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Public Engagement in Wetland Recreation through 3D Virtual Reality and Animated simulation: A Case Study in Egypt

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Abstract:
This project investigates the use of immersive digital media to visualize and communicate the ecological and social dimensions of wetland recreation. As part of the interdisciplinary initiative "Recovering Wetlands as Eco-Social Design Practice," this work focuses on the development of a 3D virtual reality (VR) simulation and an animation. The VR experience enables users to explore the spatial and environmental transformation of the wetland park landscape, while the animation illustrates the final process in creating an accessible and engaging visual format. Together, these tools translate complex ecological data into interactive experiences aimed at allowing environmental awareness, stakeholder engagement, and speculative thinking around future ecologies and behaviors. The digital content was created using Rhino, Grasshopper, and Twin-motion and was showcased on-site as an interactive installation. By merging environmental Realty with immersive technologies, the project offers a new perspective on eco-social design and highlights the role of digital tools in supporting participatory ecological recovery.
Keywords:
Wetland Restoration, Virtual Reality (VR), Environmental Animation , Ecological Design , Immersive Visualization , Eco-Social Design , Interactive Architecture.

1 Introduction

Wetlands play a vital ecological and social role as multifunctional landscapes, supporting biodiversity, mitigating climate impacts, and offering opportunities for public recreation. However, in Egypt, the public's awareness and engagement with wetland environments remain limited. The integration of immersive technologies such as Virtual Reality (VR) and environmental animations presents a powerful opportunity to enhance public interaction with these critical landscapes. This paper presents a case study from 10th of Ramadan City, Egypt, where a digital model of a constructed wetland park was developed as part of the "Recovering Wetlands as Eco-Social Design Practice" initiative. The project utilizes a three-tiered visualization approach: an animated walkthrough, a 360-degree video, and an interactive 3D VR environment using BIMmotion and environmental controls. These tools were designed not only to simulate spatial and ecological transformations but also to make environmental data more accessible and engaging to the public[1].

By merging eco-social design principles with digital innovation, this project aims to foster public awareness, community participation, and speculative thinking about the future of ecological restoration in urban contexts. The outputs were showcased as an on-site interactive installation and serve as a model for using digital media to support participatory ecological recoveryas shown inFig1.

Figure1: 3d rendering of virtual human in VR headset on futuristic technologyby Iain Robertson

Source:https://www.innovatorsmag.com/south-korea-accelerates-vrar-ambitions/

1.1 Previous Research

Previous studies on constructed wetlands in Egypt have focused primarily on their technical and ecological performance in wastewater treatment, particularly in hot arid climates. Projects such as Bahr El-Baqar and Wadi El-Natroun demonstrated successful applications of wetland systems but lacked integration with public engagement strategies. Research like "Constructed Wetland Park as Happy Public Space" (2022) has begun to explore the intersection of ecological infrastructure and public experience, linking ecological performance with social well-being and happiness indicators [1]as shown inFig 2.

Figure2: 10th of Ramadan constructed wetland Parkby (Author)

Source:https://youtu.be/icr7g75xjp0

Internationally, digital tools have been employed to simulate environmental conditions and support planning, yet the use of immersive VR and animated visualization for public engagement in wetland settings is still emerging. While assessment models like the Leopold Matrix or frameworks using sustainability indicators offer structured evaluation tools, they often do not translate data into formats that engage non-specialist audiences.

This project builds upon that gap, integrating VR and environmental simulations to bridge ecological education with interactive design, drawing on platforms such as Twinmotion and Rhino to visualize real-time changes and support user exploration[2].

1.2 Problem Statement

Despite the ecological and recreational potential of wetland landscapes, public engagement with such environments in Egypt remains limited. Current public parks and constructed wetlands do not fully utilize their potential as educational and participatory spaces. Moreover, environmental data and planning decisions are often presented in technical formats inaccessible to the general public, limiting awareness and involvementas shown inFig3.

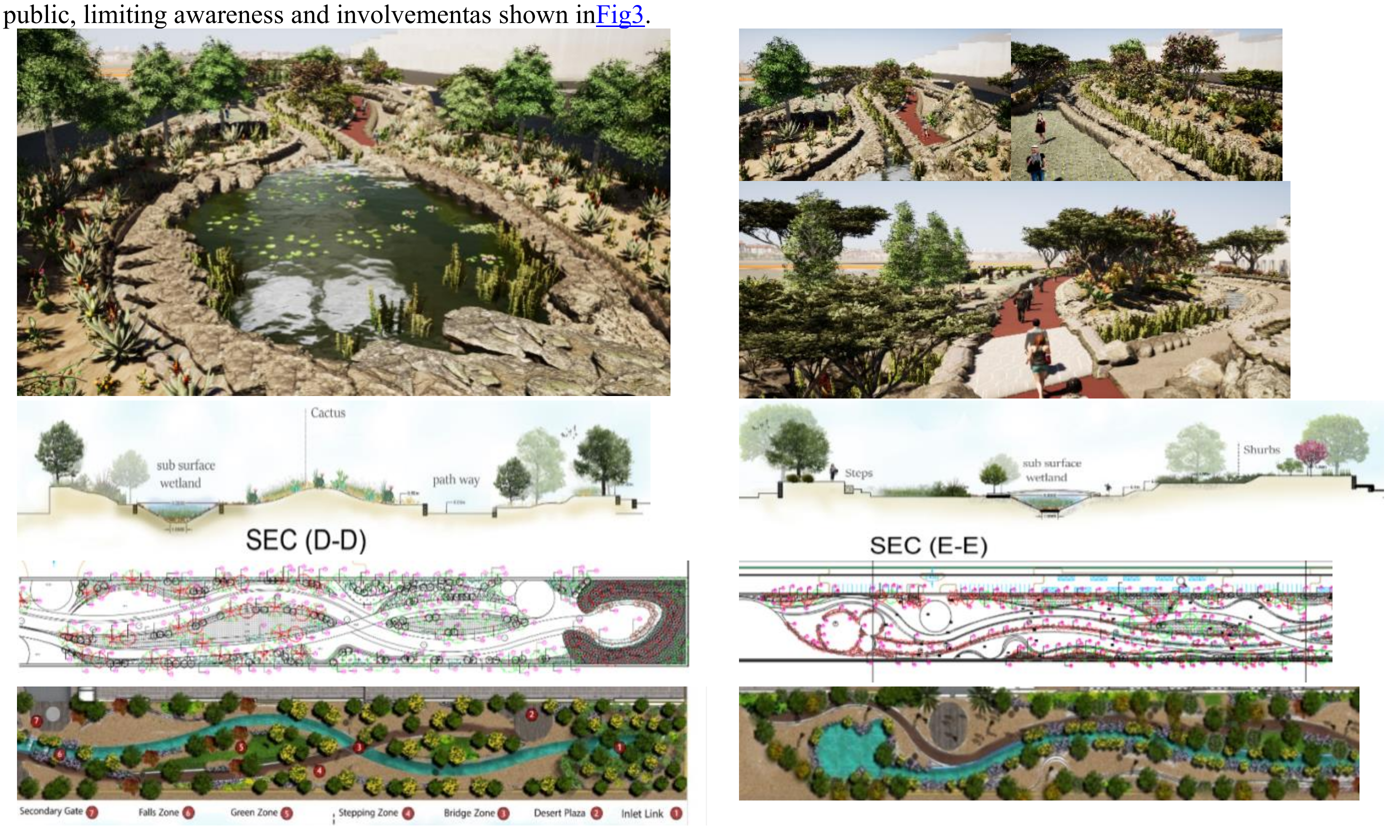

Figure 3: 10th of Ramadan constructed wetland Park detailed with plan and section by (Author)
Source:https://youtu.be/icr7g75xjp0

There is a need for innovative methods that communicate the complexity of ecological systems in a way that is both informative and engaging. Immersive technologies like VR[3], when integrated with environmental simulation, offer a promising solution. However, their application in the context of constructed wetland parks in Egypt remains largely unexplored. This study addresses that gap by designing and testing a VR-based interactive system for a constructed wetland park in 10th of Ramadan City, aiming to enhance public understanding and foster a sense of ownership toward ecological restoration projects[2]as shown inFig4.

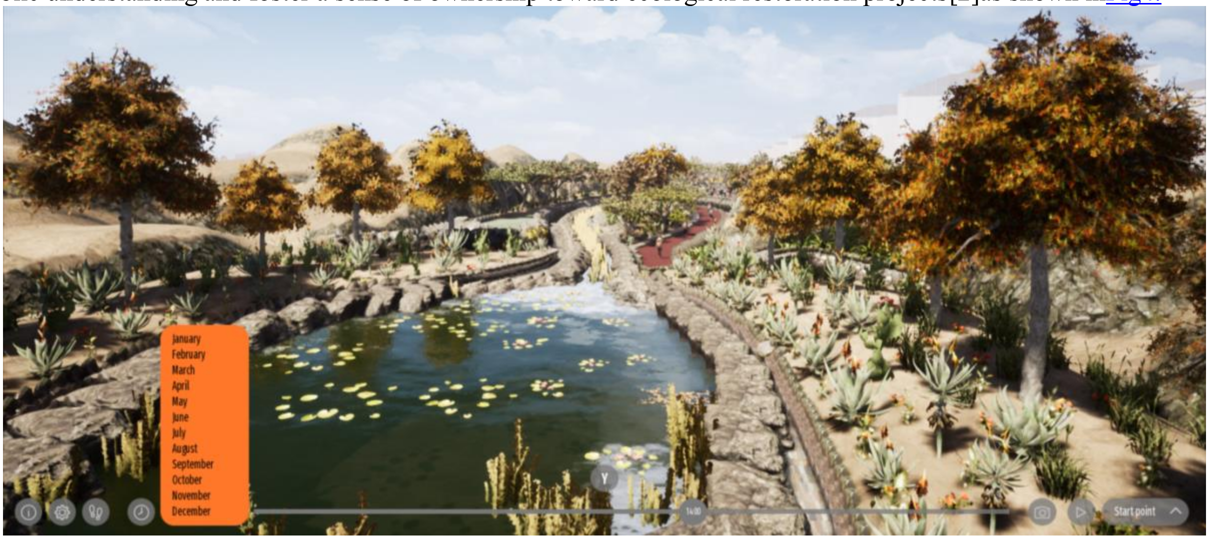

Figure 4: BIMmotion screen shot of 10th of Ramadan constructed wetland Park project by (Author)
Source:https://youtu.be/icr7g75xjp0

2 Literature Review

Immersive digital technologies have increasingly been integrated into environmental communication strategies, offering new ways to visualize ecological systems and foster public engagement. In particular, Virtual Reality (VR) and animated simulations have proven effective in translating complex environmental data [4]into interactive, experiential learning tools. These technologies help bridge the gap between scientific information and public understanding by allowing users to experience environmental change firsthandas shown inFig5.

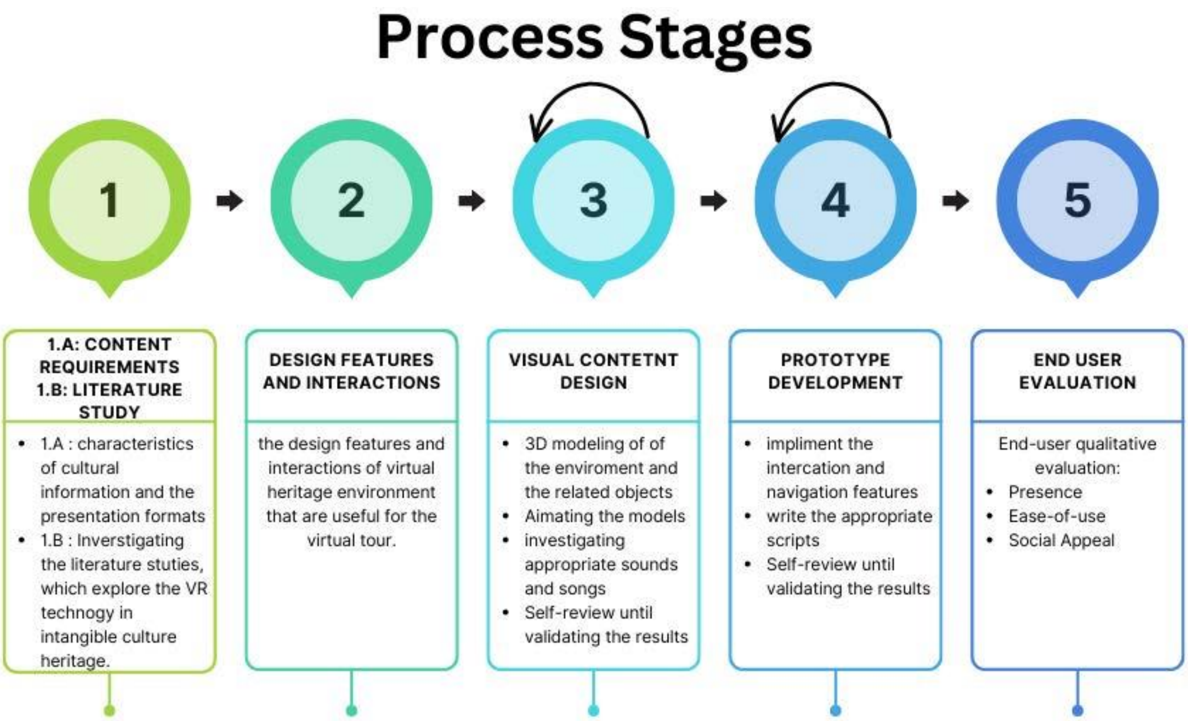

Figure5: Process Stages for Evaluation by IEEE Xplore

Source:https://ieeexplore.ieee.org/document/10373850

2.1 VR in Ecological and Public Space Education

Globally, VR has been used in environmental education to simulate disappearing ecosystems, such as coral reefs (e.g., *Coral Compass* by Stanford University) and tropical rainforests (*Rainforest VR* by Conservation International). These immersive experiences have been shown to increase environmental empathy, awareness, and behavioural intention among users (Markowitz et al., 2018). In the context of landscape and ecological planning, VR enables non-experts to visualize environmental transformation and understand ecosystem functions in real-time [5].

While **constructed wetlands** are widely used in Egypt and globally for wastewater treatment and ecological restoration, they are often presented through technical reports and engineering plans that are inaccessible to the public. There is limited research on using immersive media to represent these systems in a socially engaging way. This project addresses that gap by developing a VR-based platform that visualizes a constructed wetland in a way that supports public understanding and participation.

2.2 Eco-Social Design and Immersive Visualization

The theoretical foundation for this work draws from eco-social design, which integrates ecological systems with social and cultural practices through design. Manzini (2015) and Thackara (2005) argue for participatory approaches to environmental sustainability that engage communities directly. VR provides a medium to support such participation by visualizing abstract concepts like biodiversity, climate adaptation, and sustainability in accessible ways[5].

James Corner's (1999) work on landscape representation techniques, such as layering, projection, and animation, lays the groundwork for using digital media to represent ecological processes. VR extends these techniques, offering a multisensory and immersive layer to engage users in speculative thinking about environmental futures.

2.3 Comparative Tools: VR, AR, and Gamification

Compared to **Augmented Reality (AR)** or **gamified environmental platforms**, VR offers the highest level of sensory immersion and control. While AR is useful for overlaying environmental data onto real-world settings, it often lacks the depth of spatial engagement that VR offers. Gamification, such as environmental mobile games (e.g., *EcoCity*, *SimCityEDU*), can enhance motivation and participation but may oversimplify complex ecological systems[6].

The tools used in this project—**Rhino, Grasshopper, Twinmotion, and BIMmotion**—enable high-fidelity visualization and real-time environmental control (e.g., weather, sunlight, vegetation). This positions VR as both a **design communication tool** and a **public engagement platform** for eco-social interventions.

3 Methodology

This research adopts a design-based methodology grounded in digital architecture and environmental visualization to explore public engagement with wetland recreation. The approach is structured into three main phases: (1) 3D model development, (2) immersive simulation creation, and (3) public interaction and evaluationas shown inFig6.

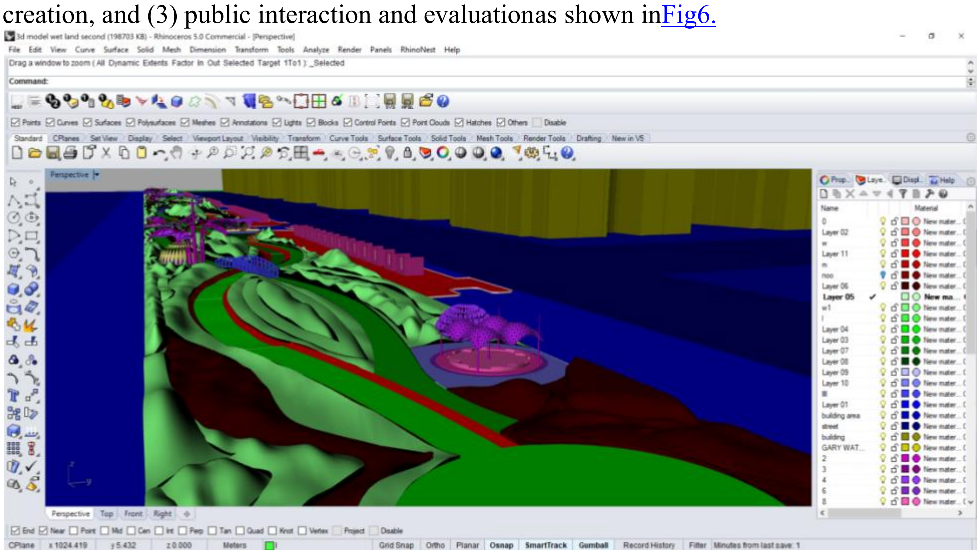

Figure 6: 3d model usingRhinoceros program screen shot of 10th of Ramadan constructed wetland Park project by (Author)

Source:https://youtu.be/icr7g75xjp0

3.1 Site Selection and Context

The case study is based in 10th of Ramadan City, Egypt, specifically south of El-Andalus District, where a constructed wetland park was proposed as part of a multifunctional landscape project [7]. The location was chosen due to its proximity to an existing water treatment plant, making it a suitable site for eco-social intervention. The site's urban-industrial context also reflects the broader challenge of integrating environmental infrastructure within rapidly developing citiesas shown inFig 7.

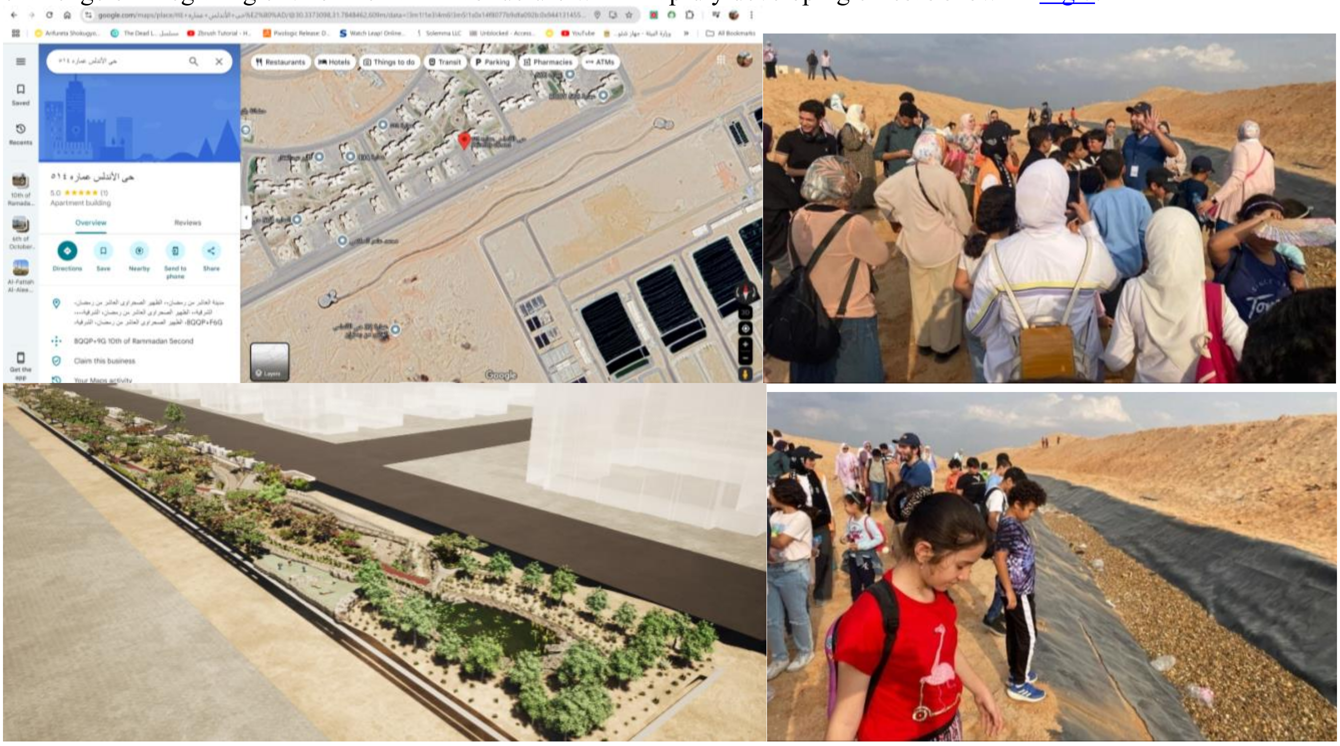

Figure 7: google maps 10th of Ramadan constructed wetland Park and images at the location by (Author)
Source:https://youtu.be/icr7g75xjp0

3.2 Digital Modeling and Visualization Workflow

The digital content was developed through a multi-platform pipeline:

- **Modelling:** Using **Rhinoceros 3D** and **Grasshopper**, a parametric model of the wetland park was generated, including terrain, vegetation zones, water flows, pedestrian circulation, and architectural elements.
- **Simulation:** Environmental performance data (sun paths, temperature, vegetation type) were embedded into the model to guide landscape and spatial decisions.
- **Rendering and Animation:Twinmotion** was used to produce high-quality, real-time renderings and video animations of the park under different weather conditions and times of day.
- **Immersive Integration:** A three-tiered experience was created:
    1. **Level 1 – Animated Video Walkthrough** (https://youtu.be/icr7g75xjp0): A guided, cinematic visualization of the wetland park with narration.
    2. **Level 2 – 360° Video** (https://youtu.be/_Q2buCNSq_E): An immersive panoramic video allowing the viewer to look around freely within the space.
    3. **Level 3 – Interactive 3D VR Simulation**(file size:5.8 gb): Developed using **BIMmotion**, this version allows users to control environmental parameters (weather, time, light) and navigate the space freely, simulating real-time environmental behaviours.

3.3 Installation and Public Engagement

The final outputs were presented in an on-site interactive installation, allowing participants—including local stakeholders, university students, and planners—to engage directly with the VR experience[8]. Users explored the digital wetland through VR headsets, touchscreen displays, and projection setups. Their responses were collected through observation, informal interviews, and structured feedback forms.

3.4 Research Tools and Evaluation

To assess the effectiveness of the immersive experience:

- A **comparative feedback survey** was administered to measure user engagement and learning outcomes across the three experience levels.
- Environmental parameters within the simulation were mapped against actual site data to verify realism.
- The VR experience was also evaluated for its potential to influence speculative thinking about ecological futures and behavioural change.

3.5 Technical Development Details

The technical development of the wetland park simulation was built through a multi-stage digital workflow combining 3D modeling, environmental analysis, real-time rendering, and immersive interactivity. The objective was to create a realistic, responsive, and accessible digital environment that could visualize ecological behaviors while engaging users through various immersive formats [9].

3.5.1 Parametric Modeling and Spatial Configuration

The base model of the constructed wetland was developed using **Rhinoceros 3D** in combination with **Grasshopper**, a visual scripting tool for parametric design. This allowed for a flexible design system that could adapt to environmental data and spatial logic. The model included:

- Terrain shaping and topographic grading
- Water flow channels and treatment zones
- Vegetation zoning based on sunlight and water exposure
- Pedestrian circulation paths and viewing platforms

Site-specific environmental parameters, including **sun path, prevailing wind direction, temperature range**, and **vegetation resilience**, were integrated early in the modelling process to influence form and layout decisions[10]. These inputs helped simulate the wetland's performance under real-world climatic conditionsas shown inFig8.

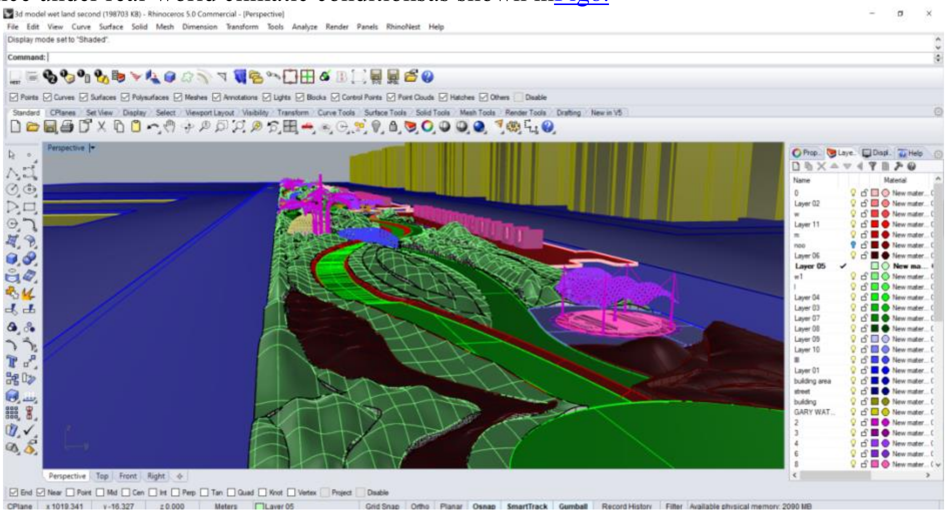

Figure 8: 3d model using Rhinoceros program screen shot shaded using basiccolors of 10th of Ramadan constructed wetland Park project by (Author)

Source:https://youtu.be/icr7g75xjp0

3.5.2 Visualization and Animation

The complete model was exported to **Twinmotion**, a real-time visualization tool that integrates seamlessly with architectural software. In Twinmotion, the wetland environment was rendered using:

- Real-time lighting and weather simulations
- Animated vegetation and water materials
- Time-of-day and seasonal variations
- Embedded ambient sound effects (e.g., birds, wind, water)

From this platform, three distinct simulation outputs were generated:

- **Level 1 – Basic Animation**: A guided cinematic walkthrough of the site showing key design features with narrative voiceoveras shown inFig9.

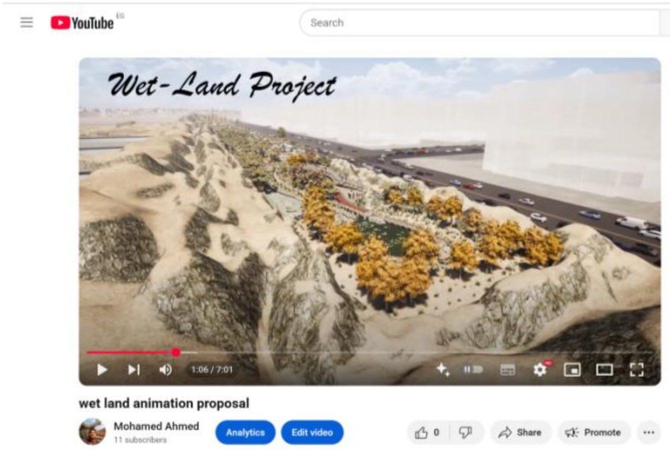

Figure 9: 3D animation high quality render of 10th of Ramadan constructed wetland Park project by (Author)
Source:https://youtu.be/icr7g75xjp0

- **Level 2 – 360° Video**: A panoramic VR video allowing viewers to look around freely and explore perspectives at various points along the landscapeas shown in[Fig 10.](#)

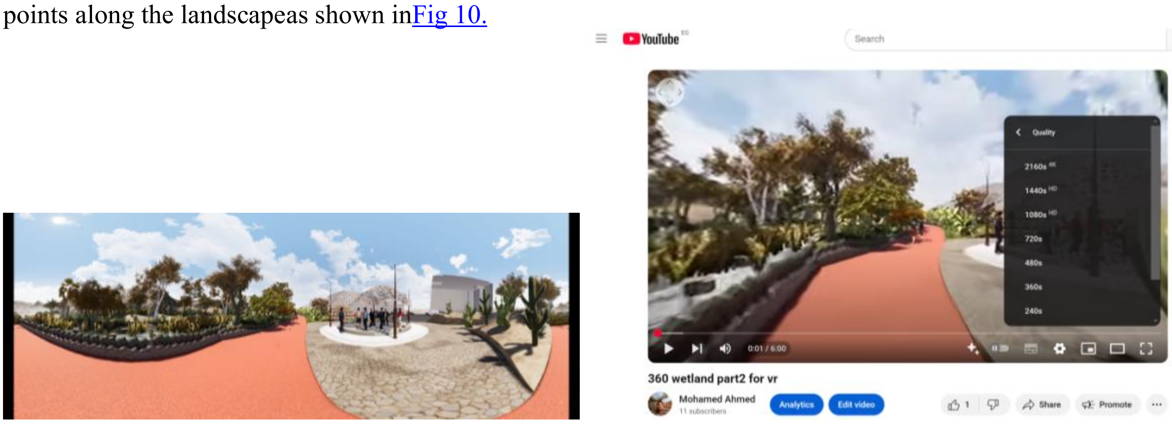

Figure 10: 3D animation 360 video of 10th of Ramadan constructed wetland Park project by (Author)
Source:https://youtu.be/_Q2buCNSq_E

- **Level 3 – Interactive VR Model**: A fully immersive 3D simulation exported through **BIMmotion**, enabling user-controlled navigation and environmental interactionas shown in[Fig 11.](#)

Figure 11: 3D animation BIMmotion screen shot of 10th of Ramadan constructed wetland Park projectby (Author)
Source:https://youtu.be/_Q2buCNSq_E

3.5.3 Immersive Interactivity via BIMmotion

The most advanced layer was created using **BIMmotion**, which generated a standalone executable application that did not require additional VR software to operate[12]. This made the simulation portable and user-friendly for on-site installations. Key interactive features included:

- **Weather control**: Users could switch between sun, cloud, and rain conditions.

- **Time-of-day slider**: Enabled simulation of daylight variation and shadow movement.
- **User navigation**: Free movement through the site using keyboard/mouse or game controller input.
- **Visual feedback**: Realistic water movement, vegetation response, and lighting effects reacting to environmental settings.

The final simulation file was approximately **5.8 GB**, optimized for high-performance desktop systems. It was tested on a VR-ready setup and included both traditional screen display and headset support (Oculus/Meta).

3.5.4 Optimization for Public Use

To ensure a smooth experience for exhibition and public interaction, the model was optimized through:

- Reduction of mesh complexity using LOD (Level of Detail) systems
- Texture compression and baked lighting to reduce real-time processing
- User interface simplification for non-expert audiences
- On-site calibration of screen resolution, controller input, and audio levels

This development process positioned the VR model as a bridge between architectural communication, environmental simulation, and public participation[13]. It became not only a design visualization tool but also a **platform for ecological storytelling and behavioural exploration**.

4 Results and Discussion

The interactive digital experiences created for the 10th of Ramadan constructed wetland park demonstrated varying degrees of public engagement, perception, and environmental understanding. The results are discussed across three dimensions: (1) user interaction across the three levels of simulation, (2) environmental realism and speculative thinking, and (3) implications for eco-social design and participatory planning[14].

4.1 User Interaction and Feedback

Each level of the immersive system provided a distinct user experience:

- **Level 1 – Animation Video (YouTube Link)**: The video was effective in providing a **visual overview** of the wetland park. Participants appreciated its aesthetic quality and smooth narrative structure. However, the lack of interactivity limited the depth of engagement, making it more suitable as a promotional or introductory tool.
- **Level 2 – 360° Video (YouTube Link)**: This experience allowed users to **look around freely**, offering a semi-immersive understanding of spatial relationships. Survey responses indicated a significant improvement in spatial awareness and curiosity, especially among users unfamiliar with ecological planning.
- **Level 3 – Interactive 3D VR Simulation**: This level received the most positive responses. Users could **navigate the space independently**, observe environmental elements, and **manipulate variables** such as weather, time of day, and lighting. This dynamic interaction fostered higher levels of environmental awareness, curiosity about ecological processes, and a sense of **agency** in imagining future scenariosTable 1.

Table 1Summary of Simulation Levels and Features

Level	*Description*	*Interaction Type*	*Technology Used*	*User Control*	*Purpose*
1	Basic animation video	Passive viewing	Twinmotion	None	Visual overview and introduction
2	360-degree immersive video	Panoramic exploration	Twinmotion 360 export	View direction	Spatial orientation and visual engagement
3	Interactive 3D VR simulation	Full immersion	Rhino + BIMmotion	Movement, weather, time	Speculative design, participatory experience

4.2 Environmental Realism and Speculative Thinking

Using BIMmotion's environment simulation tools, the third-level VR model accurately reflected site-specific environmental behaviour, such as sun angles, weather effects, and water surface changes[15]. This realism proved crucial for:

- Supporting **speculative ecological thinking**, where users imagined future states of the wetland.
- Facilitating conversations around **climate-responsive design**, particularly among students and urban designers.
- Highlighting the **ecosystem services** of wetlands, such as biodiversity support and water purification, in ways that static plans could notTable 2.

Table 2User Engagement and Learning Outcomes by Experience Level

Metric	*Level 1: Animation*	*Level 2: 360 Video*	*Level 3: VR Simulation*
Average Engagement Score (1–5)	3.2	4.1	4.8

Reported Spatial Understanding (%)	45%	70%	92%
Environmental Awareness Increased (%)	40%	68%	89%
Desire to Revisit or Learn More (%)	52%	76%	94%
Felt Emotionally Connected (%)	33%	59%	85%

(Data based on participant feedback from on-site testing and surveys; n ≈ sample of 40)

4.3 Implications for Eco-Social Design and Participation

The VR experience successfully bridged the gap between complex ecological data and public understanding[16]. The feedback gathered revealed several key impacts:

- **Increased environmental empathy**: Users reported feeling more connected to natural systems and expressed interest in contributing to ecological preservation efforts.
- **Design understanding**: The layered digital experience helped users visualize the **multifunctionality of constructed wetlands**, from recreational to environmental and social roles.
- **Public engagement potential**: The installation attracted a diverse audience, demonstrating VR's potential in engaging stakeholders across demographics[17].

Overall, the project confirms that **immersive visualization technologies**, when integrated into ecological design, can enrich public participation, support inclusive decision-making, and inspire sustainable behavioursTable 3.

Table 3Key Environmental Behaviors Simulated in Level 3 (VR)

Environmental Factor	*User Interaction Type*	*Effect in Simulation*
Time of Day	Slider control	Changes lighting, shadows, ambiance
Weather Conditions	Drop-down menu	Adds rain, clouds, or clear skies dynamically
Vegetation Growth	Pre-loaded stages	Users observe change in plant density &color
Water Flow & Reflection	Automatic + responsive visuals	Surface reacts to wind/light changes
Ambient Sound	Linked to environment	Natural soundscape adjusted based on setting

To assess the impact of each digital simulation level on public perception and engagement, participants were invited to interact with all three formats—animated video, 360-degree video, and interactive VR. Feedback was collected through surveys and informal interviews conducted on-site. Five key metrics were used to evaluate user experience: overall engagement[18], spatial understanding, environmental awareness, interest in revisiting the experience, and emotional connection to the wetland space. As shown in the graph below, the interactive 3D VR simulation (Level 3) consistently outperformed the other levels across all categories, demonstrating its effectiveness in fostering deeper cognitive and emotional engagement. The 360-degree video offered moderate interactivity and performed well in spatial understanding, while the animated video, though visually informative, showed lower scores in all categories due to its passive natureas shown inFig 12.

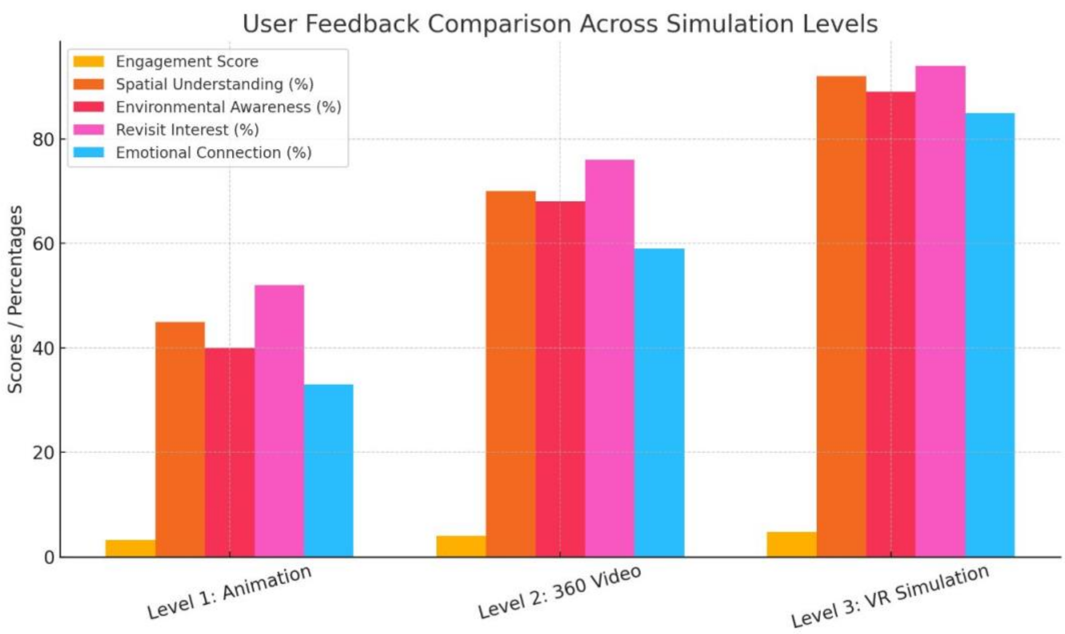

Figure12:bar graph visualizing user feedback across the three simulation levelsby Author.

bar graph visualizing user feedback across the three simulation levels. It compares:

- Engagement scores
- Spatial understanding
- Environmental awareness
- Interest in revisiting
- Emotional connection

4.4 Implications for Eco-Social Design and Participation

The integration of immersive technologies in the design and communication of ecological spaces such as constructed wetlands can significantly reshape how the public perceives, values, and interacts with the environment. This section analyzes the environmental and social impacts of the VR experience developed for the wetland park in 10th of Ramadan City, based on observed interactions and user feedback.

4.4.1 Raising Environmental Awareness

One of the most immediate outcomes of the immersive simulation was the improvement in participants' understanding of the **ecological functions of wetlands**, including:

- Natural water filtration
- Habitat for wildlife
- Microclimate regulation
- Recreational and educational potential

Participants who engaged with the third-level interactive VR simulation demonstrated increased comprehension of these benefits. By allowing users to manipulate time, weather, and explore diverse zones of the wetland, the simulation provided an **experiential learning environment** that transformed abstract ecological concepts into tangible, visual experiences.

This was particularly effective among non-specialist users such as students and community members, who reported a **stronger emotional connection** to the landscape and a better grasp of how ecological systems respond to environmental change.

4.4.2 Promoting Behavioral Intention and Stewardship

Survey results indicated that exposure to the interactive model fostered not only awareness but also **intentions to act**. Participants expressed:

- A desire to visit real wetland sites
- Interest in volunteering or advocating for ecological preservation
- Curiosity about the design and maintenance of such systems

The experience helped shift the wetland park from a passive green space to an **active socio-environmental system**, showing how ecological infrastructure could be beautiful, functional, and inclusive.

4.4.3 Social Inclusivity and Stakeholder Engagement

The VR installation succeeded in attracting a **diverse group of users**, including architecture students, local planners, residents, and children. This diversity is critical to **eco-social design**, which calls for broad participation in the creation and care of shared environments.

The ability to access and interact with the digital wetland—without needing prior design knowledge—made it a **democratic tool** for communication. Several stakeholders commented that they better understood the **value of ecological integration** in urban areas after experiencing the simulation, and some recommended its use in municipal awareness campaigns.

4.4.4 Alignment with Sustainability Goals

This project aligns with several **UN Sustainable Development Goals (SDGs)**:

- **Goal 11: Sustainable Cities and Communities** – by promoting green public infrastructure and awareness.
- **Goal 13: Climate Action** – by modeling adaptive landscapes under various environmental scenarios.
- **Goal 15: Life on Land** – by highlighting biodiversity and the role of wetlands in ecosystem health.

Through immersive visualization, the project reinforced how **digital design tools can influence long-term thinking**, responsible behavior, and inclusive planning for ecological recovery.

5 Discussion and Limitations

The integration of immersive digital technologies into environmental design—particularly for constructed wetland parks—presents both promising opportunities and notable challenges. This section reflects on the broader implications of the study while acknowledging its limitations.

5.1 The Potential of VR in Eco-Social Design

The project demonstrated how **Virtual Reality (VR)** can serve as a transformative medium in **eco-social design**. Unlike traditional 2D plans or static 3D renders, VR offers a **lived spatial experience**, helping users to intuitively grasp complex relationships between ecological processes, spatial design, and human interaction.

The ability to simulate time, weather, and user navigation created **a sense of ownership and agency** among participants. This proved especially valuable for stakeholders unfamiliar with ecological planning, such as community members and local officials. The interactive platform served not only as a communication tool but also as a **platform for speculative thinking**, enabling users to imagine alternative futures for their environment

5.2 Accessibility and Inclusivity

While the immersive experience was praised for its clarity and realism, **technical barriers** limited its accessibility:

- The full VR model (5.8 GB) required high-performance hardware to run smoothly.
- Some older users or individuals unfamiliar with gaming controls found the interface challenging at first.
- Language accessibility and interface design could be improved to accommodate broader audiences, especially in non-academic or rural contexts.

To increase impact, future iterations should consider **mobile-based VR**, **multi-language interfaces**, or **web-delivered 3D content** to ensure broader inclusion.

5.3 Evaluation Limitations

Although the feedback was generally positive, the **sample size** of users who experienced all three simulation levels was relatively small (n ≈ 40)as shown inFig13, and short-term exposure limits the ability to measure **long-term behavioral change**.

Further studies are needed to:

- Track whether participants adopt sustainable habits after the experience.
- Assess knowledge retention over time.
- Explore group-based engagement strategies (e.g., collaborative VR sessions or school programs).

Figure 13: Students from Banha University and also from website 10th of Ramadan constructed wetland Park for sample size of usersby (Author)

Source:https://youtu.be/_Q2buCNSq_E

5.4 Technical Challenges

Developing a real-time, responsive, and realistic 3D simulation involved several challenges:

- Achieving the right balance between **model detail and performance** was critical to ensuring smooth navigation without compromising realism.
- Integrating weather simulation and environmental behavior (e.g., sun/shadow movement, water reflections) in BIMmotion required careful calibration.
- Rendering 360° video with high quality and stable frame rates proved resource intensive.

Despite these hurdles, the experience confirmed that **immersive media** can be a powerful tool in environmental education and stakeholder involvement—especially when designed with inclusivity and interaction in mind.

6 Conclusion and Recommendations

Conclusion:

This study demonstrates the powerful potential of immersive digital technologies—particularly **3D Virtual Reality (VR)** and **animated environmental simulations**—to enhance **public engagement with wetland recreation and ecological design**. Through a case study located in **10th of Ramadan City, Egypt**, the project developed a three-level digital experience (animation, 360° video, and interactive VR) that translated complex ecological data into accessible, interactive formats.

The findings confirm that interactive simulations not only **raise awareness** of ecological systems but also **inspire public interest, behavioural intention, and emotional connection** to environmental issues. Participants engaging with the most immersive level (VR with BIMmotion) showed the highest levels of spatial understanding, environmental empathy, and desire to participate in ecological preservation.

From a design and communication perspective, the study validates the role of **VR as both a visualization and participatory planning tool**a medium through which the public can not only observe but also imagine and influence future ecological scenarios.

Recommendations:

Based on the outcomes of this research, the following recommendations are offered for future practice and research:

1. **Integrate immersive simulations into environmental education curricula** at schools and universities to promote early awareness and stewardship.
2. **Expand accessibility** by developing lighter, mobile or web-based versions of the VR experience to reach a broader, more inclusive audience.
3. **Collaborate with local governments and NGOs** to use immersive tools in public consultations and participatory design workshops.
4. **Incorporate multilingual options and simple navigation interfaces** to engage diverse age groups and educational backgrounds.
5. **Pursue longitudinal studies** to measure the long-term behavioral impact of immersive ecological experiences on users.

In conclusion, this project reinforces the value of combining **eco-social design with digital innovation**. Immersive technologies such as VR offer a new frontier for participatory ecological recovery, turning passive observation into active public engagement.

List of Abbreviations

Abbreviation	Definition
VR	Virtual Reality
AR	Augmented Reality
3D	Three-Dimensional
SDGs	Sustainable Development Goals
BIM	Building Information Modeling
BIMmotion	Building Information Modeling Motion (interactive viewer used in Twinmotion and ARCHICAD)
LOD	Level of Detail
NURBS	Non-Uniform Rational B-Splines (used in Rhino 3D modeling)

Declarations

- **Availability of data and materials**

The authors have not used any external datasets in this study. All visual and simulation materials were generated by the authors.

- **Competing interests**

The authors declare that they have no competing interests.

- **Funding**

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

- **Authors’ contributions**

All authors contributed extensively to the work presented in this paper. Mohamed A. Mohamed Hassan led the 3D modeling, simulation development, and digital visualization. Henar A. Kalefa supervised the research direction, structure, and academic integration. Both authors reviewed and approved the final manuscript.

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