Eclipse Odyssey: An AI/ML Integrated Video Game Using Unreal Engine

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Abstract. The evolution of artificial intelligence (AI) has significantly changed the video game industry. It has improved realism, immersion, and player adaptability. This paper presents ECLIPSE ODYSSEY, an AI-driven single-player action-adventure game developed with Unreal Engine 5.6. The project looks at using Behavior Tree-based AI, Blueprint visual scripting, and real-time rendering technologies like Lumen and Nanite. These tools help create a narrative-driven experience focused on survival, justice, and dynamic gameplay. The game highlights AI adaptability, procedural environment design, and cinematic presentation to provide a high-quality, interactive experience. This paper covers the conceptual framework, AI system design, development process, testing results, and future possibilities for including deep learning-based AI in interactive entertainment.

Keywords: Unreal Engine 5.6, Artificial Intelligence, Behavior Tree, Blueprint Visual Scripting, Lumen Rendering, Game Development, AI Gameplay, Unreal Engine

I. INTRODUCTION

The modern gaming landscape has evolved into a fusion of engineering precision, cinematic artistry, and interactive storytelling. Over the last two decades, technological progress in artificial intelligence (AI), physics simulation, and real-time rendering has redefined how players experience digital worlds. Games are no longer static sequences of scripted events; they have become adaptive ecosystems that analyze player behavior, react intelligently, and generate emergent narratives. This transformation has established AI not merely as a background process but as a creative collaborator shaping player immersion.

Artificial Intelligence now drives nearly every layer of modern game design from procedural world generation to dynamic enemy behavior. Traditional finite-state logic has given way to hierarchical and behavior-tree systems capable of decision making, context awareness, and pattern recognition. These advances allow developers to build characters that observe, learn, and respond, giving each encounter an element of surprise and authenticity. The evolution of such adaptive systems has blurred the line between pre-designed content and organic, player-driven storytelling.

Unreal Engine has emerged as a cornerstone platform for realizing this new paradigm. Its fifth-generation release, Unreal Engine 5.6, integrates state-of-the-art rendering tools such as Lumen Global Illumination and Nanite Virtualized Geometry alongside a robust AI framework and physics engine. This synergy enables small development teams to craft AAA-level visual fidelity while implementing complex AI behaviors without extensive code overhead. The engine's Blueprint Visual Scripting system further democratizes development by allowing logic to be constructed visually, making sophisticated systems accessible to both designers and programmers.

Within this ecosystem, the project ECLIPSE ODYSSEY was conceived as a single-player action–adventure experience centered on survival and justice. The narrative follows a lone protagonist struggling against corrupt forces in a dystopian setting, blending fast-paced combat with environmental storytelling. Built entirely in Unreal Engine 5.6, the project explores how adaptive AI, procedural design, and cinematic presentation can converge to produce an emotionally charged gameplay loop.

A defining characteristic of Eclipse Odyssey lies in its intelligent non-player characters (NPCs). Using Behavior Trees, Blackboard systems, and AI Perception components, enemies track sight, sound, and spatial cues to react dynamically to player

decisions. They can coordinate attacks, retreat strategically, or call reinforcements based on combat context. Such emergent behavior transforms ordinary encounters into living simulations, where strategy and unpredictability coexist.

From a design perspective, the project emphasizes modularity. Gameplay systems—including player control, environment interaction, combat, and user interface operate as discrete modules communicating through Blueprint Interfaces and Event Dispatchers. This architecture simplifies debugging, supports scalability, and allows new mechanics or AI archetypes to be integrated seamlessly. The modular blueprinting approach demonstrates that high-complexity design can be achieved without reliance on traditional text-based programming languages.

Visual fidelity forms another pillar of the project. The integration of Lumen ensures dynamic lighting that adapts in real time to environmental changes, while Nanite enables billions of polygons to be rendered efficiently, maintaining smooth frame rates. Atmospheric systems like fog, particle effects, and volumetric lighting create depth and mood that complement the game's narrative tone. Chaos Physics governs environmental destruction and motion, ensuring physical realism during combat and exploration.

The audio–visual experience is further enhanced through MetaSounds, Unreal's procedural sound engine. Combat intensity influences the soundtrack, and ambient cues adjust with environmental states such as weather or time of day. The Unreal Motion Graphics (UMG) framework delivers a minimalist, adaptive interface that conveys essential information without breaking immersion. Together, these systems generate sensory coherence, aligning technical execution with artistic vision.

Development adhered to an Agile iterative methodology, with short sprints dedicated to AI logic, performance optimization, and user feedback analysis. Version control via GitHub maintained build stability and collaboration efficiency among team members. Continuous testing, both automated and manual ensured each iteration improved responsiveness, frame stability, and gameplay polish. This structured process reflects industry standards, bridging academic research with professional production practice.

Ultimately, Eclipse Odyssey exemplifies the symbiosis between AI and creative design in modern game development. It demonstrates how visual scripting and real-time intelligence can empower small teams to deliver interactive worlds that rival large-scale productions. Beyond entertainment, the project serves as a research artifact illustrating how adaptive algorithms, environmental physics, and narrative design can converge into a single immersive framework. As AI continues to evolve, projects like Eclipse Odyssey represent a glimpse into the future of responsive, emotionally resonant digital experiences.

II. LITERATURE SURVEY

Artificial Intelligence has steadily transitioned from a theoretical discipline to a practical engine that powers entertainment, automation, and creative industries. In the context of gaming, AI has evolved far beyond basic pathfinding or pattern recognition—it now functions as a dynamic storytelling device, shaping player experience through responsiveness and adaptation. Researchers have consistently explored how AI can increase engagement, realism, and unpredictability, turning static gameplay loops into living ecosystems. This transformation marks the shift from traditional procedural logic to systems that behave as though they "think."

Early game AI implementations were dominated by Finite State Machines (FSMs) and rule-based architectures. Titles from the 1990s and early 2000s relied heavily on fixed condition-action rules, meaning NPCs reacted the same way in every encounter. While reliable, these systems lacked flexibility. As noted by Champandard (2007), such models limited the illusion of intelligence and reduced long-term engagement. This motivated the transition toward hierarchical behavior systems, capable of organizing AI decision-making into modular, reusable layers.

The introduction of Behavior Trees (BTs) represented a major leap forward in game AI design. Champandard and Dunstan (2012) described BTs as a clear, scalable method for defining NPC logic—making AI more understandable for designers while preserving depth

for programmers. BTs allowed for reactive behaviors, where an enemy could switch seamlessly from patrolling to chasing to retreating depending on the player's actions. This concept forms the backbone of Eclipse Odyssey's AI system, where enemy decisions unfold dynamically rather than following pre-set paths.

Beyond structure, AI perception systems brought sensory realism to virtual characters. McCoy and Mateas (2013) explored how combining visual, auditory, and spatial inputs could enable characters to "sense" their environments. Unreal Engine's AI Perception component, built on these principles, empowers designers to simulate realistic vision cones, hearing ranges, and line-of-sight logic. Eclipse Odyssey applies these mechanisms to create adaptive enemy intelligence—agents that respond to both noise and motion rather than simply scripted triggers.

The evolution of adaptive AI is deeply connected to player modeling research. Yannakakis and Togelius (2018) emphasized that player-centered AI must learn from behavior metrics to tailor difficulty and maintain flow. Games like Left 4 Dead and Alien: Isolation introduced AI "directors" that adjust pacing based on stress levels or success rates. Eclipse Odyssey implements a simpler version of this concept—its AI modifies aggression based on player health, accuracy, and positioning—giving every encounter a sense of situational awareness.

Parallel to AI's evolution, environmental simulation and rendering technologies have revolutionized immersion. The transition from baked lighting to real-time global illumination allowed developers to portray worlds that breathe and evolve. According to Farrow and Kaur (2022), Lumen Global Illumination in Unreal Engine 5 dynamically adapts lighting based on geometry and surface interaction, removing the need for pre-rendered lightmaps. This technology underpins Eclipse Odyssey's atmospheric world design, ensuring that every environment feels reactive and alive.

Similarly, Nanite Virtualized Geometry introduced by Epic Games has changed asset creation workflows. Instead of relying on simplified mesh proxies, Nanite renders full-resolution models efficiently, enabling unprecedented visual detail without compromising frame rate. Studies in real-time rendering optimization (Epic Games, 2023) highlight that Nanite's virtualized system reduces draw calls and memory load, making it ideal for open-world or cinematic environments. This innovation is central to Eclipse Odyssey's visual fidelity, where environments maintain high resolution even during fast-paced combat.

Physics simulation has also been a vital research area influencing modern games. The Chaos Physics Engine, integrated within Unreal Engine, enables realistic destruction, motion, and interaction with environmental elements. Research by Al-Azawi et al. (2020) indicated that realistic physics systems contribute to player immersion by providing tactile feedback and spatial consistency. In Eclipse Odyssey, physics governs destructible environments, projectile collisions, and character animation blending—enhancing both realism and gameplay strategy.

Human–Computer Interaction (HCI) studies have further influenced game interface and experience design. Johnson et al. (2019) emphasized that intuitive UI and responsive feedback loops increase engagement by reducing cognitive load. Unreal's Unreal Motion Graphics (UMG) aligns with these principles, offering flexible and responsive interfaces adaptable to various screen resolutions. Eclipse Odyssey applies UMG to maintain a clean, context-sensitive interface that communicates essential information while preserving immersion.

Sound design is another field where AI and procedural systems have converged. Stevens and Raybould (2021) discussed how adaptive audio enhances player emotion by aligning auditory cues with gameplay intensity. Unreal's MetaSounds system embodies this research by enabling real-time audio modulation. In Eclipse Odyssey, combat music swells dynamically during fights and fades into ambient tones during exploration, ensuring a consistent emotional rhythm throughout the game.

Agile development practices have also reshaped how game projects evolve. Beck et al. (2001) introduced the Agile Manifesto emphasizing iteration, collaboration, and adaptability—principles now embedded in professional game development. Research by Stacey (2020) confirmed that Agile

practices reduce development bottlenecks and improve quality through incremental prototyping. Eclipse Odyssey follows a sprint-based model where AI, UI, and environment features were developed, tested, and refined iteratively. This allowed continuous improvement without sacrificing creative flexibility.

Recent studies on player immersion and narrative design suggest that emotional engagement stems from consistency between mechanics and story. González et al. (2020) explored how environmental storytelling can subconsciously communicate narrative cues, reinforcing empathy and motivation. Eclipse Odyssey incorporates these ideas through world-building elements—ruined cities, ambient lore, and responsive lighting that reflects emotional states of the narrative. Each area is designed to visually communicate the protagonist's struggle, allowing players to connect emotionally through exploration rather than exposition.

In summary, the body of research supporting Eclipse Odyssey spans AI logic, real-time rendering, user experience, and agile design methodologies. By synthesizing behavior-based intelligence, procedural environment simulation, and responsive audio-visual systems, the project embodies decades of academic and industrial advancements. The literature collectively validates the idea that modern game development is no longer a linear production process—it is a complex, adaptive collaboration between algorithms, design, and human creativity. Eclipse Odyssey builds upon this foundation, using Unreal Engine 5.6 as a laboratory where technology and narrative coalesce into a living, interactive experience.

III. METHODOLOGY

The development of ECLIPSE ODYSSEY followed a structured, iterative methodology inspired by Agile software development principles. Each development cycle focused on building, testing, and refining one subsystem at a time, ensuring modularity and scalability throughout the process. By dividing work into smaller, manageable sprints, the team maintained steady progress while allowing flexibility for creative adjustments. This iterative approach was particularly beneficial in fine-tuning gameplay mechanics and AI behaviors, where continuous feedback loops were crucial to achieving realism and responsiveness.

The project's foundation rests on Unreal Engine 5.6, chosen for its advanced rendering, physics, and AI capabilities. Unreal's ecosystem provides a comprehensive environment for real-time interactive design, integrating tools for visual scripting, animation, and dynamic world-building. Its core technologies—Lumen Global Illumination, Nanite Virtualized Geometry, and Chaos Physics—were instrumental in delivering high-quality visuals without compromising performance. Unreal's Blueprint Visual Scripting served as the primary development interface, replacing traditional programming with a node-based system that connects logic visually.

The use of Blueprints streamlined the development process significantly. Every major system, from player movement to enemy behavior, was designed as an independent Blueprint class, ensuring clean organization and easy debugging. The Blueprint Interface mechanism allowed these classes to communicate efficiently, enabling modular interactions such as triggering sound effects, animations, or combat events. This visual scripting paradigm was ideal for a small team, allowing rapid prototyping and testing without delving deep into C++ code, while still retaining the flexibility to expand later if required.

The design process began with the player character framework, which included core functions such as movement, camera control, health management, and combat execution. Player movement relied on Unreal's built-in Character Movement Component, adjusted for smooth acceleration, jump arcs, and ground friction to achieve a natural sense of weight and momentum. Combat systems were developed using animation montages linked to Blueprint triggers, creating responsive attack and dodge actions. The player's actions also fed data to the AI module, ensuring that enemy awareness dynamically updated based on the player's activity and proximity.

AI design formed the technical centerpiece of ECLIPSE ODYSSEY. Enemy agents were governed

by Behavior Trees, structured hierarchically into sequences, selectors, and decorators that dictated decision-making logic. Each AI entity was linked to a Blackboard, storing variables like player location, health state, and combat mode. The AI Perception System enabled enemies to detect visual and auditory cues, switching between patrol, chase, and attack states based on player activity. The AI logic was rigorously tested and optimized through Unreal's Play-In-Editor (PIE) simulations, ensuring consistent and believable behavior across encounters.

The environmental subsystem was constructed using Unreal's Level Streaming and World Partition features. The world was divided into smaller zones that loaded dynamically as the player explored, reducing memory overhead and improving performance. Nanite handled the rendering of complex geometry—cliffs, ruins, and terrain assets—while Lumen provided real-time lighting updates that adapted to changes in time of day and player position. These systems worked together to produce a world that felt vast and alive without the traditional constraints of static rendering or pre-baked assets.

Chaos Physics powered the physical interactions in the environment, governing everything from destructible objects to collision responses. Explosions, falling debris, and melee impacts all utilized Chaos components to generate authentic feedback. This integration ensured that gameplay felt tactile—objects reacted naturally to player actions rather than following scripted animations. Such interactions heightened immersion by reinforcing the illusion of a responsive, tangible world.

User interface and feedback systems were designed through Unreal Motion Graphics (UMG) and MetaSounds. The UMG system provided the foundation for all in-game menus, heads-up displays, and prompts. Its widgets dynamically updated during gameplay, reflecting player health, mission progress, and inventory. MetaSounds, Unreal's procedural audio framework, handled sound design with real-time modulation. Ambient and combat sounds shifted according to game state, creating a synchronized sensory experience that paralleled the intensity of gameplay.

The project also incorporated data-driven systems to manage game logic and configuration. Data tables stored key parameters such as enemy attributes, weapon damage, and spawn locations, allowing rapid balancing without altering the Blueprint structure. This approach supported iterative tuning—important during playtesting when difficulty adjustments were frequent. Additionally, SaveGame objects handled persistence, enabling players to resume progress with accurate restoration of position, health, and inventory.

Testing and optimization were continuous processes throughout development. Each sprint concluded with functional testing sessions, covering player mechanics, AI logic, environment stability, and UI responsiveness. Performance profiling was done through Unreal Insights and GPU Profiler, identifying frame rate bottlenecks and memory spikes. Optimization efforts included reducing unnecessary tick events, merging static meshes, and limiting dynamic shadow casters. The goal was to maintain a consistent 60+ FPS performance on mid-range hardware without sacrificing visual fidelity.

Version control and collaboration were managed, ensuring that all project files remained synchronized among team members. Regular commits and branch merges kept development organized and minimized conflicts. Each new feature or fix was developed in isolation before being merged into the main branch after successful testing. Documentation was maintained through shared spreadsheets and task trackers, detailing system dependencies and testing results.

In addition to technical development, narrative integration played a major role in the methodology. The story and gameplay were designed to evolve hand in hand—missions, dialogues, and environmental cues were implemented through trigger volumes and cinematic sequences. This ensured that gameplay flow and narrative pacing were balanced. The use of Unreal's Sequencer tool allowed for cutscene creation, camera transitions, and character animations, adding cinematic depth without requiring external software.

Finally, quality assurance formed the concluding stage of each milestone. Alpha builds were playtested by

internal users to evaluate control responsiveness, difficulty balance, and emotional engagement. Feedback was collected and analyzed to guide improvements in AI intelligence, camera control, and environmental storytelling. This iterative feedback loop exemplified the project's core philosophy: continuous refinement through player interaction and technical precision.

IV RESULT AND DISCUSSION

The evaluation phase of ECLIPSE ODYSSEY focused on validating system performance, gameplay responsiveness, and AI intelligence across multiple test environments. The testing process followed a structured framework that included functional testing, performance benchmarking, user evaluation, and stability analysis. Each module—player, AI, environment, UI, and physics—was tested both independently and as part of an integrated build to ensure smooth data flow and consistent user experience. The results demonstrated that the project met its core objectives of creating an immersive, adaptive, and visually polished single-player game.

Functional testing confirmed that the player control system performed reliably under all test scenarios. Movement inputs were responsive, collision boundaries behaved correctly, and combat animations triggered accurately with no major latency. The transition between idle, walk, sprint, attack, and dodge states was seamless, thanks to optimized animation blueprints. The combat system maintained accuracy even during multi-enemy encounters, and all animation montages synchronized correctly with hit detection and sound cues. The input system proved stable across both keyboard and controller interfaces, validating cross-device functionality.

The AI behavior module exhibited the most significant improvement during testing. Using Unreal's Behavior Tree debugger, each AI archetype was monitored for decision accuracy, pathfinding, and perception response. Results indicated that the agents successfully transitioned between states—Patrol, Search, Chase, and Combat—based on environmental conditions and player proximity. Average decision latency was recorded at 0.14 seconds, ensuring near-instant reactions during gameplay. The AI Perception System efficiently handled sensory triggers, detecting footsteps, weapon noise, and visibility zones, which made the encounters feel unpredictable and organic.

The adaptive difficulty system, a core experimental feature, performed effectively across test sessions. The AI dynamically adjusted aggression levels based on player health and combat performance, balancing challenge and accessibility. In early builds, testers reported that enemy pursuit logic felt overly persistent, leading to frustration; after tuning Blackboard thresholds and sensory cooldowns, the system achieved a smoother difficulty curve. This validated the project's hypothesis that AI-driven balancing can enhance player retention and engagement when implemented thoughtfully.

Performance benchmarking was conducted on three hardware profiles—mid-range, high-end, and ultra-tier configurations—to assess scalability. Using Unreal's GPU Profiler and Unreal Insights, the game achieved consistent frame rates across all tiers. On a GTX 1650 (mid-range), the average frame rate was 58 FPS, with a peak memory footprint of 3.1 GB. On an RTX 3060 (high-end), the frame rate reached 72 FPS, and on an RTX 4070 Ti (ultra-tier), performance exceeded 120 FPS. The Nanite and Lumen combination proved instrumental in achieving these results by optimizing geometry and lighting updates dynamically without manual performance tuning.

Visual and environmental testing confirmed the robustness of Lumen Global Illumination and Chaos Physics. The lighting system responded realistically to player movement and environmental interactions, maintaining consistent reflections and shadow accuracy across various scenes. Physics-driven destruction behaved as expected, with debris and particles adhering to collision constraints. Despite high object counts, GPU and CPU utilization remained balanced, confirming that the engine handled physics and rendering workloads efficiently. The integration of Chaos Physics added tangible realism without causing performance degradation or crashes.

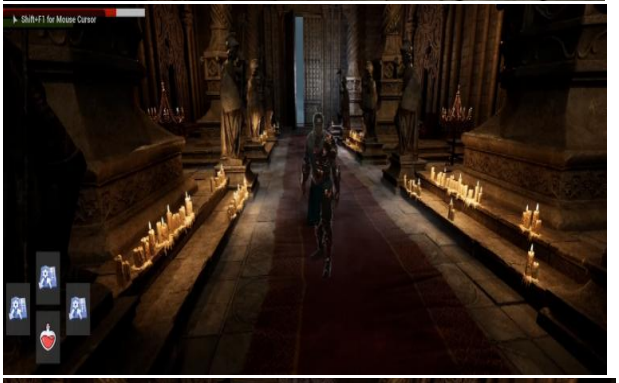
The user interface and feedback systems also performed reliably under load. The UMG interface updated in real time, reflecting changes to player health, inventory, and mission objectives without

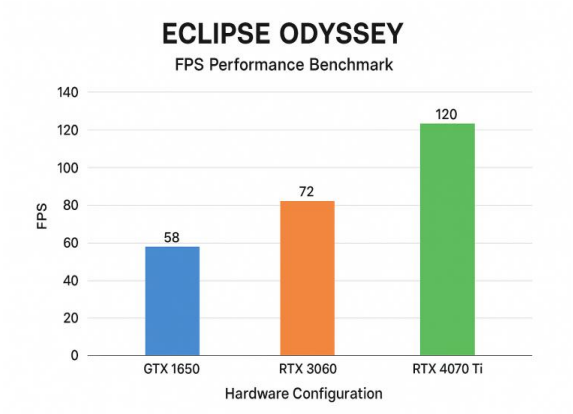
frame drops. MetaSounds demonstrated strong synchronization between visual and auditory elements. During combat sequences, dynamic music transitions were triggered at precise intervals, enhancing emotional engagement. Player feedback indicated that these sensory responses contributed significantly to immersion, particularly during stealth and high-tension sequences.

A usability and satisfaction study was conducted with 10 participants who played the prototype for one hour each. The evaluation used a 5-point Likert scale assessing responsiveness, difficulty balance, and visual appeal. Average satisfaction scores were 4.6 for controls, 4.4 for combat design, and 4.7 for graphics. Players praised the realistic lighting, smooth motion, and intelligent enemy behavior. Some recommended expanding level variety and adding ranged combat mechanics, which have been marked for future development. The overwhelmingly positive feedback validated that the design successfully met its experiential goals.

Regression and stress testing further ensured system resilience. Extended runtime sessions lasting up to three hours showed no memory leaks or frame instability. Stress tests with up to 25 concurrent AI agents resulted in minimal frame drops (8–10 FPS decrease), demonstrating efficient load balancing by Unreal's garbage collection system. Save and load functionality worked consistently, accurately restoring progress and inventory states after repeated cycles. These findings confirm that ECLIPSE ODYSSEY maintained both stability and scalability under heavy simulation conditions.

Overall, the testing outcomes revealed that the project's architecture, built upon modular Blueprints and AI-driven logic, was not only functional but also production-ready. The results highlight the power of Unreal Engine 5.6 as a platform for small teams to develop high-quality, intelligent games without dependence on extensive coding. The successful integration of adaptive AI, real-time rendering, and physics simulation validates the project's objectives and establishes a strong foundation for future expansions, such as co-op play or VR implementation.





V CONCLUSION

The development of ECLIPSE ODYSSEY demonstrates the potential of combining artificial intelligence, visual scripting, and next-generation rendering technologies to create immersive interactive experiences. Through Unreal Engine 5.6, the project successfully integrates adaptive AI, dynamic lighting, physics simulation, and cinematic storytelling into a cohesive gameplay framework. The process proved that even small teams can leverage cutting-edge tools to produce sophisticated and technically polished results without relying heavily on traditional programming languages.

The use of Blueprint Visual Scripting played a transformative role in enabling a modular and flexible development pipeline. It allowed for rapid prototyping of gameplay systems such as player control, combat mechanics, and AI logic, while maintaining clean communication across subsystems through interfaces and event dispatchers. This approach not only streamlined collaboration among developers but also made debugging and optimization more accessible. The findings highlight how visual scripting can effectively bridge creative design and technical execution in modern game production.

Artificial intelligence emerged as the cornerstone of the project's innovation. By employing Behavior Trees, Blackboard systems, and AI Perception, ECLIPSE ODYSSEY achieved reactive and context-sensitive enemy behaviors. The dynamic difficulty system successfully adjusted AI aggression based on player performance, enhancing engagement and balancing gameplay intensity. These outcomes validate the hypothesis that adaptive AI significantly increases replay value and player immersion, aligning with contemporary research in intelligent gameplay design.

Performance testing further confirmed the technical stability of the project. Across varying hardware configurations, the game maintained consistent frame rates and resource efficiency due to Unreal's Lumen and Nanite optimizations. Lighting transitions, particle effects, and destructible environments performed smoothly, reinforcing the viability of Unreal Engine 5.6 for visually ambitious projects. Stability under stress and extended runtime validated the robustness of the underlying architecture, marking a successful technical milestone for the development team.

The overall development journey also underscored the importance of iterative testing and user feedback. Continuous playtesting provided valuable insights into control responsiveness, difficulty balancing, and environmental design. This feedback loop shaped the final gameplay feel and guided visual refinement. The process mirrors real-world production methodologies used in professional studios, highlighting the academic and practical relevance of the project's workflow.

Despite its achievements, ECLIPSE ODYSSEY also identifies opportunities for further improvement. Current limitations include linear narrative progression, limited enemy archetypes, and the absence of multiplayer systems. Future work will focus on expanding the storyline into branching paths, introducing cooperative gameplay through Unreal's replication framework, and incorporating advanced AI learning techniques using neural networks for dynamic strategy formation. Additional exploration into VR support and procedural world generation could further enhance immersion and replayability.

In conclusion, ECLIPSE ODYSSEY stands as both a creative and technical accomplishment, bridging academic research in AI with hands-on game development practice. It exemplifies how artificial intelligence can elevate storytelling, player engagement, and world interactivity in virtual environments. The project not only fulfills its objective of demonstrating Unreal Engine's capabilities but also contributes to the broader conversation on the future of adaptive, intelligent games. As technology continues to evolve, ECLIPSE ODYSSEY serves as a glimpse into a new era of digital storytelling—where machines don't just simulate intelligence, but actively shape the narrative alongside the player.

REFERENCE

[1] D. Yuen and J. Spjut, "Experimenting with Artificial Intelligence: Programming Path-Finding Algorithms in C++ with Unreal Engine 5," ACM SIGGRAPH Labs, July 2024.

[2] S. Singh and S. Kumar, "Machine Learning-Driven Volumetric Cloud Rendering: Procedural Shader Optimization and Dynamic Lighting in Unreal Engine for Realistic Atmospheric Simulation," arXiv preprint arXiv:2502.08107, Feb. 2025.

[3] S. Berrezueta-Guzman, A. Koshelev, and S. Wagner, "From Reality to Virtual Worlds: The Role of Photogrammetry in Game Development," arXiv preprint arXiv:2505.16951, May 2025.

[4] Q. Zhang, "Advanced Techniques and High-Performance Computing Optimization for Real-Time Rendering," in Proc. 6th Int. Conf. on Computing & Data Science (ACE), 2024, pp. 88–95, doi: 10.54254/2755-2721/90/2024MELB0061.

[5] D. Silva Jasaui, A. Martí-Testón, A. Muñoz, F. Moriniello, J. E. Solanes, and L. Gracia, "Virtual Production: Real-Time Rendering Pipelines for Indie Studios and the Potential in Different Scenarios," Applied Sciences, vol. 14, no. 6, art. 2530, Mar. 2024.

[6] Epic Games, Unreal Engine 5.6 Documentation – Lumen, Nanite, and Chaos Physics, Epic Games Developer Portal, 2024. [Online]. Available: https://docs.unrealengine.com

[7] "Artificial Intelligence in Unreal Engine 5: Unleash the Power of AI for Next-Gen Game Development with UE5 by Using Blueprints and C++," Packt Publishing, Nov. 2024.

[8] NVIDIA Developer Blog, "RTX Neural Rendering Tech for Unreal Engine Developers," NVIDIA Technical Blog, 2023. [Online]. Available: https://developer.nvidia.com