Immersive Realities in Economic Higher Education: Bridging the Gap Between Theory and Industrial Practice through VR-Based Workflow Simulations

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Abstract

The aim of this study is to present the application of Virtual Reality (VR) within the context of the Regional and Environmental Economics MA program, highlighting its role as a methodological breakthrough in sustainability education by addressing a critical weakness in economic training: the lack of physical industrial site visits.

Traditional economic curricula often remain confined to theoretical models, leaving a profound gap in students' 'industrial literacy.' This paper introduces an innovative pedagogical framework developed at John von Neumann University, which utilizes process-oriented immersion to bridge the disconnect between classroom theory and industrial reality. By 'teleporting' students into interactive environments – ranging from the historical 1950s laboratory of John von Neumann to a modern, sustainable winery – the program transforms passive observation into active agency.

Through nine distinct workflows and interactive logic gates, students gain empirical insights into resource efficiency, waste management, and the logistical challenges of regional enterprises. The study concludes that this VR-based 'Virtual Industrial Pilgrimage' not only fosters a 'Green Mindset' but also provides international students from emerging economies with the technological empowerment necessary to design sustainable feasibility studies for their home regions. Ultimately, the research suggests that the future of the Green Economist lies in the digital symbiosis of economic theory and high-fidelity industrial practice.

1. Introduction and Historical Background: VR in Higher Education

Virtual Reality (VR) entered the academic horizon, evolving from flight simulators toward economic modelling and social sciences in the mid-1990s. One of the earliest relevant sources to connect virtual environments with economic behavioural modelling was Ken Binmore (1992). Binmore's novel text on game theory explored the way rational people should interact when they have conflicting interests. The study introduces game theory through a "storytelling" approach, utilizing examples from daily life. From technological viewpoint, the conceptual foundations for educational VR models were established by Jaron Lanier (1992) who defined and explored the transformative potential of VR, highlighting early Virtual Programming Language Research technologies like head-mounted displays and shared user-designated spaces. Lanier outlines VR as an immersive, computer-generated, 3D experience that allows for user interaction with virtual environments. Besides the head-mounted displays (HMD), the study discusses the use of the binocular omni-oriented monitor (BOOM), and the Cave Automatic Virtual

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Environment (CAVE). Lanier highlights "Reality Built for Two," a system enabling multiple users to share a virtual space, allowing non-programmers to create, design, and collaborate within virtual environments. The article was among the first ones to frame VR as a revolutionary tool for education and communication. The first significant VR visualizations in the education of complex systems appeared with the works of Pimentel – Teixeira (1993) and Rowe – Thorburn (2002), the latter describing a tutorial tool which allows the execution of a C program to be graphically displayed that is VINCE (Visual Instruction for Novices in a C Environment), written in Java, allowing it to be used on the web. Ultimately the foundations of the modern VR – namely game theory and numerical simulation – were established by John von Neumann (1944, 1951), making the current immersive applications a direct evolution of his pioneering vision.

The genesis of immersion, specifically Virtual Reality's journey in higher education, began with high-stakes technical training, most notably in medicine and aviation (e.g. Satava, 1993; Mazuryk – Gervautz, 1996). However, its entry into social sciences, specifically economics, is a more recent phenomenon driven by the need to visualize complex, non-linear systems and behavioural patterns in controlled virtual environments (e.g. Binmore, 1992; Kenwright, 2018; Blascovich et al., 2002).

The shift in *pedagogy* from the state of "passive observation" to "active agency" in the context of economic students was first addressed in the framework of experimental learning (Kolb, 1984) and later applied to immersive environments by Dalgarno and Lee (2010). In this paradigm, VR is no longer merely a visual aid; it functions as an immersive teaching laboratory significantly enhancing the effectiveness and practical aspects of education by transforming abstract economic theories into tangible, lived experience in "representational fidelity."

When the *current state of play* is considered, it must be noted that while STEM (Science, Engineering and Mathematics) subjects have adopted VR rapidly, economic higher education has lagged, often confined to static 2D data visualization. Our approach at John von Neumann University challenges this *status quo* by introducing "process-oriented immersion," which bridges the gap between abstract economic models and industrial reality.

2. The Problem Statement: The "Lost Opportunity" of Industrial Visits and the Missing Link of Industrial Site Visits

Why does traditional economic education fail to provide the necessary "industrial literacy" in case of the higher education of economics? This section examines the systemic gaps within the higher education of economics that leaves students disconnected from the practical realities of industry.

Current economic higher education suffers from a profound disconnect between classroom theory and industrial reality. While students of *Regional and Environmental Economics* are expected to become future decision-makers in the green transition, their training often takes place in "sterile" environments, far removed from the physical processes they are meant to manage. This section outlines the three dimensions of this pedagogical failure.

2.1. The "Invisible Factory" and the Lack of Industrial Literacy

Traditional curricula focus heavily on macro-level models, leaving the actual technological core – the "Invisible Factory" – completely out of sight. Whether it is a wastewater treatment plant, a high-tech recycling facility, or a precision vineyard, these systems remain mere icons on a slide for the average student. Consequently, there is a severe lack of *"industrial literacy":* graduates understand the *why* of sustainability but lack any grasp of the *how*. Without seeing a recycled plastic fibre line in operation or understanding the physical scale of a biogas reactor, the economic student cannot truly evaluate the operational risks or the actual efficiency of an investment.

2.2. The Cost of Distance: Logistical and Safety Barriers

In an ideal world, experiential learning would occur through frequent on-site visits. However, we face the *"Cost of Distance"* – a multi-layered barrier comprising logistical, financial, and safety constraints. For an MA program, organizing visits to high-tech industrial sites is often logistically impossible due to:

- **Geographic distances:** Many sustainable facilities are located in remote rural or industrial zones.
- **Safety regulations:** Strict Occupational Health and Safety (OHS) protocols often limit or prohibit student groups from entering active production areas.
- **Cost and Time:** The administrative and financial burden of transporting large groups for a single day visit often outweighs the perceived educational benefit.

  As a result, the industrial site visit – the most critical link to reality – has become the "missing link" of economic training.

2.3. The Sustainability Paradox: Abstract vs. Mechanics

This leads to what we term the "Sustainability Paradox." Higher education attempts to teach the "mechanics of sustainability" (e.g., soil chemistry sensors dictating precise fertilizer dosages or the workflow of a high-tech winery) through abstract, theoretical discourse. This paradox results in a significant conceptual gap: students enter the job market with sophisticated "Macro" knowledge but zero "Micro-level" operational understanding. They are expected to regulate, finance, or manage industries that they have never seen from the inside. They are trained to be captains of ships they have never boarded.

2.4. The Theoretical Necessity of Experiential and Immersive Learning

The shift toward experiential learning in higher education is not merely a modern trend but a pedagogical necessity, fundamentally established by David A. Kolb (1984). Kolb’s experiential learning theory (ELT) posits that knowledge is created through the transformation of experience, requiring the learner to move through a cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation.

Recent neuro-pedagogy and educational psychology research (e.g., Dalgarno and Lee, 2010; Fowler, 2015) further emphasizes that high-impact learning occurs when the student is "immersed" in the subject matter. This sense of "presence" – the psychological state of being there

– triggers higher levels of cognitive engagement and long-term retention compared to traditional, disembodied lecture-based formats.

2.5. The Deficit of Interaction in Economic Higher Education

Despite the clear advantages of experiential learning, the current higher education of economics remains largely characterized by a deficit of interaction. While engineering or medical students have long utilized laboratories for hands-on practice, economic students are typically confined to "passive consumption" of models.

Virtual Reality (VR) addresses this systemic gap through its inherent interactivity. Unlike a 2D video or a static simulation, VR provides an environment where the student is an active agent (cf. Blascovich et al., 2002). In the context of *Regional and Environmental Economics*, this interactivity is the only viable surrogate for missing industrial site visits. By allowing students to interact with complex machinery – be it a von Neumann-era computer or a modern winery bottling line – VR transforms learning from a theoretical exercise into an embodied professional experience.

3. Methodology: Experiential Learning for Sustainability

The MA program in Regional and Environmental Economics at John von Neumann University implements Virtual Reality (VR) not merely as a visualization tool, but as a strategic bridge between industrial history and modern sustainability management. This methodological framework is built upon two conceptual pillars: Historical Mentoring and the Immersive Workflow Approach. By transforming passive observation into active agency, the program fosters a "Green Mindset" through direct engagement with the physical and logical foundations of industry.

3.1. Historical Mentoring as an Anchor: The "Lineage of Innovation"

To prepare students for complex environmental engineering and management tasks, we first establish a foundation of technical literacy through historical immersion. By "teleporting" students into the formative years of modern technology, we foster a deep-seated respect for the engineering rigor required for sustainable solutions.

- **Neumann's Computing Lab** (1950s): Students enter a reconstructed mid-century computer laboratory to interact with *John von Neumann*. The pedagogical task is purely interactive: the user must assist in the manual maintenance of a first-generation vacuum tube computer. By selecting and replacing logical panels under von Neumann's guidance, students move from abstract data theory to a physical, "hands-on" understanding of the logical architecture of information.
- **Kármán's Jet Propulsion Laboratory (JPL):** At the early CalTech JPL site, students act as assistants to *Theodore von Kármán*. They are tasked with executing high-pressure testing of early jet engines, requiring strict adherence to technical protocols and manual console management. This simulation demonstrates that economic decision-making in industry is inseparable from engineering precision and risk assessment—a realization essential for future regional managers.

3.2. The Immersive Workflow Approach: The Modern Sustainable Winery

Building upon this historical foundation, the Modern Winery Application introduces students to the complexities of 21st-century regional production. This simulation serves as a high-fidelity surrogate for the missing on-site industrial visits, replacing passive 360-degree tours with a process-oriented, interactive environment.

- **Active interaction through logic gates:** Moving beyond observation, the student is responsible for managing ten distinct workflows within a high-tech, environmentally friendly winery. Using interactive logic gates, the user must perform manual settings and machine adjustments on bottling lines and fermentation tanks.
- **Immediate systemic consequences and validation:** This creates a "safe-to-fail" laboratory where operational or "economic" errors—such as incorrect machine settings or flawed workflow sequences—result in immediate visual and systemic feedback. At key milestones, technical and economic quiz modules validate the student's progress. Advancement is contingent upon correct responses, ensuring that theoretical knowledge is immediately applied in a practical context.
- **Pedagogical integration:** A virtual moderator (pedagogical agent) explains the mechanics of each stage, providing expert guidance traditionally offered by on-site engineers.

3.3. Relevance to Regional and Environmental Economics MA Program

This immersive methodology allows MA students to analyse the **micro-level operational costs** and environmental footprints of an industrial facility without leaving the campus. By mastering these nine workflows, students gain empirical insights into **resource efficiency, waste management, and the logistical challenges** inherent to regional agricultural enterprises. Consequently, the VR experience bridges the conceptual gap between classroom sustainability and industrial reality.

4. Technical Implementation and System Architecture[3]

4.1.1. System Objectives and Technical Rationale. The primary objective of the development was to engineer a high-fidelity educational Virtual Reality (VR) application tailored to the Regional and Environmental Economics curriculum at John von Neumann University. The system facilitates the exploration, comprehension, and evaluation of modern viticultural and oenological processes. Departing from conventional, passive VR demonstrations, the project was conceptualized as a **structured pedagogical trajectory** divided into modular chapters. Consequently, the technical architecture was required to simultaneously sustain immersive spatial presence, process-driven logic, an educational narrative, and real-time performance assessment.

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[3] This chapter outlines the technical and developmental specifications of the *Virtual Factory Tour* project, commissioned by **John von Neumann University** and engineered by **Printosh Advertising** for the **Meta Quest 3 standalone ecosystem**. While the documentation is structured to be accessible to interdisciplinary readers, it maintains rigorous technical accuracy regarding system architecture. Please note that the specifications align with the prevailing **Meta Developer Dashboard** and support protocols at the time of writing; however, institutional deployment and publication cycles must always be synchronized with the most current **Meta Quest Developer Hub** guidelines.

4.1.2. Platform Strategy and Hardware-Software Synergies. The application was natively developed for the **Meta Quest 3 standalone HMD** (Head-Mounted Display), eliminating the requirement for external computational tethering. This strategic decision fundamentally dictated the system architecture: the digital assets and rendering pipelines were optimized to maintain high visual fidelity while ensuring computational stability on the headset's mobile chipset. In an academic environment, standalone operation is paramount, as it facilitates seamless classroom deployment, rapid initialization, and enhanced user mobility. The architecture comprises nine distinct virtual environments, necessitating a robust, **modular development framework**.

4.1.3. Functional Decomposition and Learning Path Integration. The system's technical backbone follows a chronologically organized pedagogical sequence. Users navigate through an introductory orientation space followed by specialized modules encompassing grape cultivation, harvesting, primary processing, fermentation, maturation, stabilization, filtration, blending, and final packaging (bottling and labelling). A distinguishing feature of this architecture is its **functional interactivity**; environmental scenes are not merely illustrative but are intrinsically linked to specific oenological operations. For instance, the system integrates complex interactions such as refractometer-based sugar content analysis, destemmer parameter adjustment, and the application of **Hoffmann's barrel measurement tables** for volumetric calculations.

4.1.4. Modular Scene Management and Spatial Organization. Utilizing the **Unity engine's** capabilities, the system employs a modular scene-management logic. This approach separates environmental geometry, interactive triggers, narrative scripts, UI layers, and assessment modules into manageable subsystems. This separation was crucial for maintaining performance across diverse environments – from the sterile, high-reflectivity surfaces of the stainless-steel processing hall to the low-light, atmospheric conditions of the aging cellar. This modularity ensures that **memory allocation and asset-loading latencies** remain within optimized thresholds for a standalone VR experience.

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4.1.6. 3D Asset Pipeline and Environmental Synthesis. The 3D modelling workflow utilized **Blender** as the primary creation suite, establishing a flexible asset pipeline. The modelled inventory includes complex industrial machinery (fermentation tanks, pneumatic presses, bottling lines), architectural elements, and pedagogical props (hydrometers, pipettes, and tablet-based information interfaces). Within Unity, these assets were assigned advanced shaders, collision hulls, and interaction components. The pipeline emphasizes **material authenticity**, ensuring that the visual representation of wine-making technology aligns with industrial reality.

4.1.7. Interactivity and Behavioural Logic. A cornerstone of the system is the convergence of the interaction layer with learning outcomes. Interactions are governed by **state-management and feedback loops**; the system does not merely detect a "grab" or "trigger" event but evaluates the technical accuracy of the performed operation. For example, during the fermentation stage, the user's actions directly influence the simulated process, providing a **"safe-to-fail" environment** where incorrect parameters trigger corrective narrative feedback.

4.1.8. Narrative Integration and Hybrid UI Architecture. The pedagogical agent (narrator) is integrated as an event-driven feedback layer, guiding the user through the complex oenological cycle. This is complemented by a **hybrid User Interface (UI)** approach: spatial "diegetic" elements (such as the virtual tablet) coexist with non-diegetic interfaces (assessment screens) without compromising the sense of immersion. This ensures that technical data and educational instructions remain legible within the 3D space.

4.1.9. Assessment Metrics and Performance Tracking. The evaluation module is a core architectural component, supporting multiple-choice and task-based assessments using virtual input methods (e.g., virtual pens, drag-and-drop). The system tracks user performance in real-time, recording accuracy and dwell time. Upon completion, the architecture generates a **comprehensive statistical summary**, transforming the VR experience from a simple simulation into a validated educational tool.

4.1.10. Standalone Optimization and UX Continuity. Given the hardware constraints of the Meta Quest 3, the development emphasized **computational efficiency**. Optimization strategies targeted vertex counts, draw calls, and lighting baked-in textures to ensure that visually complex elements – such as fluid simulations and stainless-steel reflections – maintain a consistent frame rate. This technical rigor ensures **User Experience (UX) continuity**, which is vital for preventing simulator sickness and maintaining pedagogical engagement.

4.1.11. Synthesis of Development Milestones and System Maturity. The technical evolution of the project followed a rigorous, multi-stage development lifecycle. It commenced with the **pedagogical mapping** of oenological processes, translating an educational brief into a spatial system design. This was followed by the **3D asset synthesis** in Blender and the subsequent environmental construction within Unity. The integration phase proved critical, where interaction programming, narrative layers, and hybrid UI systems were synchronized into a coherent user experience. A pivotal milestone was the embedding of **formative and summative assessment modules**, ensuring that each production phase serves as a validated knowledge checkpoint.

In summary, the technical architecture of the application is characterized by high **inter-component synergy**: the 3D environments, the interactive behavioural logic, the auditory narration, and the measurable pedagogical metrics do not function as disparate elements but as a **mutually reinforcing ecosystem**. This structural integrity ensures that the Quest 3 standalone environment delivers not only a high-fidelity visual experience but also a stable, high-impact educational tool.

4.2. Development framework and programming architecture

4.2.1. Integrated Development Environment (IDE) and Ecosystem. The virtual factory tour was engineered within a sophisticated digital pipeline, utilizing **Unity** as the primary execution engine and **Blender** for high-fidelity 3D modelling. This framework was selected for its robust support of spatial computing and its specialized optimization tools for the **Meta Quest 3 standalone architecture**. The synergy between these platforms allowed for the creation of a high-performance, interactive educational ecosystem.

4.2.2. Unity as the Central Integration and Rendering Layer. Within this project, Unity serves as more than a rendering engine; it functions as the **central integration hub**. It orchestrates the convergence of 3D assets, procedural animations, interaction triggers, narrative scripts, and the state-management variables required for pedagogical evaluation. A critical advantage of this engine is its ability to manage **non-linear scene transitions** and complex spatial logic – essential for an application where the user progresses through multiple, functionally distinct industrial locations rather than a single, static environment

4.2.3. 3D Synthesis and Topological Optimization in Blender. Blender played a pivotal role in the **visual production pipeline**, tasked with the geometric synthesis of the winery's technological infrastructure. This included the modelling of specialized oenological machinery (processing units, fermentation tanks, pneumatic presses) and architectural elements. A key technical requirement was the **topological optimization** of these models; assets were engineered to balance visual realism with the constraints of **real-time mobile rendering**, ensuring fluid performance on the Quest 3's integrated hardware.

4.2.4. Programming Paradigm and Application Logic. The application's behavioural logic was implemented using **C#** within the Unity environment. In this architecture, C# serves as the foundational layer for **event handling, object-state control, and algorithmic transitions**. The codebase governs the interaction between the user and the virtual environment, managing the transition between pedagogical chapters, the execution of quiz modules, and the real-time calculation of performance metrics. This ensures that every user action – from tactile interaction to cognitive assessment – is processed through a unified logic layer.

4.2.5. Interaction Framework and XR Componentry. To ensure intuitive and consistent user engagement, the system utilizes a component-based interaction logic aligned with the **XR Interaction Toolkit**. This framework facilitates complex spatial operations such as object manipulation (selecting, grabbing, activating) and the utilization of virtual tools (e.g., refractometers or control panels). By standardizing these **spatial affordances**, the system provides a seamless transition between diverse tasks, whether the user is performing a tactile bunch-selection or a precise volumetric measurement.

4.2.6. Event-Driven State Management and Feedback Loops. The programming architecture is anchored in **event-driven state management**. The system does not merely process raw input; it evaluates the **technical validity** of each interaction against the pedagogical requirements. For instance, the selection of grapes triggers distinct logical branches depending on the accuracy of the choice, providing immediate corrective or reinforcing feedback. This necessitates a robust **Finite State Machine (FSM)** approach, where scene progression is contingent upon the successful completion of specific functional and cognitive milestones.

4.2.7. Immersive UI and Diegetic Information Architecture. Information delivery within the VR space is managed through a **hybrid UI architecture**. To maintain immersion, the system predominantly utilizes **World-Space UI** solutions, where interfaces (such as the virtual tablet or information panels) appear as integrated, diegetic elements of the 3D environment. This approach ensures that instructional content and performance data remain legible and accessible without disrupting the user's sense of "presence" within the industrial setting.

4.2.8. Auditory Narrative and Feedback Subsystems. The pedagogical agent (narrator) is implemented as a dedicated **auditory subsystem** within the architecture. The narration is dynamically linked to interaction events and scene states, fulfilling multiple roles: orientation, technical explanation, and real-time correction. This synchronization ensures that the auditory layer remains context-aware, guiding the user through the oenological cycle in a responsive and coherent manner.

4.2.9. Hardware-Specific Capabilities and Future Scalability. While the current application focuses on stable, real-time VR interactions, the architecture remains cognizant of the **Meta Quest 3's advanced capabilities**, such as enhanced resolution, hand tracking, and Passthrough/Mixed Reality (MR) integration. The modular design of the system ensures **future scalability**, allowing for the eventual incorporation of hand-tracking or MR-based collaborative learning modes as the pedagogical requirements evolve.

4.2.10. Synthesis of the Development Architecture. In conclusion, the project's technical foundation is defined as a **Unity/Blender-based, C#-controlled, and XR-compatible custom architecture**. Its primary strength lies in the seamless fusion of visual asset production, real-time 3D rendering, and measurable pedagogical logic into a single, coherent system. The result is not merely an illustrative simulation, but a **structurally conscious, data-driven educational instrument** designed for the complexities of modern economic higher education.

4.3. Deployment and Accessibility within the Meta Ecosystem

4.3.1. Deployment Paradigm: Standalone Operational Logic, The VR application engineered for John von Neumann University is natively optimized for the **Meta Quest 3 standalone ecosystem**. This architectural choice implies that the software executes directly on the Head-Mounted Display (HMD), bypassing the need for a tethered workstation. For an institutional educational setting, this **decoupled operational model** is critical: it ensures rapid deployment, high user mobility, and minimal infrastructure overhead while maintaining the high fidelity required for complex industrial simulations and performance assessments.

4.3.2. Distribution Channels and Access Architectures. The dissemination of the application utilizes the Meta Quest platform's multi-tiered distribution model. For this specific pedagogical project, two primary access strategies are identified:

- **Private Institutional Distribution:** Utilizing dedicated **Release Channels**, the development team can deploy builds to a curated group of authorized users (students and faculty). This model is ideal for academic environments, as it ensures that the simulation – which is a specialized educational asset rather than a mass-market product – remains within a controlled, secure institutional loop.
- **Public and Semi-Public Models:** Alternatively, the application can be hosted via the **Meta Quest Store** or the **App Lab**. While this simplifies versioning and updates through standardized ecosystem protocols, it necessitates rigorous compliance with Meta's metadata and publication standards.

It is important to clarify that "cloud-based access" in this context refers to **distribution and entitlement management** rather than remote rendering; the simulation logic and 3D assets reside locally on the device to minimize latency and ensure a consistent User Experience (UX).

4.3.3. Rationales for Platform Integration: Version Control and Sustainability. Integrating the application into the official Meta ecosystem is a strategic necessity for long-term **operational sustainability**. In a curriculum-based VR tool, centralized **version management** is paramount. As oenological workflows, assessment modules, or platform-level technical requirements evolve, the ecosystem ensures that all students interact with the same **validated,**

synchronized version of the software. This centralized update mechanism eliminates the "fragmentation risk" common in sideloaded applications, ensuring that learning outcomes are measured against a consistent pedagogical benchmark.

4.3.4. Technical Compliance and Quality Assurance (VRC). Navigating the Meta publication pipeline involves rigorous **Technical Requirements (VRC - Virtual Reality Check)**. Beyond mere functionality, the platform evaluates the application across several critical vectors:

- **Performance Stability:** Ensuring consistent frame rates to prevent simulator sickness.
- **Input Consistency:** Validating that interaction metaphors (grabbing, pointing, UI navigation) align with established VR standards.
- **Data Privacy and Transparency:** Verifying that the assessment modules and user data handling comply with global and platform-specific privacy regulations.

For an interactive, chapter-based system such as this, these checks serve as a **third-party quality assurance** layer, guaranteeing that the application is not only educationally sound but also technologically robust.

4.3.5. Hardware Specifications and Deployment Requirements. The system is precision-tuned for the **Meta Quest 3 hardware profile**, leveraging its specific computational power, optics, and spatial audio capabilities. Reliable institutional deployment requires:

- **Device Initialization:** Properly configured and registered Meta institutional or developer accounts.
- **Network Infrastructure:** High-speed internet access is required for initial deployment, entitlement verification, and OTA (Over-the-Air) updates, although the core simulation can function in an offline mode once cached.
- **Maintenance Toolchain:** Continued operational support utilizes the **Meta Quest Developer Hub (MQDH)** and Unity's build-management tools. Maintaining this technical lineage is essential for the future integration of advanced features such as hand-tracking or Mixed Reality (MR) overlays.

4.3.6. Version Control and Institutional Deployment Consistency. In an academic environment, the most significant operational advantage of the Meta ecosystem is the ability to perform **versioned updates**. The VR factory tour is not a "static digital asset" but a dynamic educational product with a manageable lifecycle. Whether refining the visual fidelity of oenological processes, modifying assessment rubrics, or optimizing the UI based on longitudinal user feedback, the system allows for the seamless distribution of new builds. This centralized mechanism ensures **curriculum consistency**: regardless of the physical device used, every student interacts with the same validated and synchronized pedagogical version. In this context, "deployment" transcends its technical definition and becomes a metric of **educational quality assurance**.

4.3.7. Post-Deployment Support, Maintenance, and Compliance Protocols. The operational integrity of the application is sustained through a structured support and maintenance framework. This extends beyond mere bug-fixing; it encompasses the continuous alignment of the software with the evolving **Meta Technical Standards** and privacy regulations.

- **Scope of Maintenance:** Professional support includes the mitigation of runtime errors, the deployment of optimized builds, and the maintenance of administrative metadata within the Meta Developer Dashboard.

- **Technological Sustainability:** To prevent **technological obsolescence**, a 12-month support guarantee ensures that the application remains compatible with platform-level firmware updates. This long-term maintenance logic is fundamental to the value of the interactive system, as the pedagogical efficacy of VR materials is intrinsically linked to their continuous technical stability and updatability.

4.3.8. Comprehensive Synthesis of the Deployment Architecture. In conclusion, "deployment" within this project signifies a comprehensive implementation strategy within the Meta Quest 3 standalone ecosystem. While the application executes locally on the HMD to ensure high-performance rendering, the **Meta platform services** provide the essential infrastructure for entitlement management, secure distribution, and long-term operational reliability.

For the institutional user, this architecture guarantees that the VR application is not merely "installed" but is **integrated into a professional delivery chain**. This underlying infrastructure – while transparent to the end-user – constitutes the most critical layer of stability, ensuring that the interactive factory tour and the integrated assessment system function as a reliable, standardized, and sustainable instrument of modern economic higher education.

4.4. Visual Documentation and User Interface (UI) design

4.4.1. Theodore von Kármán’s Contemporary Jet Engine Laboratory Simulation

Figure 1. Introductory Pedagogical Agent and Spatial Orientation Interface. The initial scene establishes the immersive environment, integrating the virtual instructor (pedagogical agent) with the technical equipment. The UI employs a **diegetic spatial orientation logic**, where the instructor, machine model, and control interface coexist within a unified visual field to focus user interaction and observational priority.

Figure 2. Laboratory Context and Spatial Arrangement. The simulated workspace illustrates the holistic layout of the equipment. The UI design ensures an **intelligible workspace architecture**, where tools, access points, and safety protocols are presented in relation to each other to enhance **situational awareness** and prepare the user for operational decision-making.

Figure 3. Overview of the Interactive Control Console. The primary interface for system interaction, featuring levers, switches, and analogue gauges. This **hybrid UI solution** replicates authentic industrial logic while facilitating the acquisition of operational sequences through integrated feedback and intervention points.

Figure 4. Real-time Status Monitoring and Instrument Feedback. Close-up view of the instrument clusters and status indicators. Voltage readings and circuit adjustments form a synchronous feedback system, enabling the user to interpret measurement data and comprehend the **causal relationships** between parameter changes and system behaviour.

Figure 5. Multi-view System Integration: Model and Interface Correlation. Simultaneous visualization of the control panel, the pedagogical agent, and a **cross-sectional equipment model**. This multi-view architecture allows the user to immediately observe the physical impact of their actions on internal components, fostering a systemic understanding over rote memorization.

Figure 6. Flow Visualization with Chromatic Indicators. Internal processes are rendered visible through **color-coded flow and thermal load indicators** on the cross-sectional model. This explanatory layer translates abstract technical concepts into concrete visual data, directly linking control panel interventions to internal thermodynamic changes.

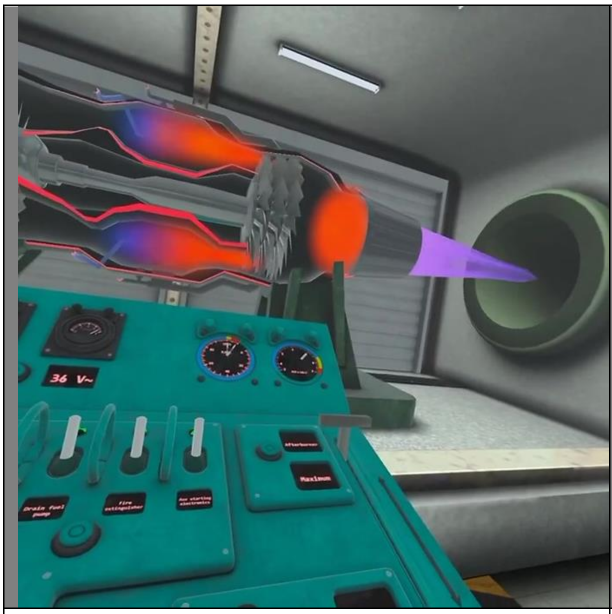

Figure 7. Terminal State Visualization: Turbine Outlet and Thrust Chain. A visual representation of the turbine's exhaust section, demonstrating the closure of the **operational cause-and-effect chain**. Chromatic energy indicators illustrate the thrust effect, allowing the user to validate the outcomes of their control-panel settings.

Figure 8. Detailed Interaction Zone for Procedural Training. Macro view of the control interface, highlighting structured intervention points. This layout supports the mastery of **operational sequences** and functional separation, emphasizing the user's transition from passive observer to **active operator** in a high-fidelity training environment.

4.4.2. John von Neumann's Contemporary Electronics Laboratory Simulation

Figure 9. Initial Workspace Topology and Navigational Reference Points. The visual architecture establishes the spatial configuration of the laboratory, defining the workstations and environmental anchors essential for task execution. The UI employs a **non-diegetic spatial orientation logic**, allowing the user to identify relevant interaction zones through environmental navigation rather than traditional menus.

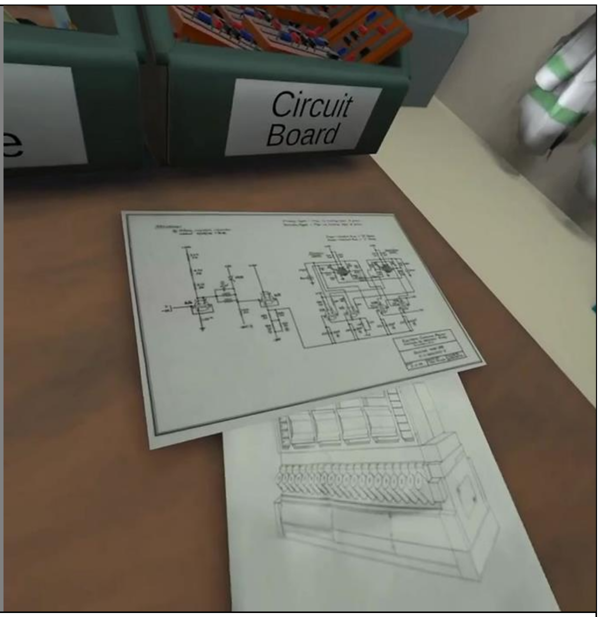

Figure 10. Schematic Documentation and Structural Blueprint Interface. This interface provides access to the technical reference data required for cognitive preparation and operational sequencing. The UI functions as a **static information carrier**, serving as a visual substrate for decision-making, component identification, and the comprehension of assembly logic.

Figure 11. System-Guided Interaction and Spatial Visual Cuing. The chromatic (blue) visual marker identifies the high-priority object, minimizing the **search-related cognitive burden**. In this stage, the UI serves as a **step-by-step guidance layer**, where spatial highlighting is projected directly onto the physical assets to synchronize the control interface with the immersive environment.

Figure 12. State Management of Active Components within the Assembly Chain. The scene captures the transition of a selected electron tube into an active state. The UI logic is **implicit**, signalling a state change through the "grab" event; the component is thus formally assigned as the active element within the subsequent operational sequence.

Figure 13. Grouped Component Highlighting for Workflow Structuring. The repetitive marker structure identifies multiple sequential input points, clarifying the set of components involved in the current assembly phase. Here, the UI serves to **structure the workflow**, extending visual cues to a functional set of elements rather than a single isolated object.

Figure 14. Real-time Process Validation and Visual State Representation. Visualization of the assembly line's intermediate state, reflecting task progression through physical configuration changes. This **ambient UI logic** allows the user to track readiness levels and process continuity without the requirement for explicit textual overlays.

Figure 15. Integration of Data Entry and Administrative Validation Layers. Representation of the documentation and verification phase, where tactile assembly is supplemented by an analytical layer. The UI facilitates the **convergence of physical interaction and information processing**, linking object manipulation to a formal validation interface.

Figure 16. Combined Pedagogical Feedback and Instructional Highlighting. The scene illustrates the evaluation phase, where a marker highlights the instructor's documentation. The UI functions as a **communicative focal point**, redirecting the user's attention from manual manipulation to the reception of expert instructions and performance feedback.

4.4.3. Case Study: Interactive Virtual Mission in a Modern Winery

Figure 17. Orientation Interface and Pedagogical Entry Point. The primary function of the initial interface is to establish the environmental context and visually prepare the user for the simulation. The **minimalist UI architecture** is strategically designed to reduce the initial **cognitive load** while providing a clear navigational reference for the learning trajectory.

Figure 18. Raw Material Selection and Initial Decision-making Node. This interface represents the first critical decision point within the technological sequence. The UI serves a dual pedagogical role: facilitating **guided interaction** and supporting cognitive engagement regarding the correct operational hierarchy of the winemaking process.

Mivel mérjük a szőlőcukor-tartalmat? (2/3)

Jelöld meg helyesnek vélt választ!

Figure 19. Embedded Formative Assessment and Knowledge Validation Panel. The assessment interface functions as an integrated evaluation mechanism within the 3D environment. This **Q&A-based UI node** enables the immediate recall of previous technological units, thereby reinforcing the **formative assessment** cycle throughout the learning process.

Figure 20. Operational Control Interface for System Activation. Visualization of a machine-level control node. The UI structure supports the initiation of industrial operations, fostering an understanding of **operational sequencing** and the functional relationships between the user's intervention and equipment response.

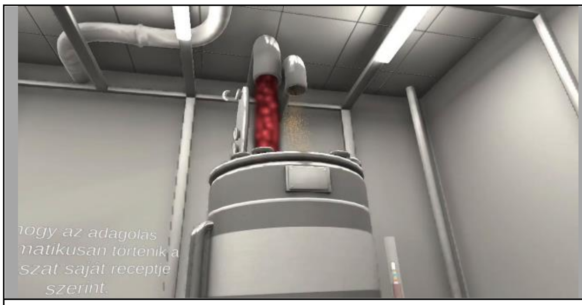

Figure 21. Contextual Process Monitoring and Equipment Status Interpretation. The scene depicts a processing stage where the technological status is conveyed through the visual representation of the equipment. The UI serves as a **contextual information layer**, assisting the user in linking specific equipment functions with current technological milestones.

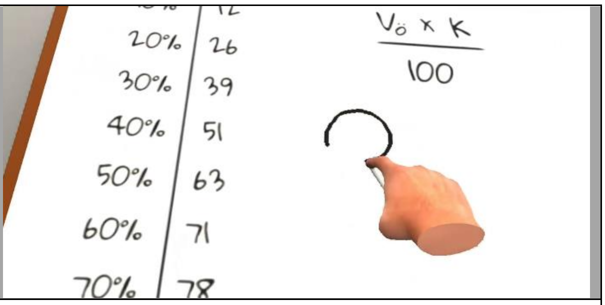

Figure 22. Quantitative Status Indicators and Computational Visualization. This interface facilitates the visual processing of **quantitative data** and its derived technological correlations. The semi-circular gauges and tabular data provide a spatially anchored UI solution for the traceable comprehension of **abstract computational steps**.

A betontartályban zajló, szabályozott mikro-oxidáció milyen textúrabeli hatást eredményez leggyakrabban egy vörösborban? (3/3)

Jelöld meg helyesnek vélt választ!

○ Lágyabb, kerekebb kortyérzet
○ Erőteljes füstös jegyek
○ Érzékelhetően magasabb savtartalom
○ Gyors borkőkiválás

Figure 23. Summative Performance Review and Retrospective Summary. The final summary screen is a pivotal element for concluding the pedagogical cycle. The interface presents a structured overview of all completed subtasks, supporting **self-assessment, error detection**, and the retrospective analysis of the interdependencies between technological stages.

Figure 24. Parametric Calculation and Explicit Data Entry Interface. Representation of the UI segment dedicated to quantitative parameterization and manual data entry. Beyond procedural knowledge, this interface encourages the recognition of complex **technological correlations**, transforming the user from a passive observer into an **active decision-maker**.

5. Future Prospects: The Vision of a Virtual Green Laboratory

The integration of Virtual Reality into the Regional and Environmental Economics curriculum is not merely a technical upgrade; it is a prerequisite for training the next generation of "Green Economists." As established in our problem statement, theoretical knowledge without industrial literacy is insufficient for managing the complex transitions required by the Green Deal and global sustainability goals.

5.1. The Immersive Industrial Seminar: A 12-week strategic roadmap

We propose a future curriculum where a single semester-long practical seminar allows students to "visit" and interact with ten distinct green industrial facilities. This "Virtual Industrial Pilgrimage" provides a comprehensive overview of the circular economy through experiential manual tasks:

1. **Sustainable Viticulture:** Advanced workflow management in winery production (as detailed in our case study).
2. **Wastewater Treatment:** Real-time management of biological and chemical filtration processes.

3. **Water Utilities:** Strategic oversight of urban water distribution and loss-prevention systems.
4. **Construction Waste Management:** Interactive control of demolition waste recycling and crushing plants.
5. **Plastic Bottle Upcycling:** Managing the workflow of polymer re-granulation and fibre production.
6. **Intralogistics in Green Warehousing:** Optimizing energy-efficient internal logistics and automated storage.
7. **Textile Upcycling:** Redirecting waste fabrics into high-value secondary production lines.
8. **Autonomous Precision Agriculture:** A pinnacle of "Sensor-to-Shooter" logic, where students manage drone-based vegetation analysis and control driverless tractors that apply nutrients with variable-rate precision based on satellite/drone data.
9. **Battery Gigafactory Environmental Controls:** Managing the sophisticated emission and safety monitoring systems of modern energy storage production.
10. **Nuclear Power Control Room:** Operating radiation monitoring systems and ensuring the safety protocols of carbon-free baseload energy.

5.2. Global Impact: Empowering International Students

For MA students arriving from emerging economies – specifically from South-East Asia and Africa – this VR-based methodology offers a unique developmental leap. The final assignment for this course would shift from traditional testing to a strategic feasibility study.

Students would be tasked with designing a proposal for a Green VR Application tailored to their home country's specific environmental challenges (e.g., plastic waste in Bangladesh or Vietnam or sustainable irrigation in Sub-Saharan Africa). By doing so, they do not just learn about technology; they become architects of the Green Transition, equipped with the "industrial literacy" to evaluate, finance, and regulate sustainable technologies in their respective regional contexts.

However, the adoption of VR technology in education faces challenges. One significant obstacle is the cost of VR equipment and software. The accessibility of VR platforms can pose a barrier for educators trying to integrate VR into education. Feridun and Bayraktar (2024) delve into the use of VR in education, and how VR can influence student learning outcomes in different applications. Apart from the advantages of VR, the study also discusses the obstacles that are impeding the use of VR in education including concerns about costs, standardizing content and the demand for training and supporting educators.

6. Conclusion: Bridging the Legacy of von Neumann with the Future of Sustainability

The transformation of Regional and Environmental Economics from a purely theoretical discipline into an industrially literate, action-oriented field is no longer a pedagogical luxury but a strategic necessity. This study has demonstrated that Virtual Reality (VR), when implemented through the Immersive Workflow Approach, provides a unique solution to the most significant gap in current economic higher education: the absence of practical, on-site industrial experience.

Our results in VR application at John von Neumann University highlight that the "Active Agency" provided by VR serves as a high-fidelity surrogate for industrial site visits. By moving beyond passive observation, students transition from "Macro-level analysts" to "Micro-level process managers." Whether it is assisting John von Neumann in his 1950s laboratory or managing the complex energy workflows of a modern sustainable winery, the student develops a profound respect for technical rigor – a quality indispensable for future environmental decision-makers.

Ultimately, the lineage of innovation – starting from von Neumann's foundations in numerical simulation and game theory – finds its modern culmination in the "Sensor-to-Field" logic of precision agriculture and the circular economy. For our international students from emerging economies, this VR-based laboratory offers more than just knowledge; it provides the technological empowerment to design sustainable feasibility studies tailored to their home regions.

In conclusion, the future of the Green Economist lies in the symbiosis of economic theory and industrial practice. By "teleporting" the factory into the classroom, we ensure that the captains of the Green Transition have not only read about their ships but have mastered their engines in the virtual space.

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