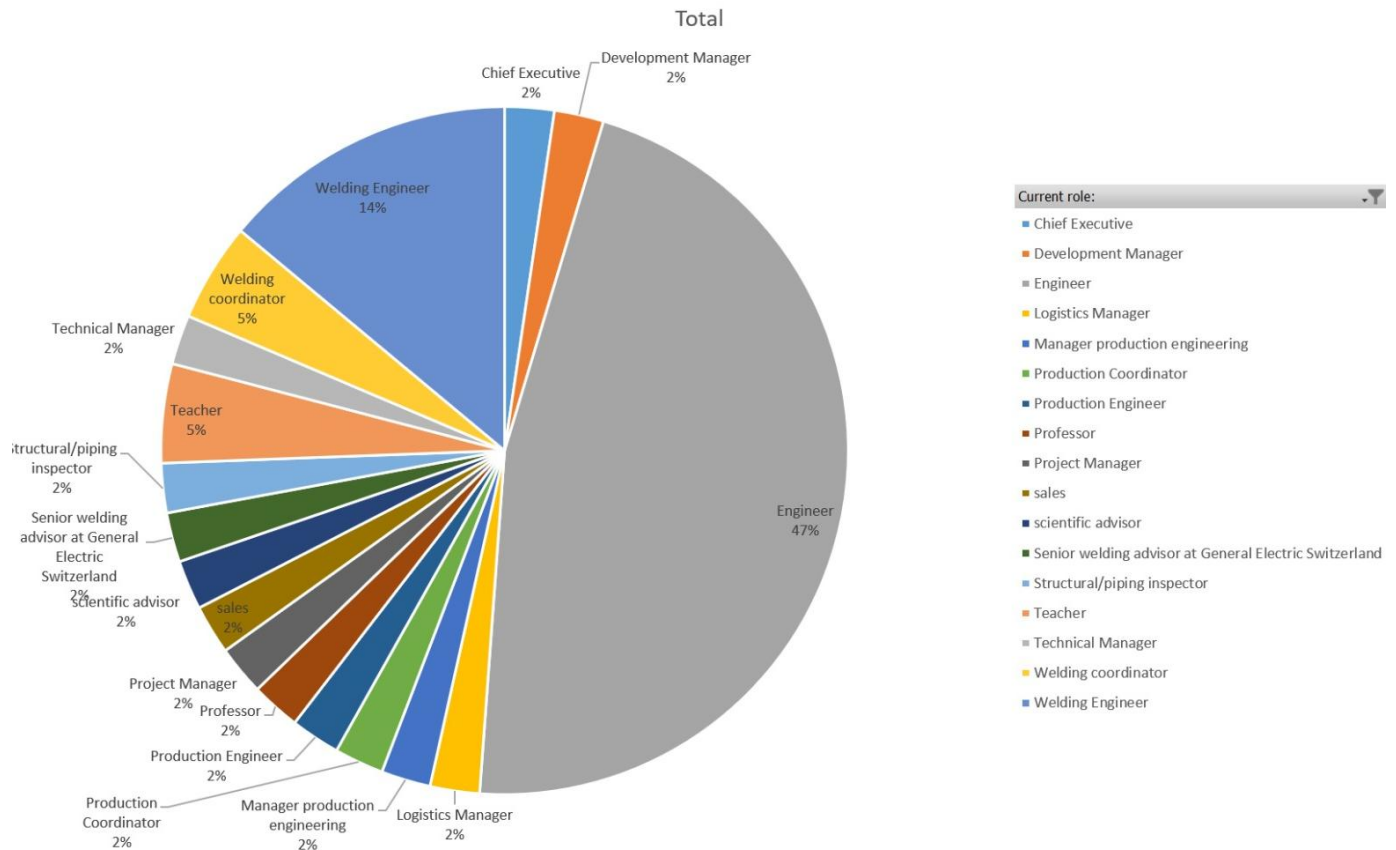


Figure 41. Current role

Previous experience with VR/AR/AI

Conclusion (Figure 42): The results show that most respondents (75.0%) had no previous experience with VR/AR/AI technologies, indicating that these technologies are still relatively new to most participants.

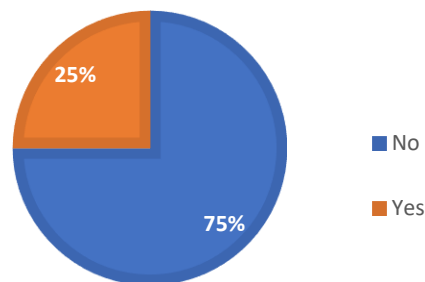


Figure 42. Previous experience with VR/AR/IA

3.2.1. Section A: Profile

Company's main field of activity

Conclusion (Figure 43): The respondents represented a diverse range of industrial sectors, with metal constructions accounting for the largest share (40.8%), followed by other industries (20.4%), energy/oil and gas (18.4%), and pressure equipment (10.2%) and transport/naval (10.2%), ensuring broad sectoral representation.

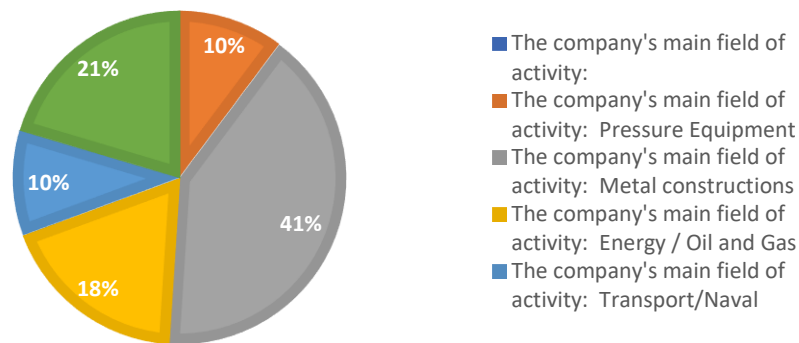


Figure 43. Company's main field of activity

Country of residence:

Conclusion (Figure 44): The survey included respondents from eight countries, with Romania (50.0%) and Poland (36.4%) accounting for the vast majority of participants, while Austria, Hungary, Ireland, Italy, Serbia, and Switzerland each contributed 2.3%, providing an international perspective with a strong representation from Eastern Europe.

The respondents were primarily from Romania (50%) and Poland (38%), with the remaining participants providing a geographically diverse sample.

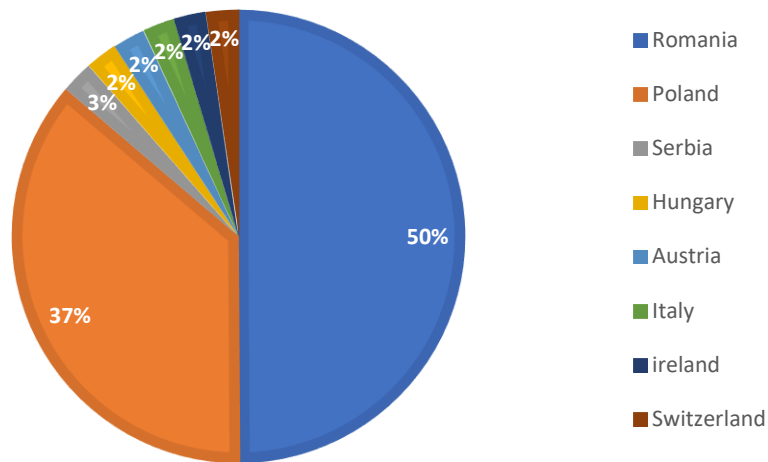


Figure 44. Country of Residence of Survey Respondents

Company size (number of employees)

Conclusion (Figure 45): The respondents were employed in companies of various sizes, with large companies (34.1%) being the most represented, followed by medium (29.5%) and small enterprises (25.0%), indicating a well-balanced organisational distribution.

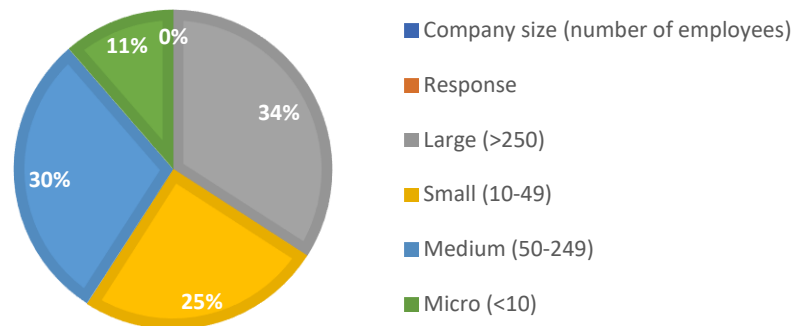


Figure 45. Company size

Company Demand for International Welding Engineers (IWE)

Conclusion (Figure 46): The results show that 52.3% of respondents already employ International Welding Engineers (IWE), while 22.7% are currently training IWE candidates, meaning that 75.0% of companies recognise the need for IWE qualifications, whereas 25.0% do not currently plan to employ or incorporate IWE professionals.

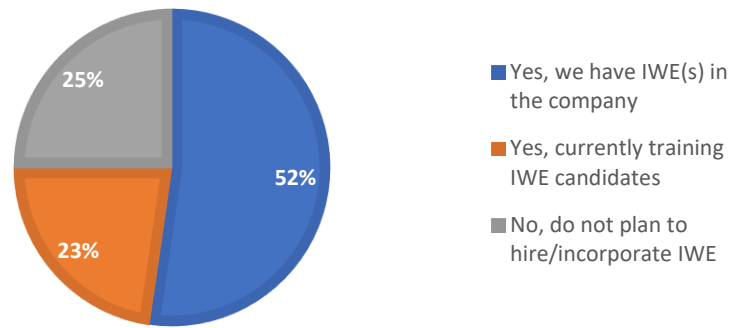


Figure 46. Company Demand for International Welding Engineers (IWE)

3.2.2. Section B: Competence needs

Importance of Continuous Training for Welding Personnel

Conclusion (Figure 47): The findings show that continuous training of welding personnel is considered highly important, with 93.2% of respondents rating it as either very important (61.4%) or important (31.8%), highlighting its key role in industry practice.

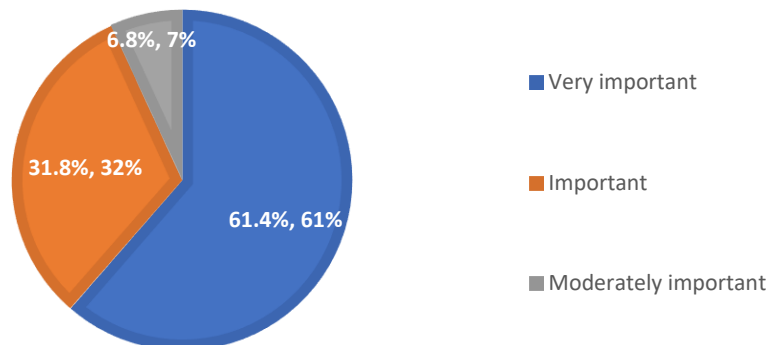


Figure 47. Importance of Continuous Training for Welding Personnel

Main Obstacles to Personnel Training

Conclusion (Figure 48): The results indicate that the main barriers to personnel training are high costs (44.6%) and production downtime (33.8%), while limited access to training centers (9.2%), equipment availability (6.2%), practical training risks (3.1%), labour shortages (1.5%), and a lack of interested candidates (1.5%) are less frequently reported challenges.

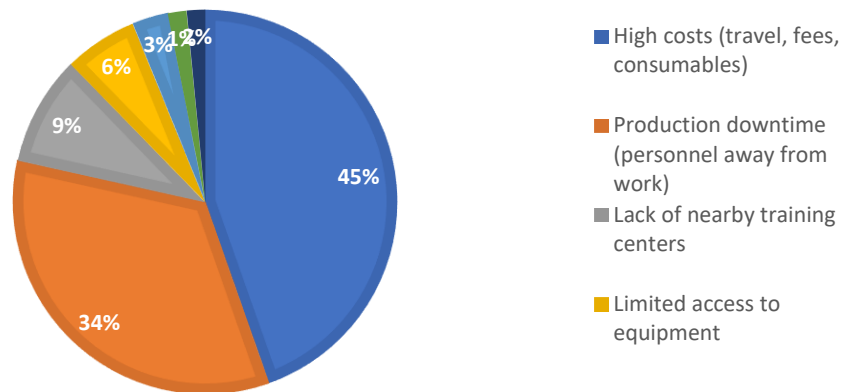


Figure 48. Main Obstacles to Personnel Training

Most Critical Training Areas for Companies

Conclusion (Figure 49): The findings indicate that welding process practical skills (30.6%) are considered the most critical training area, followed by interpretation of standards and codes (24.5%), quality control and inspection (NDT) (19.4%), and Health, Safety & Environment (HSE) (17.3%). PWHT (7.1%) and failure analysis (1.0%) were identified as lower training priorities.



Figure 49. Most Critical Training Areas for Companies

3.2.3. Section C: Perception of VR/AR

Familiarity with the Use of VR/AR in Training

Conclusion (Figure 50): The results indicate that awareness of VR/AR in training is limited, with only 13.6% of respondents reporting familiarity, while 50.0% were only partially familiar and 36.4% had no familiarity with these technologies.

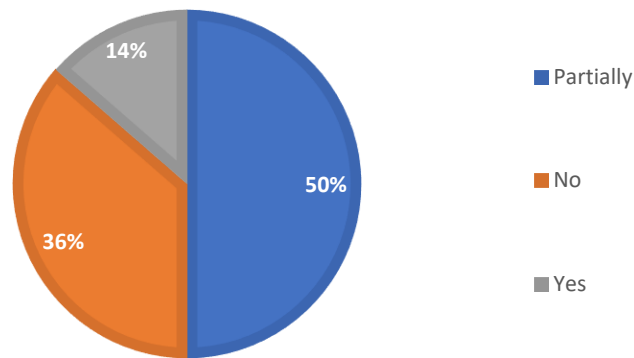


Figure 50. Familiarity with the Use of VR/AR in Training

Perceived Benefits of VR/AR Technologies for Welding Engineer Training

Conclusion (Figure 51): The findings indicate a strongly positive perception of VR/AR technologies, with 79.5% of respondents rating their potential benefits for welding engineer training as high or very high, demonstrating broad confidence in their value for education and skills development.

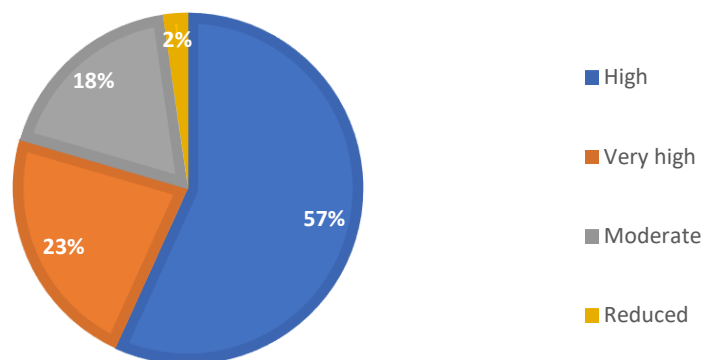


Figure 51. Perceived Benefits of VR/AR Technologies for Welding Engineer Training

Areas Where VR/AR Technologies Are Most Useful in Welding Engineer Training

Conclusion (Figure 52): The results indicate that respondents see the greatest potential for VR/AR/AI technologies in welding processes (26.6%) and defect analysis (23.8%), followed by safety and risk prevention (16.1%), design of welded structures (12.6%), and manufacturing planning (11.9%). Lower priorities were assigned to PWHT (8.4%) and manual skills training (0.7%).

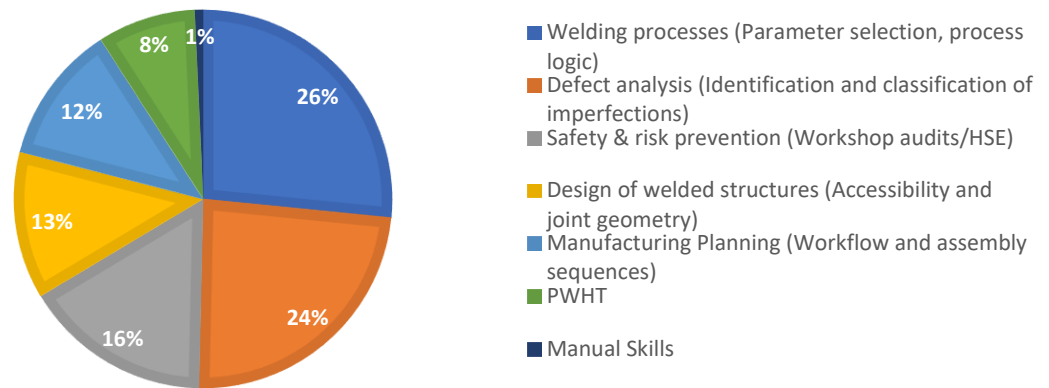


Figure 52. Areas Where VR/AR Technologies Are Most Useful in Welding Engineer Training

3.2.4. Section D: Interest and involvement

Interest in a Modernised IWE Course Using VR/AR/AI Technologies

Conclusion (Figure 53): The results indicate a high level of acceptance, with 97.7% of respondents considering the implementation of VR/AR technologies either possible (50.0%) or feasible (47.7%), while only 2.3% expressed a negative opinion.

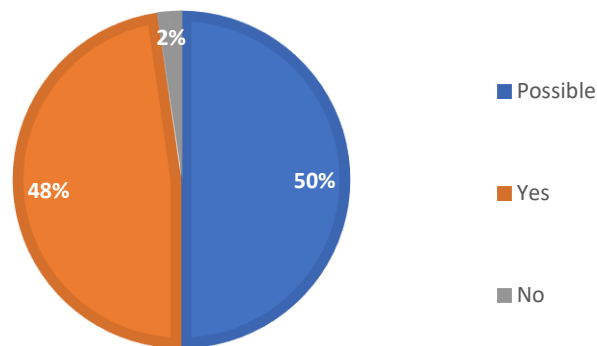


Figure 53. Interest in a Modernised IWE Course Using VR/AR/AI Technologies

Preferred Type of Involvement

Conclusion (Figure 54): The results indicate that most companies expressed at least some interest in the initiative, with 43.2% requesting information only and 31.8% willing to send learners, while a smaller proportion were interested in project partnership (18.2%) or pilot testing (6.8%).

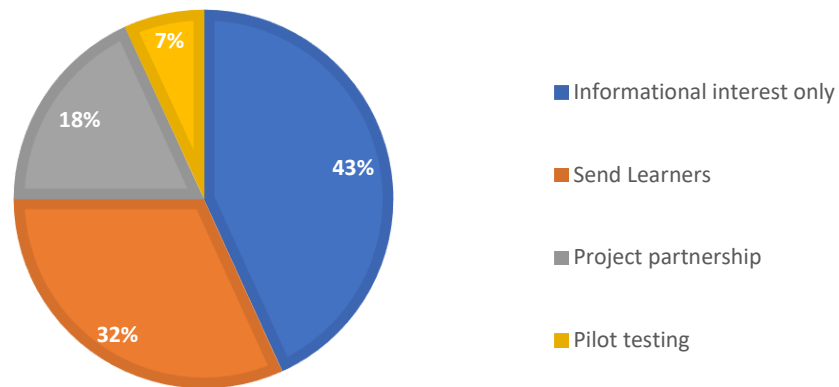


Figure 54. Preferred Type of Involvement

Perceived Usefulness of AR/VR Simulation for Practical Welding Training (MMA/MIG-MAG/TIG(welding position and pool control))

Conclusion (Figure 55): The results demonstrate a strong positive perception of AR/VR simulation, with 86.4% of respondents rating its usefulness as high or very high, highlighting its significant potential for practical welding training.

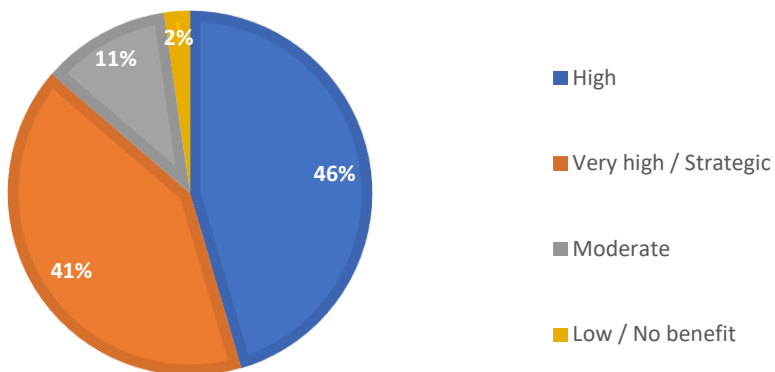


Figure 55. Perceived Usefulness of AR/VR Simulation for Practical Welding Training

Perceived Impact of AR/VR on Training for Welding Parameter Setting(current/voltage/gas) on real equipment

Conclusion (Figure 56): The findings reveal strong confidence in the value of AR/VR for training in welding parameter setting, with 93.2% of respondents rating its impact as high or very high, indicating broad support for integrating these technologies into practical welding education.

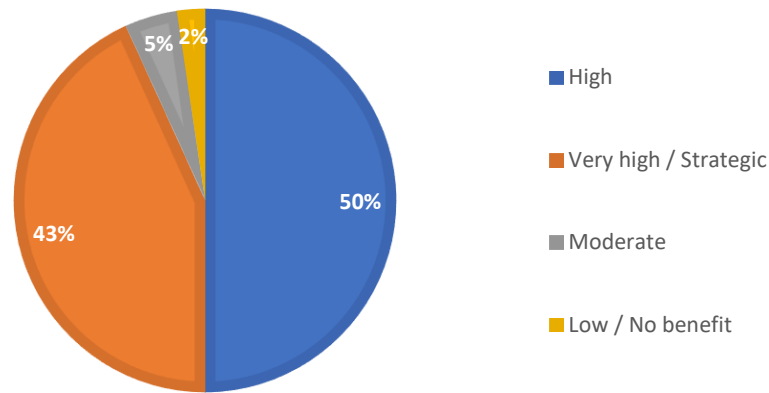


Figure 56. Perceived Impact of AR/VR on Training for Welding Parameter Setting

Perceived Usefulness of AI/AR/VR for Providing immediate Feedback on deviations (speed, angle, distance)

Conclusion (Figure 57): The results indicate overwhelming support for AI/AR/VR-based real-time feedback, with 95.5% of respondents rating its usefulness as high or very high, demonstrating strong confidence in its ability to improve welding performance through immediate correction of deviations in speed, angle, and distance

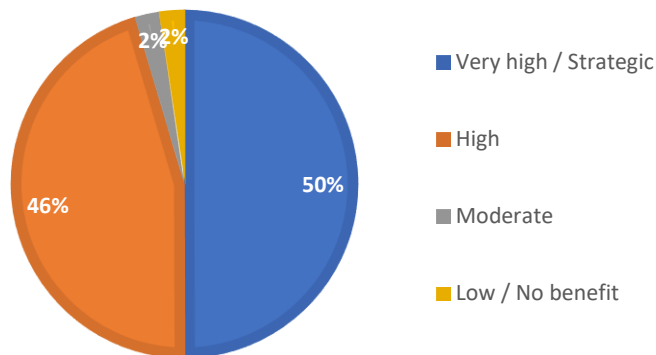


Figure 57. Perceived Usefulness of AI/AR/VR for Providing Real-Time Feedback During Welding Training

Perceived Usefulness of AR/VR for Simulating Manufacturing Flow and Identifying Risk Areas

Conclusion (Figure 58): The results indicate that AR/VR simulation of the manufacturing flow is widely perceived as beneficial, with 52.3% of respondents rating its usefulness as high and 13.6% as very high, while 29.5% considered it moderately useful and only 4.5% perceived little or no benefit.

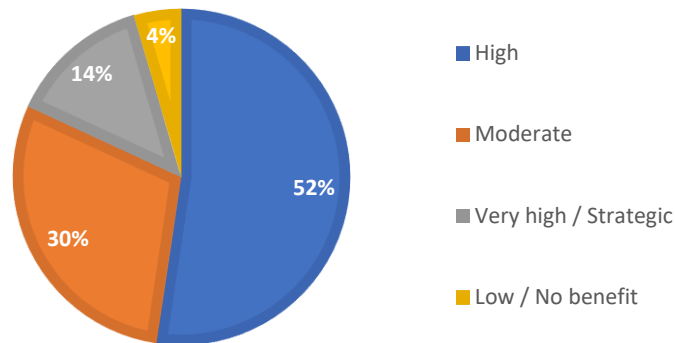


Figure 58. Perceived Usefulness of AR/VR for Simulating Manufacturing Flow and Identifying Risk Areas

Perceived Value of an AR/VR Model for Understanding the Heat-Affected Zone (HAZ) and Residual Stresses

Conclusion (Figure 59): The results indicate that AR/VR models illustrating the heat-affected zone (HAZ) and residual stresses are considered valuable for improving the understanding of welding phenomena, with 52.3% of respondents rating their usefulness as high and 15.9% as very high, while 25.0% considered them moderately useful and only 6.8% perceived little or no benefit.

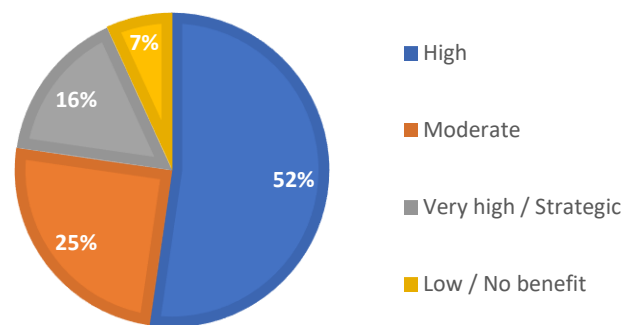


Figure 59. Perceived Value of an AR/VR Model for Understanding the Heat-Affected Zone (HAZ) and Residual Stresses

Perceived Usefulness of VR/AR for Understanding the Influence of Filler Materials and Shielding Gases on Microstructure

Conclusion (Figure 60): The results indicate that 47.7% of respondents rated the usefulness as high and 18.2% as very high, demonstrating strong support for the application. Additionally, 27.3% considered it moderately useful, while only 6.8% perceived little or no benefit.

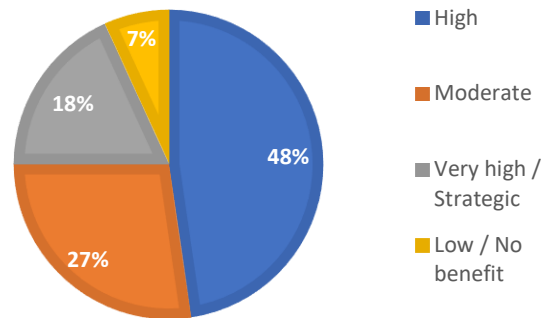


Figure 60. Perceived Usefulness of VR/AR for Understanding the Influence of Filler Materials and Shielding Gases on Microstructure

Perceived Usefulness of 3D/VR Visualisation for Improving Design for Manufacturability and Reducing Welding Distortion

Conclusion (Figure 61): The results indicate that 36.4% of respondents rated the usefulness as high and 22.7% as very high, meaning that 59.1% expressed a positive perception. Meanwhile, 34.1% considered it moderately useful, and only 6.8% perceived little or no benefit.

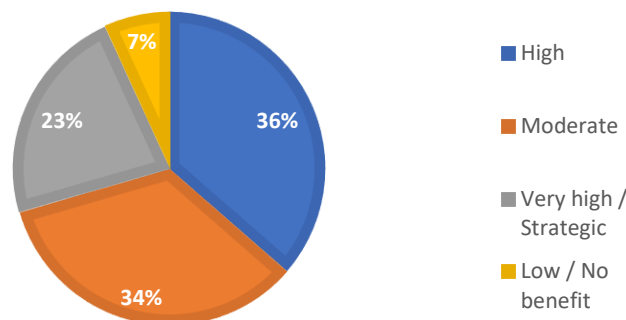


Figure 61. Perceived Usefulness of 3D/VR Visualisation for Improving Design for Manufacturability and Reducing Welding Distortion

Perceived Importance of AI/AR/VR for Design Optimisation Based on Experimental Data

Conclusion (Figure 62): The results indicate that AI/AR/VR technologies are considered highly valuable for design optimisation based on experimental data, with 68.2% of respondents rating their importance as high or very high, highlighting their potential to improve welding design decisions.

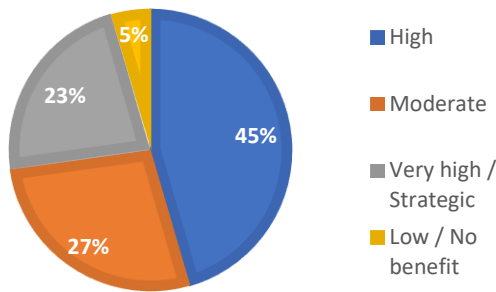


Figure 62. Perceived Importance of AI/AR/VR for Design Optimisation Based on Experimental Data

Perceived Importance of VR/AR Simulation for Improving PQR and WPS Development

Conclusion (Figure 63): The findings indicate that VR/AR simulation is perceived as an important tool for improving PQR and WPS development, with 70.5% of respondents rating its importance as high or very high, reflecting strong support for its integration into welding procedure development.

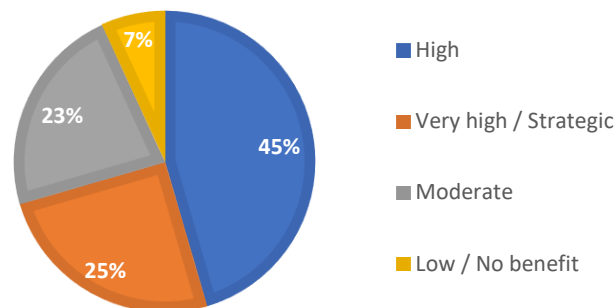


Figure 63. Perceived Importance of VR/AR Simulation for Improving PQR and WPS Development

Perceived Usefulness of VR/AR Tools Providing Real-Time Defect Information During Welding

Conclusion (Figure 64): The results show strong support for VR/AR tools that provide real-time defect information during welding, with 81.8% of respondents rating their usefulness as high or very high, highlighting their perceived value for improving weld quality and reducing production errors.

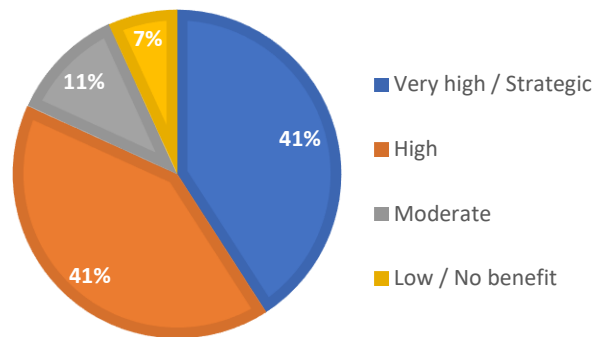


Figure 64. Perceived Usefulness of VR/AR Tools Providing Real-Time Defect Information During Welding

Perceived Importance of Digital Tools for Improving Material and Consumable Traceability in Compliance with ISO 14731 and ISO 3834

Conclusion (Figure 65): The results indicate that digital tools are widely recognised as valuable for improving the traceability of materials and consumables in accordance with ISO 14731 and ISO 3834, with 63.6% of respondents rating their importance as high or very high.

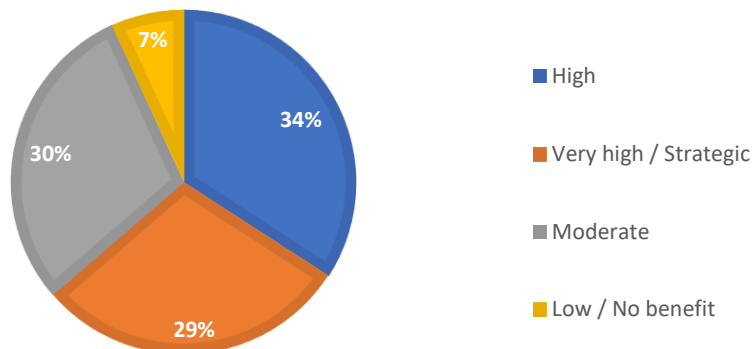


Figure 65. Perceived Importance of Digital Tools for Improving Material and Consumable Traceability in Compliance with ISO 14731 and ISO 3834

Quality and Safety Indicators Recommended for Digital Monitoring

Conclusion (Figure 66): The findings indicate that respondents prioritise the digital monitoring of failure/repair rates (29.9%), cycle time (26.0%), energy efficiency (23.6%), and smoke/fume exposure (20.5%), demonstrating a balanced focus on quality performance, production efficiency, and occupational safety.

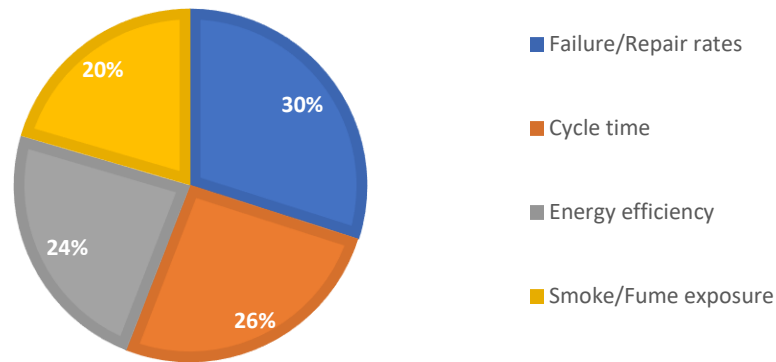


Figure 66. Quality and Safety Indicators Recommended for Digital Monitoring

Perceived Compliance of Simulator Integration with IWE/IWT/IWS Learning Outcomes and Assessment Requirements (IAB-252r5)

Conclusion (Figure 67): The results indicate that most respondents (56.8%) believe simulator integration only partially complies with IWE/IWT/IWS requirements and still requires validation through physical workshop training, while 20.5% consider it fully compliant with international standards and 22.7% remain uncertain about its alignment with the IAB-252r5 framework.

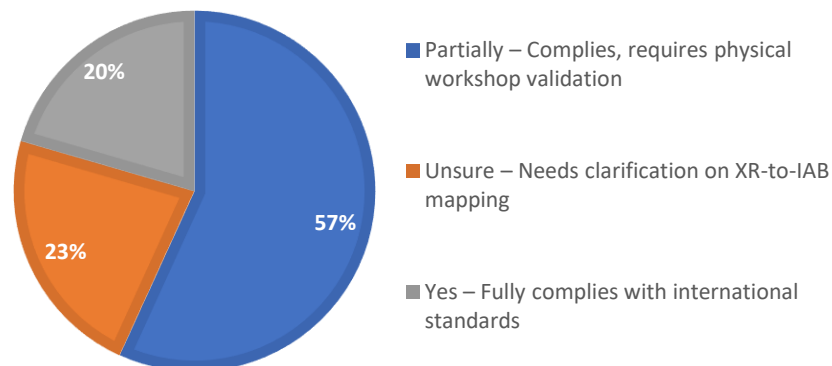


Figure 67. Perceived Compliance of Simulator Integration with IWE/IWT/IWS Learning Outcomes and Assessment Requirements (IAB-252r5)

Final comments

- “I think that the application of AR/VR/MR may still be in the introduction phase, but it is important to look for adequate areas.”

- “I’ll contact you to understand if there is any possibility to collaborate with the consortium project.”

- *"If a welder hasn't been burned and choked on smoke, he's not a real welder."*
- *"Simulators may be integrated into the IWE/IWT/IWS curriculum, but only as a supplementary teaching method, not as a substitute for the mandatory requirements set out in IAB-252r5."*
- *"A combination of traditional/practical activities and the new IWE/IWT qualification system is recommended."*
- *"XR integration will become essential for the training of welding engineers, as it enables accessibility validation, WPS/WPQR optimisation, and real-time digital quality monitoring. In the short term, XR accelerates learning; in the medium term, it will standardise competence assessment; and in the long term, it will connect training with ISO requirements and digital workflows in the factory."*

3.3. Survey Results Summary

3.3.1 Remote Physical Training Balance and XR Scope within the I/EWE Qualification Curriculum

This document summarises the findings of the two VIOLET project questionnaires (Survey 1 – Welding Engineers, n = 121; Survey 2 – Industrial Companies, n = 44) as they relate to the initial assessment objective: identifying the proportion of I/EWE training that can be delivered remotely versus in presential mode, and the scope for XR (VR/AR/AI) tools within the qualification curriculum.

3.3.2. Objective of this Summary

The initial assessment objective was to determine, from the survey data, (a) the percentage of I/EWE training that can be delivered remotely versus physically, and (b) the scope within the I/EWE curriculum that can be supported by XR tools.

The responses were analysed by curriculum area, and it was proposed to use the number of hours from the IWE/EWE curriculum, as shown in Table 1.

The surveys do contain detailed, question-by-question data on the perceived usefulness of XR tools across every major area of the I/EWE curriculum, plus explicit qualitative statements on

where hands-on/presential training must remain mandatory. This document uses that data as the closest available evidence-based proxy for the objective, and states clearly where a figure is a survey result versus a derived estimate.

3.3.3. Respondent Overview

Survey 1 (Engineers): 121 respondents completed the role/demographics section; 121 completed the digital-technologies section. The majority were International Welding Engineers (42.9%) and Engineers (33.3%). 62.0% had no prior experience with VR/AR/AI in training; 75.0% of the age/experience sub-sample reported no previous XR experience.

Survey 2 (Industrial Companies): 44 respondents, primarily metal construction (40.8%), from Romania (50.0%) and Poland (36.4%). Only 13.6% reported being familiar with VR/AR in training; 50.0% were partially familiar, and 36.4% were not familiar at all.

Both samples therefore represent a sector with low current XR exposure but, as shown below, high stated willingness to adopt it.

4. Conclusions

The participants who can be considered experts for the analysis are:

- **121 respondents** from the category of welding engineers and IWE specialists;
- **44 representatives** from the industrial sector;
- Representation from **11 countries** for the engineering respondents and **8 countries** for the industrial companies;
- Diverse professional backgrounds, including IWE professionals, instructors, examiners, course coordinators, and technical managers.

Level of Expertise of the Panel

The panel can be considered highly relevant because:

- More than **37%** of the respondents have over **10 years of professional experience**;
- **75%** of the participating companies employ or provide training for IWE personnel;
- The participants are directly involved in the training, coordination, and implementation of welding processes.

Strategic Question

To what extent should XR technologies (VR/AR/AI) be integrated into the I/EWE qualification, and which curriculum areas should be prioritised for digitalisation?

Priority I (>80%)

1. Real-time feedback on welding parameters

- 95.5% of the industrial companies consider this functionality highly valuable.
- 82.6% of the welding engineers rated it as highly valuable or essential.

2. Practical simulation of MMA/MIG/MAG/TIG welding processes

- 86.4% of the companies rated its usefulness as high or very high.
- 81.5% of the welding engineers evaluated the simulations as *Good* or *Excellent*.

Priority II (70–80%)

3. Real-time defect detection

- 81.8% of the companies support the use of XR technologies for defect detection.
- 94.2% of the welding engineers consider this functionality useful or essential.

4. WPS/PQR development

- 70.5% of the industrial respondents consider XR valuable for this activity.
- 92.5% of the welding engineers believe that simulations are useful for the development of Welding Procedure Specifications (WPS) and Procedure Qualification Records (PQR).

The Analysis Conclusion

The analysis reveals a strong consensus among both experts and industry representatives regarding the integration of XR technologies into the I/EWE qualification, particularly **for cognitive, procedural, and analytical activities such as monitoring welding parameters, providing real-time feedback, technological simulations, WPS/PQR development, quality control, and traceability.**

At the same time, there is an almost unanimous consensus that practical training and psychomotor skill development must continue to rely on face-to-face instruction. **XR technologies are therefore perceived as a learning catalyst rather than a substitute for hands-on workshop training.**

The educational model recommended by the expert panel is a **blended learning** approach, in which XR technologies complement traditional instruction and contribute to the modernisation of the I/EWE curriculum.

5. Recommendations

5.1 Curriculum Areas with the Strongest Case for Remote/XR-Based Delivery

The table below ranks curriculum areas by the percentage of respondents (Industrial Companies survey, Section D) rating XR usefulness "high" or "very high". This is the most direct quantitative proxy available in the data for how much of a given topic could shift toward remote/XR delivery.

Table 1

Curriculum area	% rating high / very high	Delivery implication
Overall interest in a modernised VR/AR/AI-based IWE course	97.7%	Strong mandate for remote/XR integration
Real-time feedback on deviations (speed, angle, distance)	95.5%	Well suited to XR / remote practice
Parameter setting on real equipment (current/voltage/gas)	93.2%(chapter. 1.12 – 2 hours))	Well suited to XR / remote practice
Real-time defect information during welding	81.8% (ch.4.7 – 3 hours))	Well suited to XR / remote practice
Practical welding simulation (MMA / MIG-MAG / TIG)	86.4%(ch.1.7 – 3 hours, cap 1.8- 6 hours), ch 1.9 -6 hours))	Strong XR support, blended recommended
Overall perceived benefit of VR/AR for IWE training	79.5%	Broad support for remote/XR components
PQR / WPS development	70.5% (ch.4.2 – 3 hours))	Suitable for blended delivery
HAZ and residual-stress understanding	68.2% (ch. 4.3 – 1 hour, 2.5 – 1 hour, 2.8- 1 hour))	Suitable for blended delivery
Design optimisation (AI/AR/VR)	68.2% (ch. 3.3 -2 hours))	Suitable for blended delivery
Manufacturing-flow simulation	65.9% (ch. 4.2- 2 hours)	Suitable for blended delivery
Filler materials / shielding-gas microstructure	65.9% (ch. 1.6 – 1 hour), 1.19 – 7 hours))	Suitable for blended delivery

Curriculum area	% rating high / very high	Delivery implication
Material traceability (ISO 14731 / ISO 3834)	63.6%(ch. 4.2 – 2 hours)	Suitable for blended delivery
Design-for-manufacturability visualisation	59.1% (ch 3.2 – 2 hours))	Moderate case, blended delivery

- **42 hours from all modules, in accordance with IAB 252r2-19.**

The 42 hours are obtained by using the next process: 2 hours (chapter 1.12) + 3 hours (chapter 4.7) + 3 hours (chapter 1.7) + 6 hours (chapter 1.8) + 6 hours (chapter 1.9) + 3 hours (chapter 4.2) + 3 hours (chapter 4.3(1), chapter 2.5(1), chapter 2.8(1)) + 2 hours (chapter 3.3) + 2 hours (chapter 4.2) + 1 hour (chapter 1.6) + 7 hours (chapter 1.19) + 2 hours (chapter 4.2) + 2 hour (chapter 3.2) = 42 hours.

Chapter 1.12 (2 hours): - *Parameter setting on real equipment (current/voltage/gas)*

- Welding Processes: electro-slag, friction; friction stir, magnetically impelled arc butt (MIAB); magnetic pulse welding, ultrasonic; explosive; diffusion; aluminothermic; high-frequency; stud, cold-pressure welding.
- Welding parameters for each process
- Joint preparation: typical joint design for welding, fit-up, cleaning
- Relationship between welding parameters and joint configuration

Chapter 1.6 (1 hour): - *Filler materials / shielding-gas microstructure*

- Shielding gases (inert, active) and their effect on arc characteristics
- Handling and storage of gases (overview)
- Influence of the welding parameters on the weld bead morphology

Chapter 1.7 (3 hours): *Practical welding simulation (MMA / MIG-MAG / TIG)*

- Effect of current type and polarity: DC (+), DC (-) and AC
- Consumables: shielding gases, filler materials, electrodes
- Welding parameters: current, voltage, travel speed, gas flow rate
- Joint preparation: typical joint design for welding, fit-up, cleaning
- Special techniques: pulsed arc, spot-welding, keyhole, hot-wire, orbital welding, tube to tube and tube to sheet, narrow gap and others
- Standards for filler materials and electrodes (at least for non-alloy steels).
- Welding applications, typical problems and how to solve them

Chapter 1.8 (6 hours): *Practical welding simulation (MMA / MIG-MAG / TIG)*

- Effect of current type and polarity
- Metal transfer modes (dip, globular, spray, pulsed and rotating), controlled
- Transfer modes and their application
- Welding parameters and settings: current, voltage, travel speed, gas flow rate, etc.
- Special techniques: electro-gas welding, high efficiency processes, spot welding, single wire and multiple wire techniques, flat wire, brazing, electronic stability control (arc and wire feed), etc
- Relation between the consumables and the type of Metal transfer mode, and their applications
- Consumables: shielding gases, filler materials (flux cored wires), and their combinations
- Welding applications, typical problems and how to solve them

Chapter 1.9 (6 hours): *Practical welding simulation (MMA / MIG-MAG / TIG)*

- Welding parameters: current, voltage, run-out length, etc
- Joint preparation: fit-up, cleaning, welding position
- Relationship between electrode diameter and current range, rod material,
- electrode length and welding position
- Special techniques (gravity welding, etc.)
- Health and safety specific to the MMA process

Chapter 1.19 (7 hours): *Filler materials / shielding-gas microstructure*

- Practical exercises showing the effect of each main welding parameter on the weld bead shape
- Exercises should cover: MMA, TIG, MIG/MAG, Flux Cored wires, SAW,
- Oxygas
- Practical exercises showing the effect of each main cutting parameter on the cut surface

Chapter 2.5 (1 hour): *HAZ and residual-stress understanding*

- Weld pool, weld shape
- Dilution
- Structure of weld metal
- Effect of multi-pass welding

Chapter 2.8 (1 hour): *HAZ and residual-stress understanding*

- Heat treatment of welded joints and workpieces

- Post-Weld Heat Treatment (Stress relieving, normalising, hardening)
- Technical guidelines for heat treatment
- Heat treatment procedures

Chapter 3.2 (2 hours): *Design-for-manufacturability visualisation*

- Types of stresses (normal stress, shear stress)
- Types of deformation (axial strain, shear strain)

Chapter 3.3 (2 hours): *Design optimisation (AI/AR/VR)*

- Classification of groove shapes (by material type, thickness, welding process, accessibility)
- Tolerance requirements (ISO 13920)
- Welding symbols on drawings, symbols for groove shapes
- Symbolic representation of welded, brazed and soldered joints according to ISO 2553

Chapter 4.2 (7 hours): *Material traceability (ISO 14731 / ISO 3834), PQR / WPS development, Manufacturing-flow simulation*

- Welding coordination and inspection personnel; qualification tasks and responsibilities
 - (ISO 14731, ISO 9712, CEN and National standards)
 - Brazer and Welder Approval /Qualification and Brazing and Welding Procedure
 - Qualification - Introduction/Overview
 - Brazer and Welder Approval/Qualification (ISO 9606, CEN and National Standards)
 - Brazing and Welding Procedure Specification – The goal, how to create and develop (ISO 15607 and 15609, CEN and National Standards)
 - Brazing and Welding Procedure Qualification (ISO 15610, 156111, 15612,15613 and 15614), CEN and National standards)
 - Brazing and Welding Operator Qualification (ISO 14732, CEN and National Standards)
 - Traceability (materials identification, welder/operator, procedures, certificates)
- **22 hours can be completed through the practical component, i.e., the welding demonstrations.**
 - **It is possible to use the advantages of Virtual Weld Training systems but at a maximum of 50% of the practical training hours!**

I.4.1 For the IWE; IWT, and IWS

This part does not aim at providing practical skills to the welding engineer/technologist/specialist but on gaining knowledge on the control of the different welding processes. The students shall become as familiar as possible with the problems and typical defects associated with incorrect use of the different welding methods. During their exercises the students are guided by skilled welding teachers.

Practical Training	hours:
Oxygas welding and cutting	6
MMA	8
TIG	8
MIG/MAG + Flux Cored Arc Welding	16

It is possible to use the advantages of Virtual Weld Training systems but maximum to 50% of the practical training hours!

	hours:
Demonstration or video presentations of processes	22
Gouging	
Brazing	
Plasma welding	
Plasma cutting	
Submerged-arc welding	
Resistance welding	
Friction welding	
Electron beam welding	
Laser welding	
Other processes	

⇒ Approximately 15% of the IWE course could be delivered using VR/AR tools on a welding simulator

The corresponding Survey 1 (Engineers) results confirm the same pattern: AR/VR simulation for MMA/MIG-MAG/TIG practice was rated Good or Excellent by 81.5% of respondents; parameter-setting training was rated as improving training significantly or moderately by 90.0%; real-time deviation feedback was rated Very Useful or Essential by 82.6%; and cutting-process training (plasma/oxy-gas/laser) was rated Relevant or Highly Relevant by 90.9%.

5.2. Curriculum Areas Requiring Physical / Hands-On Delivery

The survey data also identifies where remote/XR delivery is explicitly seen as insufficient:

- Manual/physical welding skills were rated the lowest-priority area for VR/AR support by industrial respondents (0.7% of votes) — the clearest quantitative signal in the dataset that this scope must remain presential.
- The most frequently cited limitation of XR overall was "lack of physical feel" (44.8%), followed by high initial investment cost (30.4%).
- 56.8% of industrial respondents stated that simulator integration only partially complies with IWE/IWT/IWS learning-outcome requirements and still requires validation through physical workshop training (only 20.5% considered it fully compliant).
- Multiple free-text responses explicitly frame XR as a "competence catalyst" and a "supplementary teaching method, not a substitute for the mandatory requirements set

out in IAB-252r5", citing sensory feedback (heat, smell, arc noise, tactile control) as irreplaceable for certification-level skill acquisition.

5.3. Synthesis: Closest Available Answer to the Objective



Cognitive/analytical/procedural scope (process parameters, real-time feedback interpretation, design and QA reasoning, defect analysis, PQR/WPS development, standards compliance): consistently rated 60–98% suitable for XR-supported remote or blended delivery across both surveys.



Manual/psychomotor / certification-critical scope (physical welding execution, torch handling, sensory calibration): rated as requiring presential delivery, both by direct survey response (0.7% priority for VR/AR) and by qualitative consensus that IAB-252r5 mandatory requirements cannot be met remotely.

If a single planning estimate is required for the modernised I/EWE curriculum, the data supports treating XR/remote-capable content as covering the majority of the theoretical, analytical, and procedural curriculum, with the practical/certification core remaining presential and XR used there as a preparatory and supplementary layer — consistent with respondents' own description of XR as a "catalyst," not a replacement.

6. Annexes: survey questionnaires

The detailed results of both questionnaires are provided in the accompanying documents "Annex 1 AR_VR International Welding Engineer Qualification (Engineer)EN.xls" and ' Annex 2 AR_VR International Welding Engineer Qualification (Industry)EN' which contain the complete survey responses.