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FROM DRAWING TO ACTION: EXPERIENTIAL REPRESENTATION FOR TECHNICAL TRAINING

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Recent advances in digital modelling and information visualisation are reshaping how technical knowledge about the built environment and infrastructure systems is produced, communicated, and transferred, redefining the representational conditions through which competencies in critical-infrastructure asset management can be developed. In this context, the discipline of Drawing assumes a structural role as a mediating project between reality, model, and user, supporting the shift from static documentation to interactive and verifiable operational environments. Within this framework, the paper examines immersive virtual reality serious games through the lens of gaming mechanics, not as mere engagement devices, but as forms of experiential representation in which operational legibility is deliberately organised across spatial hierarchies, functional dependencies, signals, constraints, and risk conditions. This approach is explored through the Safety & Operations Training Hub, with a wastewater treatment plant serving as a demonstrative case. The demonstrative application illustrates how storyline, role-based interaction, hazard modelling, and feedback can turn the digital model into a training-and-assessment environment designed to support comprehension, enable the safe rehearsal of tasks, and provide measurable access to complexity.

Keywords: Visual storytelling, Virtual reality serious game, Critical infrastructure, Data-driven learning, Knowledge accessibility.

¹ The expression Educational Technologies is used here in a broad sense, referring to the field concerned with the design and application of learning processes, resources, and environments intended to improve learning and performance; a recent work-related and lifelong-learning perspective is provided by Lyndgaard, Technological support for lifelong learning: The application of a multilevel, person-centric framework.

² The relevance of virtual reality for training, especially in relation to procedural learning, situated experience, and simulation-based skill development, has been widely acknowledged in recent literature, including Li et al., *Extended Reality (XR) Training in the Construction Industry: A Content Review*, and Jongbloed et al., *Immersive procedural training in virtual reality: A systematic literature review*.

³ The value of serious games in training and assessment has been increasingly recognised in recent literature, particularly for their capacity to structure authentic tasks, sustain engagement, and integrate feedback into performance-based learning, as discussed by Bijl et al., *Serious games in high-stakes assessment contexts: a systematic literature review into the game design principles for valid game-based performance assessment*, and Lampropoulos, Kinshuk, *Virtual reality and gamification in education: a systematic review*.

Framing complexity

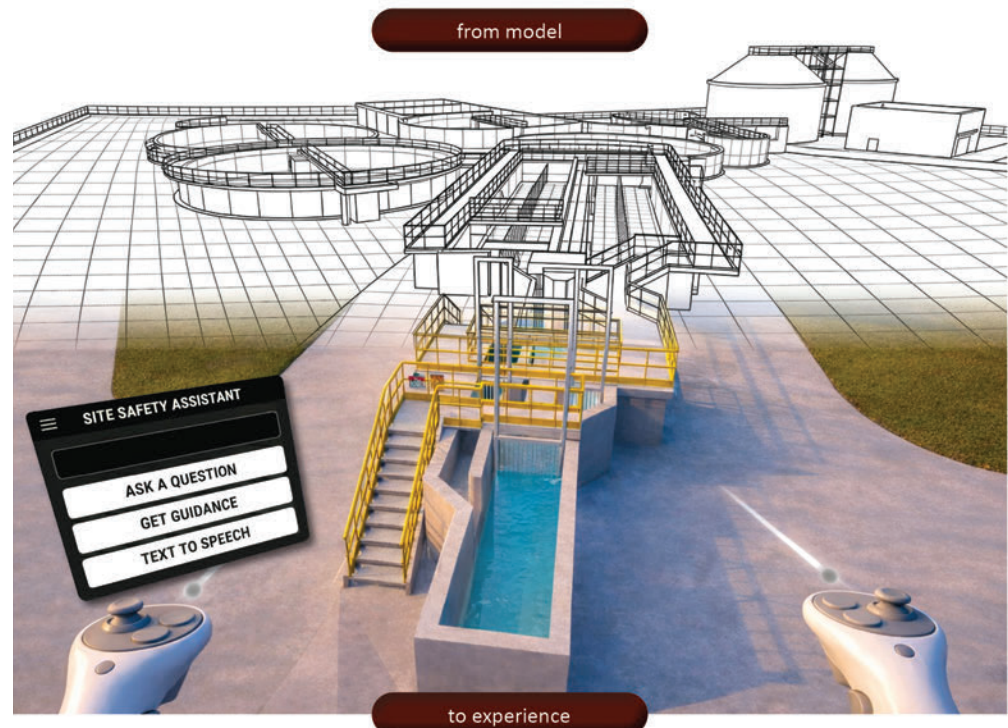
In the domain of critical infrastructure, technical training cannot be reduced to the simple transmission of information, but must be approached as a problem of operational access to complexity. Such systems are defined by the interplay of interdependent processes, restricted-access areas, multifactorial risks, and formalised procedures, generating a knowledge ecosystem distributed across drawings, manuals, regulations, tacit know-how, and situated practices. In this context, Educational Technologies¹ can be understood as a hybrid field at the intersection of pedagogy and digital innovation, aimed at supporting learning processes as well as reskilling and upskilling pathways. Within this field, virtual reality² and serious-game³ approaches are particularly significant be-

cause they integrate simulation, interaction, and feedback into learning systems in which knowledge is acquired through situated experience. They are especially suited to domains where learning depends on spatial awareness, procedural understanding, and risk-sensitive decision-making. This paper therefore approaches virtual reality, within the framework of gaming mechanics, not as an engagement strategy, but as a device of technical representation. In this perspective, the wastewater treatment plant becomes a paradigmatic case for observing how Drawing can make infrastructural complexity cognitively accessible, and operationally navigable (fig. 1).

Drawing as Operational Access

The disciplinary relevance of immersive environments lies in their capacity to

1 | From digital model to immersive experience: representation shifts from static description to operational and interactive access.



extend representation beyond the documentary plane and into the operational and interactive one (fig. 2). From the perspective of Drawing, representation acts as a mediating structure between the real infrastructure, the digital model, and the user who must interpret, access, and act within the system. In this shift, the digital model no longer serves only to show or document an object, but becomes an environment to be explored, interrogated, and validated through action. Representation therefore unfolds through the design of operational legibility: information hierarchies, spatial anchoring, affordances, and feedback mechanisms that make complex technical content understandable for different users. In this sense, Drawing also performs a cultural function. By translating specialised content into legible, situated, and assessable forms of experience, immersive representation widens access to knowledge that would otherwise remain confined to expert documents, procedures, and professional routines, thereby reducing the interpretative gap between experts and non-experts. Virtual reality amplifies this condition by bringing together the visual, practical, intellectual, emotional, and participatory dimensions of Drawing within a single experiential form⁴. It does so by coupling immediate perception, rooted in direct sensory

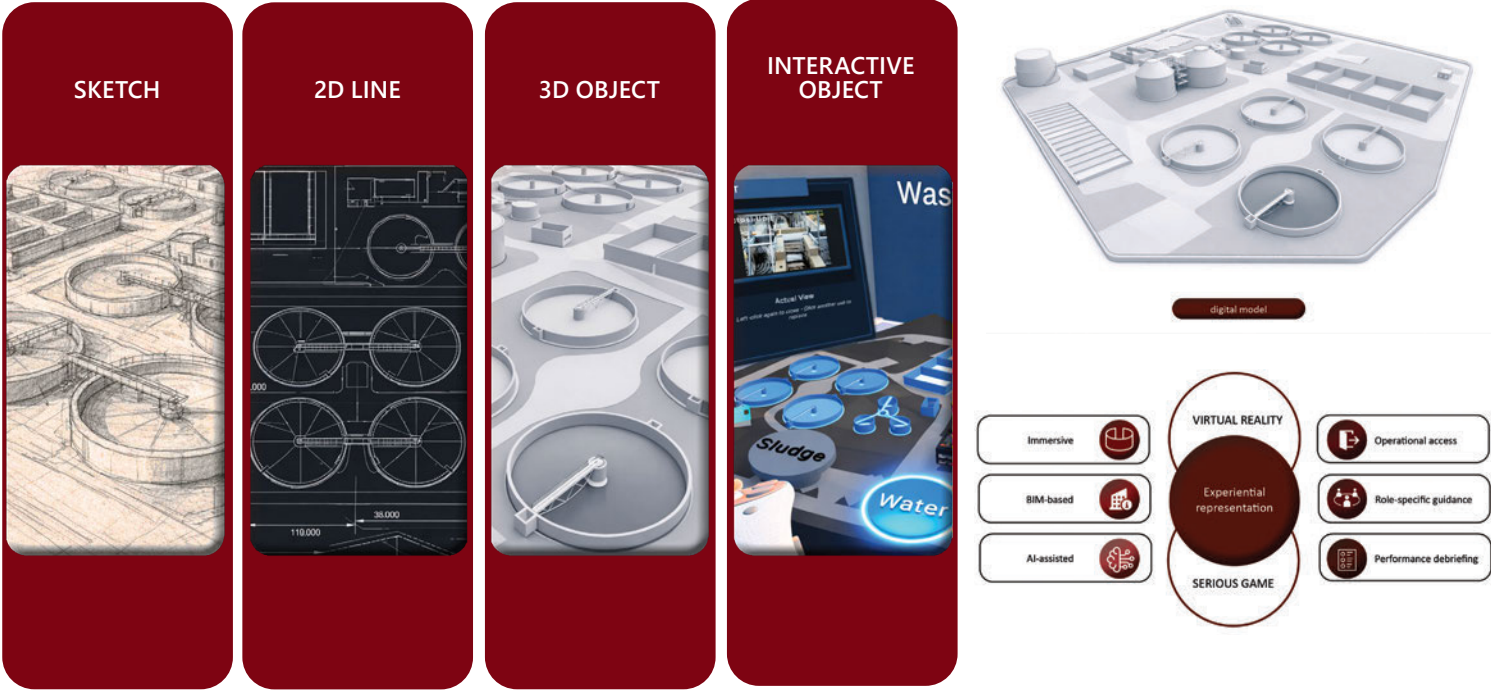
experience, with mediated description, which structures that perception through graphic and informational codes. What emerges is not an immersive container of information, but a performative representation in which technical content becomes meaningful through navigation, task execution, interruption, validation, and feedback. For this reason, a Building Information Model (BIM) cannot simply be transferred into a virtual scene; it must be transformed into a usable asset whose immersive legibility, behaviour, and task-oriented interaction are deliberately designed. The virtual infrastructure remains a common spatial backbone, while informational layers and possibilities for action are filtered according to roles, responsibilities, and tasks. In this way, representation functions as a cognitive infrastructure that articulates complexity into recognisable spatial, procedural, and informational units.

Building the Representational Framework

The case study discussed in this paper is the Safety & Operations Training Hub (SOTH), an immersive virtual reality serious game (IVRSG) developed within the RETURN project⁵. Conceived to support the asset management workforce,

⁴ A related reflection on experiential representation is developed by Ugliotti, Zucco, *From Sketch to Immersive Representation: Techniques and Tools to Unravel Meaning*.

⁵ The activity is part of the participatory and dissemination initiatives of the Multi-Risk science for resilient communities under a changing climate project, funded under the National Recovery and Resilience Plan. Within Spoke TS2, the role of representation is explored through investigated concerning information and communication theories and techniques, particularly in applying extended reality to develop sustainable training pathways for the asset management workforce of critical infrastructures. Further information on the project is available at Fondazione RETURN, institutional website.



the prototype explores the feasibility of IVRSG as a technical training tool for complex infrastructural systems characterised by operational complexity and multi-risk conditions⁶, consolidating heterogeneous content, including operational procedures⁷, safety protocols⁸, and process documentation, into a unified and interactive simulation environment. The platform is examined through a wastewater treatment plant as a demonstrative case (fig. 3), since this type of infrastructure condenses many of the spatial, operational, and organisational conditions typical of critical systems⁹. Through an experiential design approach integrating narrative, interactivity, and advanced digital technologies, SOTH aims to foster a more intuitive understanding of infrastructural processes, strengthen users' ability to recognise risks and operational conditions, and address differentiated training needs ranging from professional operators to non-expert visitors. By immersing users in a virtual representation of the plant enriched with information, procedures, actions, and simulated scenarios, the system enables the safe exploration of complex processes and supports the development of decision-making skills without exposing users to real hazards. Methodologically, SOTH is grounded in the transformation of a BIM-derived

infrastructural model into an interactive, role-sensitive training environment. The virtual plant is conceived not as a three-dimensional reconstruction for visualisation alone, nor as a static repository of geometric and semantic data, but as a usable training asset in which space, process, risk, and action are reorganised into a coherent experiential system. In this configuration, the model functions simultaneously as a spatial environment, an informational support, and a procedural interface. On this basis, SOTH combines model-based spatial accuracy, VR technologies for immersion, and Artificial Intelligence (AI)-driven interactions based on large language models to provide contextual guidance (fig. 4). This integration makes it possible to transform procedural manuals, safety documents, and risk registers into adaptive, context-aware instructions tailored to the user's role and position within the plant. The system architecture is based on a multilayer pipeline (fig. 5) that integrates heterogeneous data sources, digital models, interaction systems, informational layers, and assessment components into a single training framework. Its aim is to transform technical and documentary information into a navigable virtual environment that remains consistent with the real infrastructure

2 | Evolution of drawing: from freehand sketch to digital sign, from informational model to interactive object.

3 | Digital model of the wastewater treatment plant used as the demonstrator case study.

4 | Methodological approach of the research, structured around experiential representation.

6 The role of digital and immersive technologies in training for critical infrastructure resilience and risk management has been increasingly acknowledged in recent literature, as discussed by Ugliotti et al., *Rethinking Education on Critical Infrastructure Resilience and Risk Management: Insights from a Systematic Review*.

7 On procedural training in immersive virtual reality, see Jongbloed et al., *Immersive procedural training in virtual reality: A systematic literature review*.

8 On safety and emergency training in virtual reality, see Stefan et al., *Evaluating the Effectiveness of Virtual Reality for Safety-Relevant Training: A Systematic Review*. J.R. Abbas et al., *Virtual reality in simulation-based emergency skills training: A systematic review*.

9 Comparable experiences in this field are discussed in the following publications: Lee et al., *Experiential Learning Through Immersive XR: Cybersecurity Education for Critical Infrastructures*; Ji et al., *Revolutionizing safety training: enhancing safety knowledge acquisition, retention, and user experience with adaptive VR-LLM integration*.

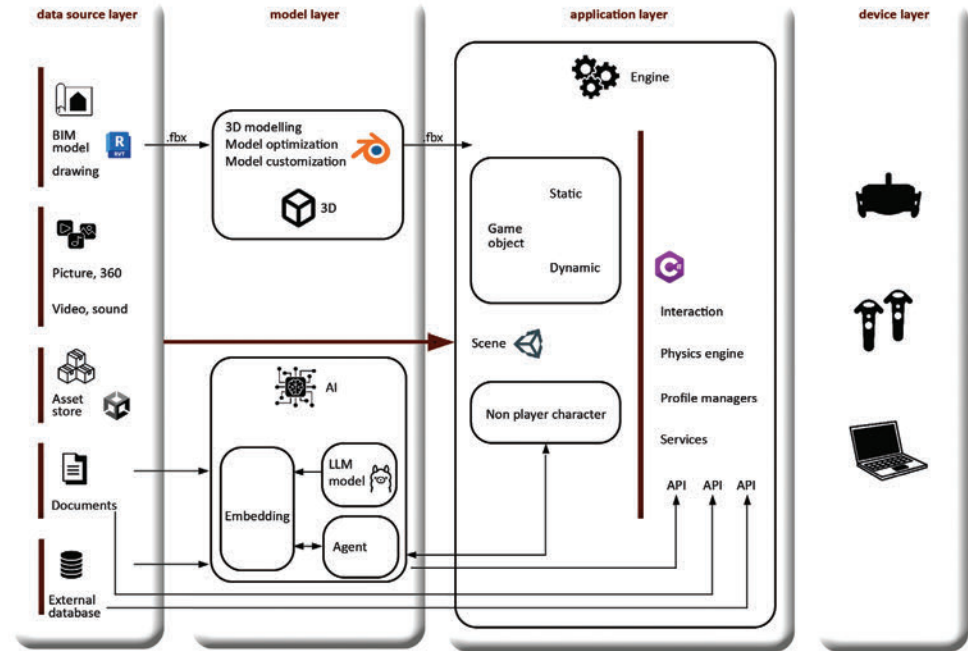
while providing advanced forms of user support.

The Data Source Layer gathers the inputs required to feed the system.

At its core lies the digital model of the infrastructure, which provides the common spatial and semantic backbone for the scene generation. This is complemented by multimedia materials, such as audio descriptions, operational videos, and 360° panoramic images, which contribute realistic and contextual references. Technical documentation, including manuals, procedures, safety guidelines, and risk registers, together with structured operational databases, provides the knowledge base on which the training environment relies.

The Model Layer transforms raw input data into assets and structures that can be directly used within the game engine. The BIM-derived model is optimised for real-time rendering and enriched with additional scene elements, indicators, and media to support the narrative, functional, and didactic requirements of the virtual experience. In this way, a model originally conceived for design and documentation is reconfigured as a training resource. Since no immersive scene can statically contain all the knowledge required for technical training, this layer also prepares the content for AI-assisted guidance. Technical documents and database records are segmented, converted into vector embeddings, and stored in a semantic database, allowing the system to access distributed knowledge beyond what is permanently embedded in the scene. A retrieval pipeline based on LangChain performs semantic search and forwards the most relevant passages to a local language model executed through Ollama, enabling contextual interpretation and adaptive guidance while preserving the spatial and procedural coherence of the immersive experience.

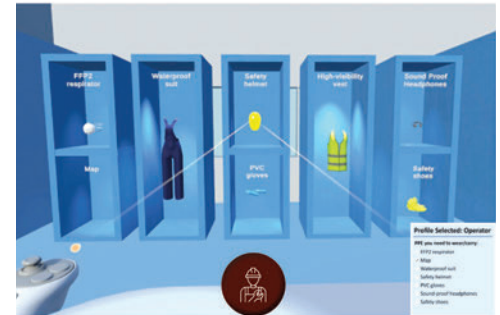
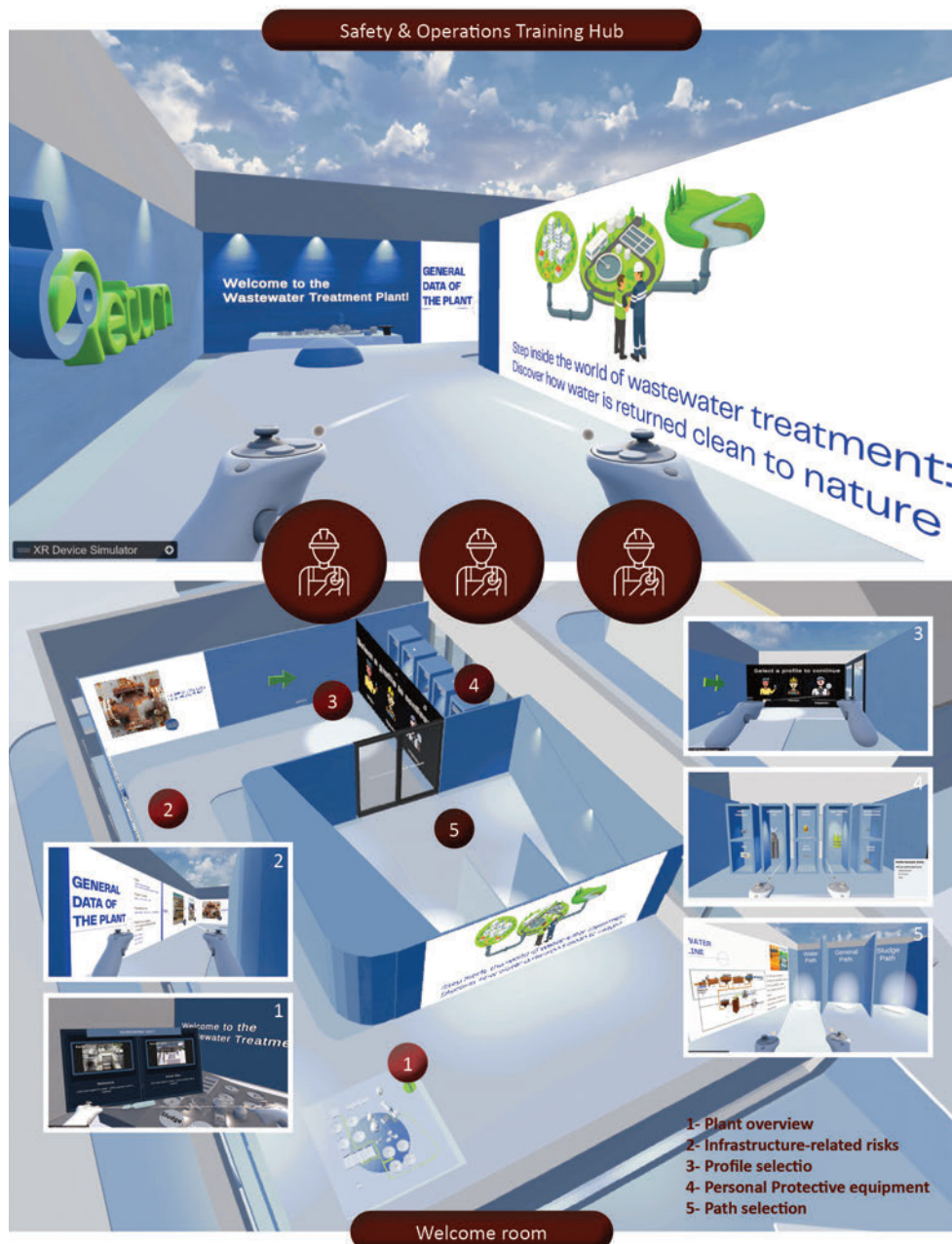
The Application Layer orchestrates the runtime behaviour of the immersive serious game by integrating scene composition, user interaction, and intelligent services. Here, the assets generated in the Model Layer are instantiated within the game engine and configured to create a coherent, navigable, and re-



sponsive environment. Through storyline, hazard scenarios, profile-specific interfaces, world-anchored information panels, and task-based interactions, the environment is structured as an operational and didactic experience. *C# scripts* govern user interactions, procedural sequences, physics, role-based logic, and action validation, supporting task-based learning. Through API calls, the layer also connects the VR environment with external and AI-driven services. The AI assistant is not limited to functioning as an interactive manual but contributes to both learner-initiated and system-initiated support. User questions are answered according to the selected role, current location, active task, and authorised technical sources, while observed errors, missing prerequisites, or safety-relevant conditions may trigger contextual hints, guided paths, demonstrations, or verification requests. However, the LLM does not autonomously modify the procedural scenario or determine what is safe or permitted. These functions remain governed by the backend orchestration, role-based logic, and safety constraints, while the LLM primarily verbalises and synthesises grounded information.

Finally, the Device Layer defines the hardware configuration through which the immersive serious game is executed and experienced. The immersive experi-

5 | System architecture of the proposed training platform.



6 | Entry interfaces of the Safety & Operations Training Hub: platform access and configuration through the Welcome Room.

7 | Role-based PPE selection required to enter the visit path.

8 | Modelling of the hazard scenario associated with biological risk.

ence is achieved through the integration of the workstation, VR head-mounted display, and handheld controllers, which jointly support rendering, spatial presence, navigation, and interaction.

Structuring Access through Storyline

The training experience developed within the SOTH is organised through a mission-based storyline that gives each session a recognisable temporal structure. Rather than presenting the virtual plant as an undifferentiated exploratory environment, the platform frames interaction through a sequence with a clear beginning, development, and closure. Each session begins in the Welcome Room, conceived as a single-entry con-

figuration space, that functions as the initial threshold of the experience between model and action, framing the conditions under which users enter the serious game.

Organised into five functional areas (fig. 6) it introduces the wastewater treatment process, recalls the main infrastructure-related risks, and allows users to define their role, required equipment, and operational trajectory before entering the virtual plant. A simplified representation of the wastewater treatment process presents the main units and clarifies the relationship between the water and sludge lines. The experience is deliberately organised across three coordinated representational scales. At the macro scale, the plant is presented

“In this way, representation functions as a cognitive infrastructure that articulates complexity into recognisable spatial, procedural, and informational units.

as a process system, clarifying the relationship between the water and sludge lines; at the intermediate scale, users navigate individual treatment units and understand their spatial and functional interdependencies; at the micro scale, technical components, controls, hazards, and procedural actions become directly interactable. Consistent labels, highlighted process paths, world-anchored panels, and task cues maintain continuity between these scales, allowing local actions to remain legible in relation to the overall treatment process. The transition is therefore not merely a change in visual magnification, but a controlled shift between diagrammatic, spatial, and operational forms of representation.

The risk area recalls the principal hazard categories relevant to the plant, aligning the immersive scenario with the risk taxonomy adopted in technical documentation and risk registers. In the profile selection area, users choose between visitor, operator, or inspector modes, translating abstract learner profiles into an actual game configuration. The personal protective equipment (PPE) area recalls the mandatory equipment associated with the selected role and, where relevant, with the chosen path, thereby reinforcing the link between digital training and real safety requirements. To facilitate understanding, PPE items not required for a given profile are disabled, while a checklist panel progressively confirms the equipment as it is picked up by the user (fig. 7). Finally, the path selection area allows users to choose between the water line, sludge line, or full-plant trajectory defined by the storyline. From this initial configuration scene, the session branches into three parallel normal-operation paths corresponding to the water line, the sludge line, or a combined full-plant trajectory. Along each path, progression may be unexpectedly interrupted by hazard episodes that introduce abnormal or risk-related conditions within an otherwise regular operational sequence. Hazards are not treated as generic alarm events or isolated didactic inserts, but as situated disruptions anchored to specific units, processes, and operational conditions within the plant. Their modelling translates the risk taxonomy derived from techni-

cal documentation and safety records into spatially and temporally articulated scenarios that can be activated during the training sequence. In this way, biological, chemical, and explosion-related risks are operationalised through environmental cues, hazard indicators, animations, and task-related consequences (fig. 8). Hazard modelling thus acts as a bridge between abstract risk classification and situated experience, allowing users to encounter risk not as detached information, but as a condition embedded in the logic of the represented infrastructure. All trajectories ultimately converge in a shared Debriefing Room, which closes the session and reconnects the immersive experience to the broader training and assessment framework. At the scale of the serious game as a whole, representation must continuously ensure operational intelligibility, so that users can always understand where to go, what to do, and how to progress. This depends on a calibrated interplay of graphic devices, audio cues, object interactions, non-player characters, and dialogue interfaces, which together support orientation, narrative continuity, and the overall legibility of the training sequence. Within this structure, narration should not be understood as a secondary layer added to the model, but as a mechanism for organising access to complexity. The storyline gives temporal order to the represented environment by guiding attention, sequencing information, and connecting ordinary operations with hazard-based disruptions and final evaluation. In this sense, it becomes part of the representational logic of the system, organising not only what is encountered, but also the conditions under which it becomes meaningful for training. The storyline should therefore be understood less as a list of scenes than as a representational template through which scenarios can be composed, repeated, and compared across sessions.

Role-Based Access to Complexity

While the storyline defines the shared temporal and spatial structure of the serious game, the three user profiles determine how that structure is accessed, interpreted, and acted upon. Visitor,



9 | Simplified representation of the wastewater treatment process, highlighting the main units and the relationship between the water and sludge lines, particularly to support orientation for the visitor profile.



10 | Operator-profile interfaces showing support panels for operational procedures and maintenance tasks, integrated with AI-based guidance and reminders about the risks associated with each unit and the required PPE.

Technical Operator, and Inspector represent different modes of access to the same virtual environment.

What changes from one profile to another is not the world itself, but the layer of complexity that becomes actionable. In this sense, the platform uses representation not to simplify the infrastructure, but to organise its technical, spatial, and procedural density through differentiated forms of access.

For the Visitor, the plant is configured as an intelligible process environment through which non-expert users can approach the facility in educational or outreach contexts. A guided narrative pathway introduces the main stages and units of wastewater treatment, from screening

to final disinfection, while granting access to both the water line and the sludge line (fig. 9). Dynamic illustrations, highlighted components, and audio-guided explanations support a general understanding of process flows and of the regulatory framework governing effluent quality. In this profile, representation makes the infrastructure readable without removing its internal articulation.

For the Technical Operator, the same environment becomes a procedural and safety-oriented training space in which control, monitoring, and maintenance tasks are simulated through checklists, scenario-based interactions, and video-guided procedures. Operators navigate walkways and platforms located near equipment and local control points. World-anchored panels provide information on mandatory PPE, local hazards, and maintenance requirements, while interactive checklists and task lists support operational activities such as inspections, cleaning, and functional tests (fig. 10). Through these interfaces, operators can activate procedural steps, record the completion of actions, and, where necessary, query the AI-supported assistant for short, context-aware clarifications based on the technical documentation encoded in the Model Layer. In this profile, representation supports action by making visible not only equipment behaviour and workflow sequences, but also the operational hazards embedded in the plant, including biological risks associated with aerosols and microorganisms, explosion risks related to biogas in anaerobic digesters, and chemical risks linked to corrosive substances (fig. 8). These dimensions are conveyed through dedicated animations, hazard indicators, and informational panels. The profile is therefore designed to strengthen procedural adherence, situational awareness, and safe decision-making.

For the Inspector, the virtual plant is configured as an analytical environment for verification, assessment, and compliance monitoring (fig. 11). In this profile, the same physical locations are augmented with verification tools rather than operational controls. Inspection panels are organised into thematic tabs, including signage, mechanical protection, safety devices, wear and condition, and documentation/PPE.



11 | Inspector-profile interfaces showing inspection activities conducted through checklists.

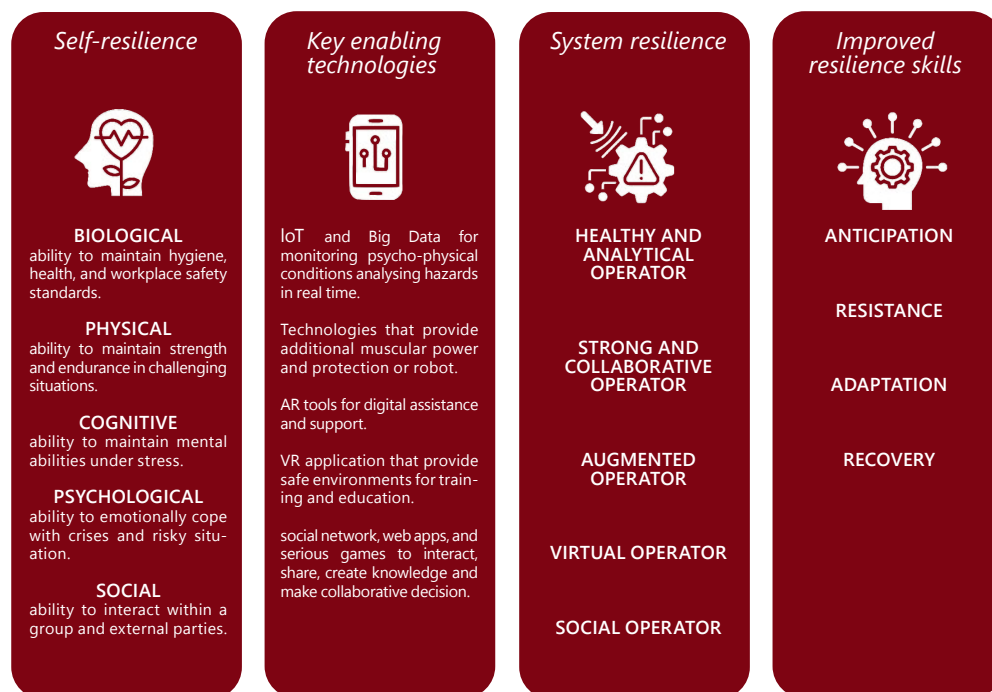
Each item corresponds to a concrete requirement, such as the presence and correct positioning of safety signs, the integrity of guards, or the accessibility of emergency stops. Inspectors move along platforms and corridors, observe the scene, and record findings directly within the virtual environment. In this way, inspection practice is translated into a repeatable and measurable interaction sequence aligned with real procedures and regulatory expectations. The profile also provides access to system overviews, risk maps, and linked documentation, enabling users to examine operational conditions, verify whether procedures are correctly implemented, and assess compliance with safety and regulatory requirements. In this profile, representation supports evaluation by structuring the plant as an environment that can be read critically, compared against expected standards, and interrogated through role-specific informational layers.

The main objective is therefore to strengthen analytical capability, risk identification, and the assessment of safety measures within the virtual environment.

Taken together, these three profiles show how the same virtual environment can sustain different training perspectives without fragmenting the underlying infrastructure. Rather than producing separate experiential worlds, the system organises a shared spatial and informational framework through role-specific layers of interaction, attention, and evaluation. Representation thus functions as a selective interface to complexity, enabling different users to access the plant according to their responsibilities while preserving the coherence of the simulated environment.

From Experience to Evidence

At the end of each session, all user profiles converge in a debriefing scene that



12 | *The Operator 5.0 paradigm, highlighting the role of virtual reality in supporting cognitive and psychological resilience.*

closes the serious-game loop and reconnects the immersive experience with the wider customised training platform.

In this space, the system aggregates the main elements of the session: selected role and path, visited units, encountered hazard scenarios, completed tasks, and inspection outcomes. For visitors, the emphasis lies on the process stages explored and the key messages covered; for operators, on the execution of procedural steps and responses to abnormal conditions; for inspectors, on the completeness of inspection coverage and the identification of non-conformities. To render these results evaluable, the platform translates user interaction into discrete and traceable events. Visited units, activated panels, completed checklist items, responses to hazard scenarios, and inspection records are logged as observable actions and then aggregated into profile-specific KPIs. Because storyline and evaluation criteria remain stable across sessions, these indicators make it possible to compare performance over time for the same user as well as across different user groups. The debriefing scene therefore functions not merely as a summary of the experience, but as a structured interface through which performance becomes readable, comparable, and discussable within the broader training ecosystem. From a representational perspective, this final stage is especially significant because it extends the logic of the immersive en-

vironment beyond situated experience. The serious game does not end when the user exits the virtual plant; rather, it transforms action into evidence and experience into interpretable feedback. In this sense, gaming mechanics and representational mechanics converge. Missions, branching paths, hazard episodes, role-based interactions, and debriefing are not simply devices for engagement, but mechanisms through which operational access to complexity is both organised and made measurable.

At the current stage, the prototype has undergone formative testing by the researchers involved in the project. The tests focused on technical functioning, interaction consistency, information legibility, navigation, and task sequencing, supporting the iterative refinement of the application. However, the system has not yet been formally tested with representatives of the three intended user profiles. The proposed KPI framework should therefore be understood as the basis for the subsequent user-validation phase rather than as evidence of training effectiveness or experiential usability among target users.

Drawing Complexity into Action

This paper has argued that immersive serious games can be understood not only as educational technologies, but as representational systems for tech-

nical training in critical infrastructure. From this perspective, the virtual environment does not merely visualise an infrastructure or simulate its appearance; it organises how the system is accessed over time, how different users engage with it according to role, and how their actions are translated into evaluable outcomes. The wastewater treatment case illustrates how representation can support training not by reducing complexity to static information, but by structuring operational access to it. The relevance of this approach for the field of Drawing lies in the extension of representation from description to experiential mediation. In the proposed framework, drawing becomes operative: it structures visibility, hierarchy, orientation, interaction, narration, and informational accessibility within a shared digital environment. At the same time, gaming mechanics demonstrate that missions, branching paths, hazard episodes, role-based objectives, and debriefing can function as representational devices rather than merely motivational features. Their contribution lies in making complexity legible, actionable, and assessable. Viewed within broader training ecosystems, this approach also points toward a profile that can be associated with the emerging notion of the Operator 5.0¹⁰ (fig. 12). In this perspective, the operator is no longer understood simply as an executor of predefined tasks, but as a human-centred, information-aware, and adaptive subject capable of combining procedural knowledge, situated decision-making, and interaction with digitally augmented environments. The value of the system does not lie in replacing documentation or expert judgement, but in mediating between them by transforming the digital model into an environment in which complexity can be accessed, rehearsed, interpreted, and discussed. Understood in these terms, experiential representation offers a promising framework for future training environments in critical infrastructure, because it maintains the coherence of the represented system while enabling differentiated access, situated learning, and measurable feedback.

¹⁰ For a broader framing of Operator 5.0, see the following publications: Romero, Stahre, *Towards the Resilient Operator 5.0: The Future of Work in Smart Resilient Manufacturing Systems*; Zambiasi et al., *Supporting Resilient Operator 5.0: An Augmented Softbot Approach*.

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