The Future of Creative Engineering Education: Application of Virtual Reality for Water-Energy-Food Nexus

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Abstract

In this era of rapid technology advancement, information transfer through conventional educational methods has failed to create the future champions of change. Thus, there is a need to adopt new educational technologies that allow students to visualize complex engineering and sustainability concepts. This paper presents a virtual reality-based water-energy-food (VR-WEF) nexus visualization and simulation tool for teaching engineering students. VR-WEF is a powerful immersive tool that places students at the center of an alternative virtual world making it easier for them to experiment and learn complex engineering concepts effectively and understand the consequences of different engineering decisions. VR-WEF can be used to mimic the natural process (anaerobic digestion) of converting wastewater and food waste into renewable energy (biogas), fertilizer, and nutrient-rich recycled water. Through its functionalities, the tool provides an immersive and interactive environment, can increase student interest and engagement, and provides immersive visualizations that are not possible in the traditional classroom.

Keywords

Water-energy-food nexus, virtual reality, immersive tool.

1. Introduction

Given the need to maintain water, energy and food security and combat environmental challenges in the face of population growth and global warming, today's technologies need to be used in the right way to prepare engineering students for the transition to a sustainable economy. Students today are what futurist and former Disney Imagineer Joe Tankersley calls "Digital natives...unencumbered by our analog history." The digital natives will not wait for permission to empower themselves and in so doing will empower everyone[1]. More than half of brick and mortar colleges may be forced to close their doors in the next decade as on-line resources become more prevalent and the digital natives become increasingly skeptical of the need to pay for encounters with live humans who merely direct their attention to digital resources available outside of school classrooms[2]. Current models for engineering education need to adapt.

There is a greater level of interest in the impacts of the new tools on preparing the next generation of engineers as digital natives. As part of this enhanced learning, three-dimensional virtual environments are available as educational resources[3]. In Virtual Reality (VR), users are immersed and able to interact with a 3D environment[4,5]. Most importantly, customizations to the specific needs of the learner make this a powerful and necessary tool for institutional engineering education. Unlike traditional user interfaces, VR places the user inside a virtual world.

Using VR as a tool to educate within the field of engineering is not a new concept. In 1997, Pantelidis[6] proposed the use of VR as a teaching aid - detailing the types of VR available at the time, reasons to use it as an educational engineering tool and when to use it. Many of Pantelidis' suggestions apply in the present age just as well as (if not better than) they did decades ago. VR enhances teaching by incorporating various engineering concepts and encouraging active participation during the learning process. This is of particular importance when dealing with complex subjects. In particular, VR is proving vital where a 3D visualization can be used in the development of solutions for global challenges. In this manner, virtual environments can be reviewed and used to make decisions without the need of a real physical prototype or can be used to assist in more cost/material/time efficient creation of analog solutions through rapid digital prototyping of objects whose behavior can then be observed and tested in realistic simulated environments. This reduces risks, development time, costs, and improves product quality. In this paper, the authors present a virtual reality-based water-energy-food (VR-WEF) nexus visualization and simulation tool for teaching engineering students.

2. Framework for VR based Educational Tool

The development of a typical VR based educational platform requires educators and developers to establish the desired perspective, intended learning goals, design parameters, and overall framework that will be virtually built for user interaction. Conceptual models can be utilized as a starting point to describe the proposed features and interactions that a VR tool is intended to include. Conceptual models should present an overall idea of what the model aims to achieve, dimensions of components of the system, and how user interaction will accomplish the goal. Similarly, a physical/full scale model can serve the same purpose, if it exists. With a conceptual or physical model fully established, a virtual model can be mapped into a 3D environment. Once the 3D model is constructed, the VR system can be utilized to create immersive educational platforms with interactive features. Figure 1 shows a framework for the development of VR-based educational platform.

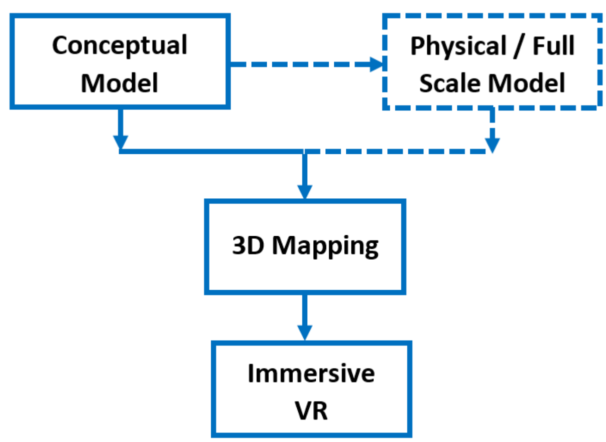

Figure 1: Framework for the development of VR-based educational Module

3. VR-based Educational Tool for Water-Energy-Food Nexus System

The increasing development of VR technologies has matured enough as to expand education and research from the military visualization realm into more disciplines, such as engineering, art and psychology. In this study, the water-energy-food (WEF) nexus is selected as it is central to sustainable development[7]. The inextricable linkages between these critical domains require a suitably integrated approach to ensuring water and food security, sustainable agriculture and energy production. However, the analysis of one resource sector is sufficiently complex, suggesting that integrating multiple resource sectors simultaneously poses an appreciable challenge[8]. The framework shown in Figure 1 is employed to develop a VR-WEF model for educating undergraduate engineering and sustainability graduate students.

3.1. Conceptual and Full Scale WEF System

The main components of the WEF system include biodigesters, floating biogas tank, settling tanks, sand filtration, recycled water storages and a hydroponic garden. The conceptual model with components and dimensions is presented in Figure 2. The WEF system takes organic wastes and produces an energy source in the form of methane gas (used to fuel gas appliances) and a nutrient rich effluent capable of supporting agriculture in a hydroponics system as well as garden beds. Food waste, liquid waste, and solid waste initially enter the system through the primary digester.

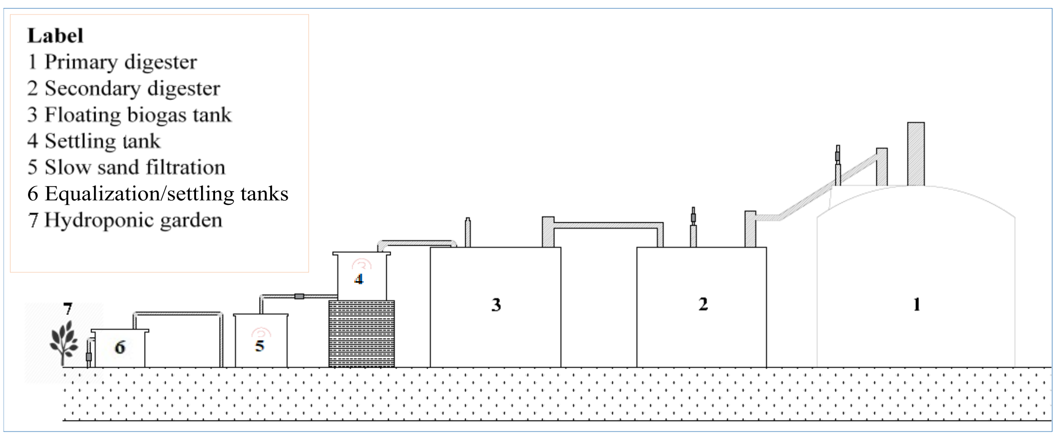

Figure 2: Profile view of the WEF nexus model

The waste is degraded in the biodigester until the volume is exceeded and an overflow mechanism allows liquid to overflow into the secondary digester. Because of the overflow pipe system, the liquid effluent, or liquid digestate, moves from one tank to another tank at a rate based on the incoming influent volume rate. The liquid digestate passes through a sub-system filtration process that improves water quality for hydroponic crop production.

3.2. 3D Mapping

The gaming world is already making more emotive impactful simulations of “green futures” playable to everyone through titles for the PC, Xbox and Playstation such as “Cities Skylines -- Green Cities” that enable users to create a sustainable future (often by playing as the “mayor” or “city planner”) with all the WEF nexus parameters – ecological, economic, and budgetary, including trade-offs and political conflicts. Users have an up-to-date ever-expanding menu of green technology choices that allow them to implement everything from urban wind and solar farms and geothermal heat pumps, to green roofs. It’s only deficiency is the ability to model one’s particular geographically accurate real-world environment.

To remain relevant and engaging, engineering education needs to incorporate the best of GIS programs and MMORPGs (Massively multiplayer online role-playing games) and do so in a way that is free or inexpensive and accessible for all students. With the improvements to cost free browser based services like Google Earth and Google Maps and Open Street Map (OSM), and the availability of Open Source 3D modelling and gaming software like Blender 3D with its new OSM and DEM/SRTM data plug-ins (for Digital Elevation Map/ JPL – NASA Shuttle Radar Topography Mission data) and free-to-use world building software such as Unreal Engine, Unity 3D, Autodesk 3DS Max and Roblox Studio, students are beginning to see that they can do better than “a thousand pictures.” In addition, educators can use 3D Warehouse to download and share free SketchUp 3D models for engineering, architecture, and construction. By mastering these tools, educators can create truly interactive, immersive simulation platforms tied to specific geographical information, allowing students to “play through” scenarios relevant to them and their futures in real time – scenarios that include the cultural, psychological and emotive content that open-world gaming with real-time multiplayer functionality brings to the table and make better decisions based on the impressions of a multitude of stakeholders.

3.3. Immersive Virtual Reality Model

VR-WEF is developed by the Civil and Environmental Engineering Department at U.A. Whitaker College of Engineering, Florida Gulf Coast University in collaboration with the Patel College of Global Sustainability at the University of South Florida. The facility in the Virtual Immersive Portal for Engineering Research (VIPER) Lab located at U.A. Whitaker College of Engineering is used to create the VR-WEF tool where students can adjust input concentrations to determine impact on output results. Unreal 3D, Blender and 3D-warehouse [software packages] were employed to develop the 3D maps for the VR-WEF system. The inflow-outflow is represented using 3D animation that places viewers at the center of the WEF system interaction. In this way, the need to address resource scarcity are effectively communicated—making it hard for students not to be affected by and act on what they see. The VR-WEF Simulation Software consists of the following components:

- SimulationLevel, which is the environment space where a user is placed inside virtually.
- OculusControl, which is the implementation of all the controls required for a user to interact with the MenuInterface by using an Oculus Rift device.
- MenuInterface, which is the component that assists a user, allowing them to interact with the simulation software through the OculusControl.
- The Digester that receives waste input from the SimulationLevel to simulate the waste digestion and sends output data back to the SimulationLevel.
- The Hydroponics, which is the component where the simulation of the vegetation takes water and fertilizer level inputs from SimulationLevel.

Figure 3 depicts the 3D components of the WEF system in the simulation software from the simulation level component.

Figure 3: 3D VR-WEF system developed in Unreal Engine

4. VR-WEF Benefits and Implementation Challenges

4.1. The Benefits of VR-WEF System

Engineering education typically employs laboratory demonstrations or field studies to enhance students' practical knowledge and performance. Alternatively, VR computer technology can help quantitatively and qualitatively expand, deepen, and enhance the understanding of complex systems[9,10] such as the dynamic interaction between WEF systems. For the VR -WEF system to have relevance, students need to be able to manipulate parameters that mirror realistic interventions in another layer of reality.

It is well-established that 3D-visualization's interactivity, safety, engagement, and immersion arguably play the most important part in the learning process[11]. In this paper, the authors demonstrate the use of a 3D VR-WEF system in preparing engineering students for practical experience of real-world challenges (resource scarcity). Table 1 summarizes the features of VR-WEF system that enhance the teaching and learning processes in engineering education.

Table 1: Key features of the VR-WEF system and their implications to enhance the student learning environment.

Key Features	**Benefits**
Virtual World	A 3D environment that better visualizes and mimics the real world. Visual perspectives change with interaction and movement, similar to real-world experiences.
Interactivity	Responds to a student's action in a natural manner. It also allows students to create objects as part of interaction.
Engagement	Students can interact with others in the virtual environment, even remotely.
Immersion	Creates the perception of being physically present in a virtual world, enhances mental immersion and exhibits physical engagement.

Sensory feedback	Can provide sensory feedback through the stimulation of vision, hearing and touch which engages the emotions and cognitive functions of the brain.
Motivation	Allows students to choose and control features so they become the architect of their learning.
Scale learning	Can act as a whole science lab for water-energy-food interaction allowing the creation of scenarios that would otherwise be impractical if brought to scale.
Safety/ Cost	Allows for high-risk scenarios without the costs or dangers of real life.

The VR-WEF interactive technology inevitably improve all aspects of teaching and learning of the nexus between the WEF systems. It allows the students to practice in step-by-step experiments and simulate scenarios. It improves students' learning environment, leading to the performance improvement. Universities have always been at the cutting edge of new technologies, driving development and creating the next generation of engineers. VR technologies are currently at the frontier of development. Engineering and Sustainability educators can employ the VR environment to frame any engineering concepts that cannot be recreated in reality. VR can motivate and engage students making the science, technology, engineering, and math learning process faster, more fun, and better than ever before. The opportunity here is evident.

4.2. Implementing Challenges

Fully implementing the VR-WEF system requires to close current digital divides between those who can afford the hardware, software, and time to become 'digital natives,' and those for whom this is a foreign and intimidating experience. Without strong leadership and guidance, it is not immediately clear that engineering students will be able to realize the promises offered by this new educational paradigm. It is not a given that digital natives themselves will immediately see how to apply their familiarity with digital tools to the educational arena unless we create excitement about the connections between real world education and escapist gaming. Game designer, Jane McGonigal[12] has stressed that young people are making a 'mass exodus' away from school and reality (which she calls 'broken') precisely because the way we teach doesn't offer them much hope for the kind of tomorrows we are creating on their behalf and which they don't feel they can meaningfully contribute to[13]. To achieve the epic win that she says young people are demanding, they need to be empowered with skill sets that can act as a bridge between 'superbetter' fantasy world creation through digital "imagineering" and reality fixing through real world engineering.

Even the most dedicated gamers are abandoning real environment in favor of simulated environment and online games[13]. They can be adept at building complex bases and shelters and crafting tools in sandbox games like Minecraft, Fortnight, Rust, ARK Survival, and even Roblox Building, but lack clear idea how to apply those skills to bringing their own school sites, communities, neighborhoods or homes to life. The foundational skills of digital engineering for 3D simulation and VR are lacking in most engineering and sustainability programs as are many of the real-world engineering skills. Minecraft uses Python, Unreal Engine 4 uses C++ and Unity uses mostly C# or JavaScript while Roblox uses Roblox Lua. Conceptually the use of these languages is very similar, and one doesn't need to be highly qualified to use programming objects to make a functional game. However, sustainability education still sees basic computer programming as a specialized skill rather than a core capability. At some point soon, these divides must be crossed. VR world building for sustainability engineering education can help close the gap.

4.3. Future Directions

It is well-established that the use of 3D interactive technologies for engineering education produced dramatic extensions of the once traditional lectures, demonstrations, and hands-on experiences. In the present study, the focus is on the development and potential application of the 3D VR simulation for engineering education. The developed VR-WEF tool will be applied to classroom setting for upper level undergraduate and graduate courses at the Florida Gulf Coast University and the University of South Florida.

More research will be conducted investigating the effectiveness of VR-WEF compared to other 3D but non-interactive platforms. Comparative surveys will be included with a design focused on different target groups (undergraduate and graduate students in laboratory conditions). VR-WEF effectiveness will also be investigated using different teaching styles and with blended learning module (face-to-face, online material, etc.). Students will be involved as co-designers, recommending innovative ideas and radical approaches in an effort to meet their own needs. They are only required to have access to computers and oculus VR headset. VR can transform the way engineering content is delivered. It works on the premise of creating an alternative world and allows students to interact with it.

5. Conclusion

This paper presents a virtual reality-based water-energy-food (VR-WEF) nexus visualization and simulation tool for teaching engineering students. VR-WEF can be used to mimic the natural process (anaerobic digestion) of converting wastewater and food waste into renewable energy (biogas), fertilizer, and nutrient-rich recycled water. The use of a VR-WEF system in preparing engineering students for practical experience of real-world challenges is presented. The development of VR-WEF interactive technologies inevitably improves all aspects of teaching and learning the nexus between WEF systems. Schools should enable these powerful tools to be used in the local context and with an aim toward mastering the content of sustainability and the WEF Nexus with zero waste, circular economy goals.

Even though, this study presents the application of VR technology for the WEF Nexus as an case study, the increasing development of VR technologies has matured enough as to expand education and research from the military visualization realm into more disciplines, such as anthropology, economics, biology, art and psychology. The capability and generic nature of VR open doors to new vistas in multidisciplinary curriculums, and the research that supports them.

As educators we must also create focused tutorials that are content/outcome driven and relieve the students of the burden of having to stumble blindly through a bewildering landscape of menu options, techniques and multiple software packages in order to achieve desired results. Since the goal is to have productive demand driven conversations about realistic simulations and alternative scenarios for the sustainability of “their futures in their locales”, educational tools need to be developed in such a way that they provide a heuristic for asking the important relevant questions about landscape change and infrastructure decisions and be able to visualize different outcomes based on parameters that can be interacted with and manipulated until everybody is satisfied with the results. VR-WEF gaming hardware and software allows for such precision and accuracy as well as for less structured experimentation. It is our goal to bring these worlds together to create a new form of education that inspires involvement by seamlessly blending the virtual and the real.

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