

Metaverse-Based Virtual Campus Tour for Higher Education: Insights from Development to User Experience Validation

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Abstract— In archipelagic countries with thousands of islands separated by wide regional spans, geographic barriers often prevent prospective students from experiencing campus life before making enrollment decisions. This limitation constrains institutions' capacity to expand outreach and enhance their visibility in the higher education landscape. Metaverse platforms present significant opportunities to transform campus tours. However, most virtual tours are still constrained by static visualizations and single-user experiences. This study aims to systematically develop and evaluate a Metaverse-based virtual campus tour, addressing the limitations of existing platforms and examining its usability and user loyalty. The system was created systematically through a four-phase Discover, Blueprint, Develop, and Validate framework. This process consolidated requirements, translated them into design artifacts, and implemented them within a scalable layered architecture, ensuring usability and loyalty. Evaluation results showed that users perceived the system as both usable and recommendable. While usability varied according to familiarity and role-specific expectations, loyalty remained consistently strong across groups. These findings confirm that the system delivers meaningful value, demonstrates strong adoption potential, and offers a replicable development model for applying Metaverse technologies in higher education.

Keywords—higher education digital transformation, metaverse, usability evaluation, user loyalty of metaverse, virtual campus tour

I. INTRODUCTION

Metaverse has the potential to significantly change education. Metaverse consists of the words "meta" and "universe" which refer to a combination of the virtual and real worlds. It can be defined as a new concept being used in education". The Metaverse in education refers to immersive 3D virtual environments, where users can interact with digital avatars through shared, persistent, and decentralized in digital spaces to enhance the quality of learning through technology-based simulations, collaboration, social interaction, and exploration [1]. The Metaverse is primarily used in education to support and implement learning processes [2]. It offers numerous opportunities to implement diverse learning scenarios such as virtual, collaborative, and blended learning. This technology is actively contributing to the emergence of new educational possibilities [3]. However, Tlili et al. [4] claims this technology is still in its infancy.

Various educational institutions are integrating the Metaverse into their learning processes, including early childhood, elementary, secondary, and higher education. According to [5], higher education has emerged as a leading domain in adopting Metaverse. These findings show that higher education institutions use the Metaverse to create interactive and immersive learning experiences. This approach enables educators and students to explore innovative pedagogical methods and emerging technologies. Teachers have demonstrated favorable attitudes toward using this technology, as they perceive it to be valuable and impactful in improving learning outcomes. They recognize its potential to stimulate active participation, immersive learning, and collaborative, innovation-driven activities [6, 7]. Students believe that this technology plays a significant role in enhancing their academic performance and motivation [8, 9, 10]. However, most higher education institutions focus on using the Metaverse-based learning, but they have yet to explore its potential for other aspects like training, student orientation, and campus tour.

Campus tours help students connect with the university environment. Universities organize campus tours as formal interaction rituals to familiarize prospective students with the physical layout, social dynamics, cultural values, and symbolic identity [11, 12]. Digital innovation has redefined campus tour practices from "campus tour" to "virtual campus tour". Virtual Campus Tour is a digital platform allowing prospective students to explore the campus environment in a virtual setting [13]. The platform allows prospective and current students to explore the campus in an immersive way without requiring physical presence. This feature is especially beneficial for individuals facing financial, geographical, or mobility-related constraints.

Virtual campus tours have enhanced universities appeal and expanded their promotional reach from an institutional marketing perspective [14]. Research findings demonstrate that most prospective students receive positive responses from digital campus tours, with some suggesting they can effectively replace in-person visits [15, 16]. Spicer and Stratford [17] analyzed student perceptions of virtual campus tours compared to real field trips. Students found them inadequate as substitutes but helpful for enhancing learning



before and after the visit. These findings suggest that although virtual campus tours have not fully replaced physical visits, they hold significant potential to support promotion and engagement tour strategies in higher education.

Universities adopt virtual tours by incorporating advanced technologies like panoramic video capture, interactive mapping systems, and immersive multimedia tools. Grosser et al. [18] developed a 360-degree virtual tour to replace or complement field trips. This approach helps overcome mobility barriers and maintain learning continuity. Garcia et al. [19] developed a 360-degree and VR-based virtual campus tour that offers a game-like experience for prospective students to explore the campus online. Users provided positive feedback on the application, particularly its usability and immersive experience. This study identifies the virtual campus tour as a promising strategy for supporting student recruitment efforts. Rohizan et al. [20] developed a virtual campus tour using photo-stitching techniques to generate panoramic views. This approach allowed prospective students to explore campus facilities remotely and simulated aspects of an in-person visit.

Sim et al. [21] implemented the digital twin concept through a modular platform to develop an interactive 3D campus tour representing architectural features. Salim and Khalilov [22] developed a Virtual Tour Guide Application using 3D modeling and VR to deliver an interactive and visually realistic campus experience. The findings highlight how adaptive digital media can increase user engagement and support institutional efforts to attract prospective students. Romli et al. [23] developed a mobile AR application using ARCore to display 2D and 3D visualizations of campus buildings and rooms with pop-up text. Nordin et al. [24] developed a similar technology using ARToolKit to provide indoor campus navigation through AR-based visual guidance.

Previous studies have contributed significantly to developing virtual campus tours using various technological approaches like 360-degree panoramas, AR, VR, and digital twins within the Metaverse context. These approaches still present fundamental limitations, particularly immersion, social interactivity, and virtual environment dynamics. Studies by Grosser et al. [18] and Rohizan et al. [20] show that 360-degree and photo-stitching technologies can provide a visual experience of the campus environment. However, both technologies remain passive and offer limited interactivity. Garcia et al. [19] and Salim and Khalilov [22] have explored VR and game engine technologies to create more interactive campus tour experiences. However, their implementations still face accessibility challenges and risks of user discomfort. Related studies by Sim et al. [21] have adopted Metaverse and digital twin concepts. However, they emphasize architectural visualization without integrating social collaboration features such as multiplayer interaction. Romli et al. [23] and Nordin et al. [24] applied AR-based approaches to enhance information access through 2D/3D visualization and marker-based navigation. These systems operate only on specific devices and fail to support real-time exploration and user-to-user interaction.

This study addresses an important gap in the literature, as most prior research has largely overlooked the integration of interactive features when developing virtual campus tours. We present a Metaverse-based virtual campus tour that integrates interactive and immersive features, advancing beyond prior technologies limited to static visualizations, minimal interaction, and single-user experiences. By developing and evaluating this system, we demonstrate how immersive, collaborative, and user-centered features enhance engagement in higher education. In addition, we contribute a systematic development methodology and propose new design principles that provide theoretical insights and practical guidance for institutions integrating Metaverse technologies into their digital transformation strategies, offering a replicable framework for future research and implementation.

Based on these research gaps and practical challenges, this study aims to explore the following research questions:

- RQ1: How to develop the Metaverse-based campus tour systematically?
- RQ2: How can the interactive and immersive features of the developed system address the limitations in existing campus tour platforms?
- RQ3: 3. How does the user reflect on the developed system's usability and loyalty?

II. METHOD

This study employs a four-phase development methodology specifically tailored to the Metaverse context. The phases include: (1) Discover, emphasizing literature review and the identification of research gaps as the primary sources for defining system requirements and aligning them with current trends in Metaverse-based educational technology; (2) Blueprint, focusing on the design of the virtual campus environment, avatar interaction mechanisms, and 3D environment modelling; (3) Develop, implementing core functionalities through modular tools and third-party technology integration; and (4) Validate, assessing the usability and user loyalty of the Metaverse-based campus tour experience.

A. Discover

The Discover phase establishes the system requirements through a literature review and the identification of research gaps in prior studies. We identified a set of transversal requirements that consistently emerged across the literature on virtual tours and the metaverse. Virtual navigation is critical to virtual tours, as it directly influences user orientation and spatial learning. Recent studies show that map-based navigation strongly influences the development of spatial understanding, emphasizing the importance of well-designed maps during initial orientation [25]. These findings confirm the relevance of virtual navigation as a key feature in virtual campus tours, ensuring that users, especially first-time visitors, can explore complex environments with greater ease and confidence.

Avatar customization is fundamental in virtual environments, as it shapes how users perceive themselves and interact with others. A recent systematic review highlights that customizable avatars significantly influence identity, self-expression, and engagement [26]. These insights underline the importance of avatar customization in virtual campus tours, enabling users to build a stronger sense of presence and connection within the digital environment.

Multiplayer and social interaction features are central to virtual environments, as they create opportunities for collaboration and shared experiences. A systematic review on social and collaborative VR emphasizes that such environments can effectively enhance collaborative learning [27]. In addition, a recent review of multi-user VR highlights the importance of peer-to-peer interaction and the careful design of cooperative mechanisms [28]. These findings confirm the relevance of multiplayer and social interaction features in virtual campus tours. Such features replicate real-world group dynamics and foster a stronger sense of community among users.

NPC-based information access serves as an essential feature in virtual environments, functioning as virtual guides that support user orientation and learning. Recent findings show that guidance cues provided by virtual pedestrians or NPCs can improve user experience and facilitate route knowledge acquisition [29]. These insights highlight the importance of integrating NPCs as accessible information points in virtual campus tours, ensuring that users receive contextual guidance and can navigate complex environments with greater confidence.

Moreover, AI chatbots and intelligent agents extend the functionality of virtual environments by enabling dynamic and personalized interactions. A recent study demonstrates that integrating chatbots into Metaverse settings helps overcome comprehension barriers [30]. These findings underline the relevance of AI chatbots in virtual campus tours, where they can function as interactive Q&A agents to provide timely, curriculum-related information and enhance user engagement.

Realistic and dynamic environments are essential in shaping immersion and user comfort in virtual spaces. Recent work argues that realism should be carefully managed, as excessive detail may increase cognitive load, whereas functional realism provides clearer benefits for learning [31]. These findings confirm the importance of realistic yet balanced environmental design in virtual campus tours, ensuring immersion while maintaining usability and accessibility.

After conducting a literature review, we mapped the transversal requirements identified in previous studies to assess their coverage and relevance. Most campus tour studies have concentrated on individual features, with limited attention to their combined implementation within comprehensive virtual tour systems. The transversal requirements and the corresponding gaps in earlier studies are summarized in Table I.

TABLE I. MAPPING OF TRANSVERSAL REQUIREMENTS AND RESEARCH GAPS IN VIRTUAL CAMPUS TOUR STUDIES

Transversal Requirements Feature	Previous Studies							Metaverse-Based Campus Tour
	[18]	[20]	[19]	[22]	[21]	[23]	[24]	
Virtual Navigation [25]	-	-	✓	-	-	✓	-	✓
Avatar Customization [26]	-	-	-	-	-	-	-	✓
Multiplayer/Social Interaction [27, 28]	-	-	-	-	-	-	-	✓
NPC-based Information Access [29]	-	-	-	✓	-	-	-	✓
AI Chatbots/Agents [30]	-	-	-	-	-	-	-	✓
Realistic & Dynamic Environment [31]	-	-	✓	-	✓	-	-	✓

Based on Table I, previous studies examined transversal requirements individually, but rarely within an integrated framework. What sets our system apart is the simultaneous implementation of all key features: virtual navigation, avatar customization, multiplayer interaction, NPC-based information access, AI chatbots, and realistic environments within a single Metaverse-based campus tour. In addition to these transversal requirements, our system incorporates several supporting features, including a personalized home spawn point, integrated chat and social functions, and gamification elements. This holistic integration addresses the gaps identified in prior work and delivers a more comprehensive and immersive exploration experience than previously reported systems.

B. Blueprint

The Blueprint phase is the initial design stage of the Metaverse-based campus tour. This stage applies a reality-based approach to ensure authenticity in the virtual representation. The process begins with creating a storyboard that outlines the narrative flow of location exploration and lists the main features for implementation. This storyboard supports a structured and immersive user experience. Avatars are designed to represent students wearing university blazers with the institutional logo displayed on the upper right pocket. Both male and female options are provided to uphold gender representation and inclusivity. All environment and avatar designs are then realized using a photorealistic 3D modelling approach in Unity. Modular assets achieve visual consistency between the real campus and its virtual counterpart.

C. Develop

The Develop phase implements the Metaverse-based campus tour system using a modular and integrated approach. Unity serves as the primary development engine, supported by various third-party plugins and services. Multiple technical components are integrated to deliver a functional, adaptive, and immersive virtual campus environment. These include a visual development engine, a multi-user communication system, artificial intelligence for virtual agents (NPCs), and

avatar personalization and user data management services, as illustrated in Figure I.

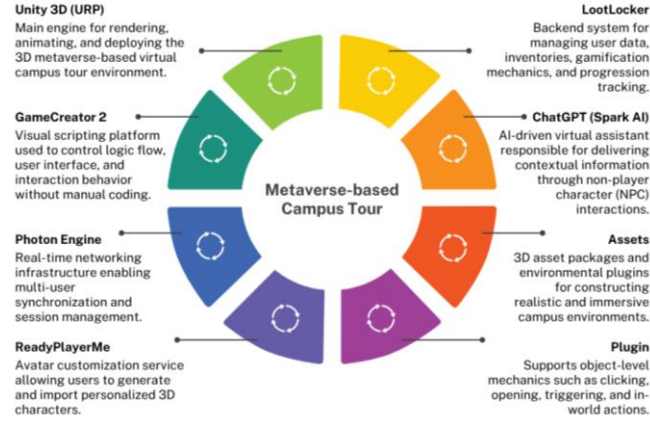


FIGURE I. TECHNICAL COMPONENTS INTEGRATED INTO THE DEVELOPMENT OF THE METAVERSE-BASED CAMPUS TOUR

The development process follows a series of key technical steps. First, a multiplayer server is configured using Photon Engine to enable real-time user interaction. GameCreator2 is integrated as a visual scripting tool to manage navigation logic, object interactions, and user flow. The backend utilizes LootLocker to handle authentication, track exploration progress, and manage avatar data. An AI-driven virtual agent, powered by a GPT-based tool, facilitates interactive conversations with NPCs. Avatar personalization is implemented through ReadyPlayerMe, allowing users to create digital avatars via a web interface, while avatar selection and storage logic preserve user preferences across sessions. Additional programming defines avatar movement and interaction behaviors. Finally, a visual user interface is developed by comprising a campus map, navigation menus, notifications, and system settings.

D. Validate

The Validate phase focuses on evaluating the user experience in terms of usability and user loyalty. Usability is measured using the System Usability Scale (SUS), which captures participant perceptions of ease of use and overall satisfaction with the platform. User loyalty is measured using the Net Promoter Score (NPS), which assesses the likelihood of participants recommending the platform to others. During the evaluation, participants independently explored the system and completed a questionnaire covering both dimensions.

1. System Usability Scale

Responses were collected for ten SUS items rated on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Odd-numbered items were positively worded, while even-numbered items were negatively worded. The final SUS score was calculated following the standard scoring procedure in [32]. For each item i ($i = 1, 2, \dots, 10$), let Q_i denote the participants rating. The adjusted score s_i was computed as:

$$s_i = \begin{cases} Q_i - 1, & \text{if } i \text{ is odd} \\ 5 - Q_i, & \text{if } i \text{ is even} \end{cases}$$

The total SUS score was then obtained using:

$$SUS \text{ score} = \left(\sum_{i=1}^{10} s_i \right) \times 2,5$$

This yields a score ranging from 0 to 100, with higher scores indicating better perceived usability.

2. Net Promoter Score

The NPS is a widely used metric for measuring user loyalty. Respondents are asked to rate their likelihood of recommending the system on a scale from 0 to 10. Based on their ratings, respondents are classified into three categories [33, 34]:

- Promoters: scores of 9–10 (highly likely to recommend)
- Passives: scores of 7–8 (neutral to moderately likely to recommend)
- Detractors: scores of 0–6 (unlikely to recommend)

The NPS is calculated by subtracting the percentage of Detractors from the percentage of Promoters, resulting in a score that ranges from –100 to +100. Let:

- n = total number of respondents
- n_p = number of respondents with scores 9 – 10 (Promoters)
- n_d = number of respondents with scores 0 – 6 (Detractors)

The NPS is then computed as:

$$NPS = \left(\frac{n_p}{n} \times 100 \right) - \left(\frac{n_d}{n} \times 100 \right)$$

A higher NPS value indicates stronger user loyalty and a greater likelihood of positive word-of-mouth recommendations [35].

3. Instruments

The evaluation employed two standardized instruments to measure distinct aspects of the user experience. The SUS comprising 10 items, was used to assess the platforms usability, focusing on perceived ease of use and overall satisfaction. The NPS consisting of a single item, was used to measure user loyalty by evaluating the likelihood of participants recommending the platform to others. The questionnaire incorporated 11 statements adapted from [36]. Prior to completing the questionnaire, participants independently explored the system. Table II presents the complete set of items used in the evaluation.

TABLE II. QUESTIONNAIRE ITEMS FOR USABILITY AND USER LOYALTY EVALUATION

Instrument	Items	Questionnaire Details
SUS	SUS1	I think that I would like to use this Metaverse-based campus tour frequently.
	SUS2	I found the Metaverse-based campus tour unnecessarily complex
	SUS3	I thought the Metaverse-based campus tour was easy to use

Instrument	Items	Questionnaire Details
	SUS4	I think that I would need the support of a technical person to be able to use this Metaverse-based campus tour.
	SUS5	I found the various functions in the Metaverse-based campus tour were well integrated
	SUS6	I thought there was too much inconsistency in this Metaverse-based campus tour
	SUS7	I would imagine that most people would learn to use this Metaverse-based campus tour very quickly
	SUS8	I found the Metaverse-based campus tour very awkward to use
	SUS9	I felt very confident using the Metaverse-based campus tour
	SUS10	I needed to learn a lot of things before I could get going with this Metaverse-based campus tour
NPS	NPS1	How likely are you to recommend this Metaverse-based campus tour to a friend or colleague?

Note: The SUS items were rated on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree), with odd-numbered items positively worded and even-numbered items negatively worded. The NPS item was rated on an 11-point scale (0 = Not at all likely to 10 = Extremely likely).

4. Participants

This study involved 40 participants, consisting of 31 active students, 5 prospective students, and 4 lecturers, recruited through convenience sampling within the campus community. The sample size is sufficient for usability testing and has been consistently supported in prior research. Sauro and Lewis [37] indicated that 40 participants provide reliable estimates of population behavior in quantitative usability studies, while Faulkner [38] demonstrated that such a number can reveal nearly all usability problems. Othman et al. [39] further confirmed the feasibility of employing 40 participants in a usability study of a virtual reality system, highlighting its effectiveness in virtual environment evaluations.

In this study, the distribution of participants across the three groups was uneven, reflecting the demographic reality of the user community. Nielsen and Landauer [40] suggest that five participants are generally sufficient to uncover most usability problems, with at least three participants recommended per user group when multiple groups are involved. Getto [41] further emphasizes this point by applying a flexible approach, highlighting that each group should be represented to capture diverse usability insights, even with uneven group distributions, including smaller groups. In addition, several studies indicate that numerical balance is less important than ensuring representativeness and contextual diversity in usability findings [37, 42, 43, 44].

In addition, we present the demographic composition of the participants in Table III to provide further context for the user experience evaluation.

The demographic composition of the sample included 31 active students (77.5%), 5 prospective students (12.5%), and 4 lecturers or staff members (10.0%). Most participants were between 21 and 25 years old (55.0%), followed by those aged 17–20 years (35.0%) and above 25 years (10.0%). The gender

distribution comprised 28 males (70.0%) and 12 females (30.0%) respondents. Regarding Metaverse experience, more than half of the participants (57.5%) reported never using such platforms, 37.5% had tried them once, and only a small minority identified as frequent users (5.0%).

TABLE III. DEMOGRAPHIC COMPOSITION OF PARTICIPANTS

Characteristic	Category	N	%
User Group	Active students	31	77.5%
	Prospective students	5	12.5%
	Lecturers	4	10.0%
Age Range	17–20 years	14	35.0%
	21–25 years	22	55.0%
	>25 years	4	10.0%
Gender	Male	28	70.0%
	Female	12	30.0%
Metaverse experience	Never	23	57.5%
	Tried once	15	37.5%
	Frequent	2	5.0%

5. Procedures

The usability testing was conducted through a series of structured steps designed to ensure consistency and reliability in data collection. The detailed procedures of the study are outlined as follows:

- **Participants recruitment:** A total of 40 participants were recruited using a convenience sampling approach from the campus community. The inclusion criteria required participants to have basic experience with computers and mobile devices, while no prior exposure to the Metaverse platform was necessary.
- **Testing setting:** All participants evaluated a controlled laboratory environment. To maintain consistency, every participant used the same institution-provided device connected to a stable Wi-Fi network. The device used was a PC AIO Acer Veriton N4 (VN4/0017) equipped with an Intel Core i7-13700 processor, 8 GB RAM, 512 GB SSD storage, and a 27-inch display running Windows 11 Home.
- **Briefing session:** Participants were briefed about the study's purpose and the step-by-step testing procedure. They were informed that the system represented a Metaverse-based virtual campus tour.
- **Informed consent:** Each participant was asked to read and sign an informed consent form provided via Online Form. They were informed about data confidentiality, voluntary participation, and the right to withdraw at any time without consequence.
- **Onboarding tutorial:** Before starting the evaluation, participants were guided through a short tutorial explaining how to control avatars, navigate the environment, and interact with embedded features. Assistance was limited to this onboarding stage; no intervention was provided during the evaluation unless participants encountered technical errors that prevented task completion.
- **System exposure:** Participants were asked to freely explore the virtual campus tour for at least 15 minutes.

They were encouraged to interact with key features. No strict time limit was imposed, but most participants spent 15–30 minutes in the system.

- Questionnaire administration: After completing the tour, participants were required to fill out an online questionnaire that included the SUS and NPS.
- Debriefing session: At the end of the session, the instructor facilitated a short debriefing.

III. METAVERSE-BASED CAMPUS TOUR BLUEPRINT

A. Storyboard

The design process adopts a reality-based approach, visualized through a storyboard that outlines the main features to be implemented in the Metaverse-based campus tour. The storyboard integrates reality sketching and sequence-based approaches to narratively and interactively model the intended user experience in the Metaverse environment (Figure II).

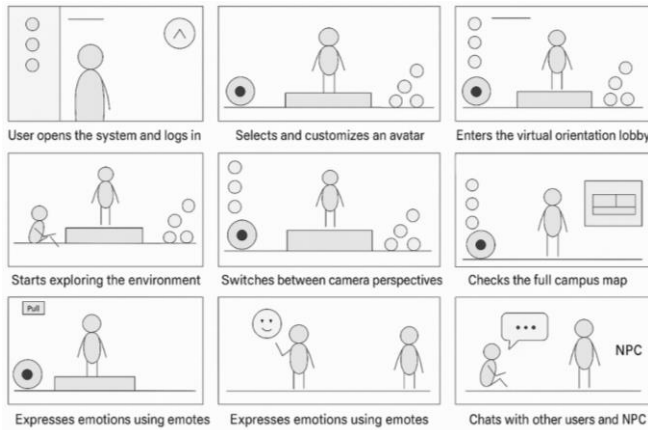


FIGURE II. STORYBOARD OF THE METAVERSE-BASED CAMPUS TOUR ILLUSTRATING THE SEQUENCE OF USER INTERACTIONS

The process begins when users access the platform and log in. After authentication, they select and customize an avatar as their virtual representation during campus exploration. Upon completing avatar selection, users are directed to a virtual orientation lobby, which serves as the starting point of the virtual experience. They can freely explore the campus environment from this lobby and switch between first-person and third-person camera perspectives to match their viewing preferences. A comprehensive campus map facilitates navigation across key locations within the virtual campus. Emote features allow users to visually express emotions during interactions, while real-time social communication via chat enables engagement with other users and Non-Player Characters (NPCs). These elements foster collaborative interaction and strengthen the sense of social presence within the virtual environment.

B. Avatar

Avatars play a central role in representing users, facilitating engagement, and enhancing comfort within virtual learning environments [45]. They act as symbolic extensions of the self, enabling users to interact with the virtual space in ways that reflect their individuality. In the Metaverse-based

campus tour, avatars serve as the primary interface for user interaction within the virtual environment (Figure III).



FIGURE III. AVATAR DESIGN FOR THE METAVERSE-BASED CAMPUS TOUR

The avatar design represents students wearing official campus uniform with the institutional logo displayed on the upper right pocket. Official campus uniform and the institutional logo are intended to reinforce institutional branding and foster a sense of belonging among users [46]. In addition, providing both male and female versions ensure inclusivity and allows users to select an avatar that aligns with their identity.

C. 3D Environment Modelling

This study applies a three-dimensional (3D) model to reconstruct the campus environment within a Metaverse platform. The virtual environment follows the principles of a photorealistic 3D environment, emphasizing visual consistency between real-world settings and their digital representations. The objective is to deliver a visual experience that mirrors the physical campus. According to Nebel et al. [47], the photorealistic environment design incorporates key features to enhance visual realism and immersion. High-resolution textures capture fine surface details, while dynamic lighting adjusts to the time of day and the user's perspective. Accurate shadows and reflections improve spatial depth and coherence, and physically based materials with realistic color schemes replicate real-world appearances. Figure IV compares the physical campus building and its 3D model representation in the Metaverse-based campus tour.



FIGURE IV. COMPARISON BETWEEN THE PHYSICAL CAMPUS BUILDING (LEFT) AND ITS 3D MODEL REPRESENTATION IN THE METAVERSE-BASED CAMPUS TOUR (RIGHT)

This modelling uses Unity and educational-themed modular assets. Each building and public space is developed to resemble its real-world counterpart. In total, 28 buildings are modelled with high fidelity to the original structures. In terms of user engagement, the immersive realism of the environment strengthens the sense of presence, a key factor in sustaining attention and promoting active exploration within virtual spaces. Familiar visual cues derived from the real-world campus foster an emotional connection with the environment, promoting loyalty and increasing the likelihood of return visits. These design considerations align with findings from Fares et al. [48], which indicate that visual

realism is important in shaping the perceived quality and long-term adoption of virtual learning platforms.

IV. DEVELOPING METAVERSE-BASED CAMPUS TOUR

A. System Architecture

The system architecture for the Metaverse-based campus tour is designed based on the Software-Defined Metaverse

(SDM) Architecture framework proposed by Abd Elkareem et al. [49]. This architecture adopts a three-layer structure comprising the Application Layer, Control Layer, and Physical Layer, as illustrated in Figure V.

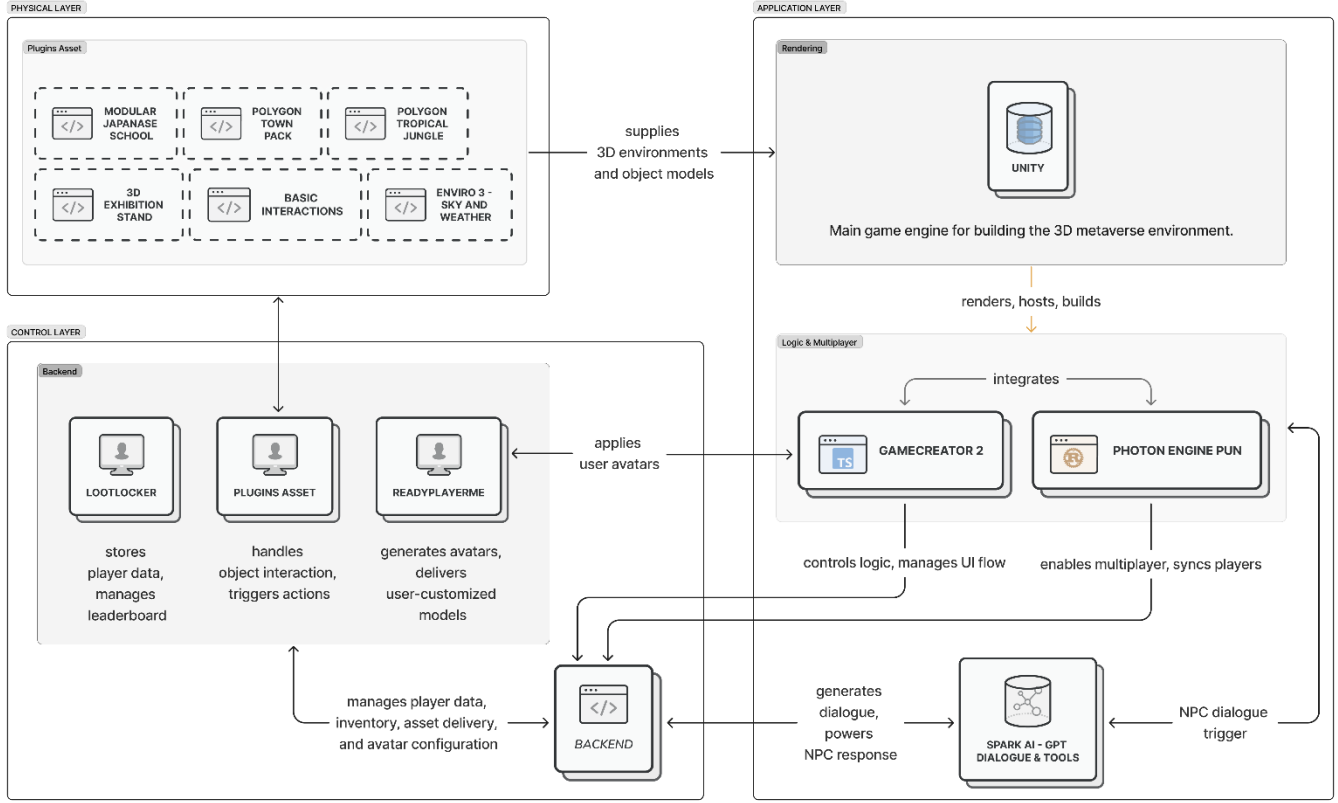


FIGURE V. PROPOSED SYSTEM ARCHITECTURE FOR THE METAVERSE-BASED CAMPUS TOUR CONSISTING OF PHYSICAL, CONTROL, AND APPLICATION LAYERS

The Application Layer is the primary interface through which users interact with the Metaverse environment. It integrates the core components that define the overall user experience. The Unity engine renders the interactive virtual campus, while GameCreator2 manages user interactions and navigation via visual scripting. The ReadyPlayerMe module is integrated to enable avatar personalization, allowing users to create digital representations aligned with their identities. In addition, a GPT-powered AI dialogue system is embedded to enhance interaction quality, providing expressive and context-aware communication with virtual agents and non-player characters (NPCs).

The Control Layer is the central unit for backend logic and resource management. It handles data transmission, processes application logic, and manages user-related information. LootLocker is used for user authentication, progress tracking, and profile management within the immersive environment. The Photon Engine Plugin enables real-time multiplayer capabilities, shared virtual spaces, and synchronized user activities. This layer effectively bridges interactions at the Application Layer with the underlying infrastructure of the Physical Layer.

The Physical Layer provides the technical foundation for the entire system. It encompasses the visual assets and the hardware or computing infrastructure required for system development and execution. Modular 3D campus elements are created using plugin assets such as Modular Japanese School, Polygon Town Pack, and Basic Interactions. Unity is used within this layer for rendering, scripting, and application packaging. Photon and backend hosting servers are deployed on cloud-based or on-premises infrastructure to ensure scalability and reliability.

B. Metaverse Development

The development of the Metaverse-based campus tour system was structured to deliver an immersive, interactive, and user-centric digital experience. This stage extends the initial design process, which defined the conceptual layout of the virtual environment, narrative flow, and avatar representation.

The development process adopts a Unity-based modular approach by integrating third-party technologies such as multiplayer systems, backend services, AI-driven virtual agents, and avatar personalization. This combination enables

the creation of a visually rich virtual world while ensuring synchronous, stable, and user-friendly system performance. The development stages, covering multiplayer configuration, interaction logic setup, avatar personalization, AI integration, and graphical user interface (GUI) implementation, are systematically illustrated in Figure VI.

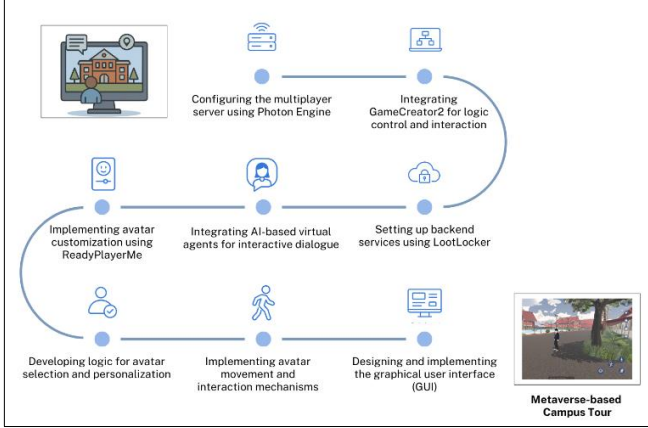


FIGURE VI. DEVELOPMENT WORKFLOW FOR THE METAVERSE-BASED CAMPUS TOUR

The process begins with configuring the multiplayer server using Photon Engine to support collaborative exploration by multiple users in real time. This setup manages session rooms, player identities, and position synchronization between avatars. Once the server was established, GameCreator2 was integrated into the Unity project to develop navigation logic, object interactions, scene transitions, and user experience flows using modular visual scripting without extensive manual coding.

The backend system implemented using LootLocker, manages user authentication, tour progress storage, mission or gamification status, and avatar data. This backend is the main bridge between the system logic (GameCreator2) and stored user information. AI-driven virtual agents were then integrated to serve as NPCs, providing natural text-based dialogue to answer visitor questions, offer building information, and assist with navigation.

Avatar personalization is implemented via ReadyPlayerMe integration, enabling users to select avatar appearances directly from a web-based UI and import them into Unity. This functionality includes avatar previews, gender and skin tone settings, storage through LootLocker, and avatar recognition upon user login. Avatar movement logic (walking, running, jumping, and dashing) was also developed, along with interaction mechanisms for opening doors, triggering information points, and teleportation. These features were implemented using a combination of Unity Animator Controller and GameCreator2s event system.

Finally, a graphical user interface (GUI) was designed and implemented to include the main menu, campus map, dialogue panels, notifications, tooltips, and a settings menu, ensuring intuitive and accessible user interaction throughout the virtual tour.

V. RESULT

Unlike most previous virtual campus tour platforms focused primarily on static visualizations or linear video presentations, the proposed system integrates nine complementary features within a single Metaverse-based framework. Its distinct contribution lies in the holistic combination of photorealistic rendering, personalized avatars, multiplayer interaction, NPC-based information delivery, real-time environmental dynamics, and gamification. This integration addresses the gaps identified in prior studies and provides a more immersive, interactive, and socially engaging campus tour experience than previously reported systems.

A. Avatar Customization for Identity Representation

Metaverse-based campus tour implements avatar customization features to support user personalization and digital self-representation in campus tour environment. The system initiates the customization process before users enter the virtual environment. It provides two default avatars: a male and female student wearing official campus uniform (Figure VII, Figure VIII).



FIGURE VII. REPRESENTATION OF A MALE STUDENT AVATAR

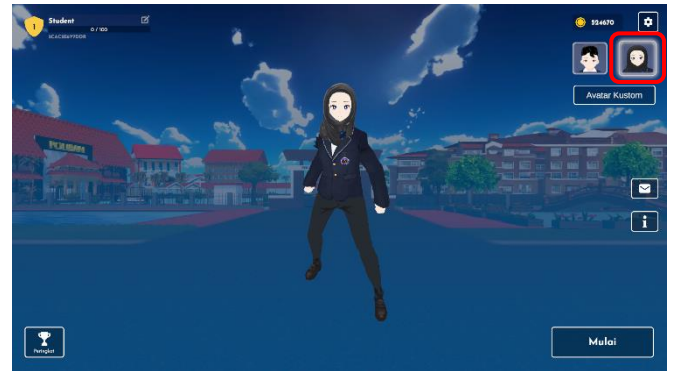


FIGURE VIII. REPRESENTATION OF A FEMALE STUDENT AVATAR

In addition, the Metaverse provides customizable avatars through the ReadyPlayerMe platform, which offers a web-based customization interface with various visual attribute options such as gender, skin color, facial features, hairstyles, and clothing, as shown in Figure IX.



FIGURE IX. USER-CUSTOMIZED AVATAR

Avatars enhance immersive realism and enhance perceived authenticity. This effect fosters greater emotional engagement and builds stronger connections with the institution. According to Pakanen et al. [50], avatar personalization can enhance user presence and engagement in virtual spaces. These two elements are key factors in creating an immersive experience. Furthermore, customizing self-representation through avatars gives users the autonomy to choose an appearance that reflects their personal preferences. Studies Tinmaz and Singn Dhillon [51] also emphasize that this feature can strengthen the emotional connection between the virtual environment and the user.

B. Photorealistic Virtual Environment

The Metaverse-based campus tour features a photorealistic 3D environment that closely replicates real-world settings with high visual accuracy, as shown in Figure X.



FIGURE X. VIRTUAL CLASSROOM REPRESENTING REAL-WORLD LEARNING ENVIRONMENT

This visualization gives users the impression of viewing a photograph or being physically present at the real location. Users can virtually explore buildings, streets, and landmarks with visuals that mimic real-world conditions. These visualizations are developed using the Unity game engine, with support for high-resolution modular assets and dynamic lighting to create a sense of depth and spatial realism. The system employs rendering techniques such as baked lighting, reflection probes, and post-processing effects to improve visual quality and maintain system performance.

Previous studies Fares et al. [48], and Newman et al. [52] found that visual realism in virtual environments significantly influences users affective responses and perceptions. Photorealism enhances visual perception and bridges the

experiential gap between virtual and real worlds. Another studies by Feng and Zhao [53] show that a convincing visual representation enables users to form an emotional connection with the virtual environment. This connection enhances how users perceive the institutions credibility and appeal.

C. Virtual Home Spawn Point

Each user begins their tour at a designated Virtual Home Spawn Point, where the system positions the avatar upon entering the virtual environment. This enclosed and personalized area is a secure starting zone before users commence the campus tour. Providing a spawn point aligns with best practices in immersive environment design, where a safe zone facilitates the user's psychological adaptation during the transition into virtual spaces. According to Zackoff et al. [54], an initial familiarization area allows users to gradually adjust to the controls, perspective, and interaction mechanics without external distractions. This approach reduces cognitive load, minimizes initial disorientation, and improves navigation readiness.

Furthermore, Tserenchimed and Kim [55] highlight that such controlled entry points can enhance the sense of presence by enabling users to establish a mental anchor within the virtual world before engaging in exploratory or collaborative tasks. In the context of Metaverse environments, a spawn point also supports onboarding strategies that increase user comfort and confidence, which in turn can improve engagement throughout the virtual experience.

D. Multiplayer

The Metaverse-based campus tour includes a multiplayer feature that allows several users to connect and explore the same virtual environment simultaneously, as shown in Figure XI.



FIGURE XI. MULTIPLAYER FEATURE IN METaverse-BASED CAMPUS TOUR ENABLING USERS TO EXPLORE THE VIRTUAL CAMPUS TOGETHER

When users log in, they can immediately see other user avatars moving around in real time. This shared presence creates a dynamic atmosphere that feels closer to face-to-face interaction. The feature supports multiple forms of interaction. Users can send messages through a chat panel, express emotions using emoticons, or observe the movement of other avatars in the space. These options make the environment feel more alive and encourage spontaneous social contact, strengthening the sense of co-presence in the virtual campus.

In educational Metaverse environments, multiplayer functionality is not limited to social interaction. It also supports collaborative learning and shared exploration. According to McCarthy et al. [56], synchronous multi-user participation in virtual spaces enhances cognitive engagement by enabling real-time knowledge exchange. At the same time, it strengthens social bonds through shared experiences. This feature also contributes to affective engagement, as the perception of “being together” can increase motivation and enjoyment during the learning process [57]. Social presence has been found to predict cognitive and affective engagement through peer interaction, and it is also recognized as a factor that promotes sustained participation, highlighting its importance in the design of immersive and collaborative virtual environments [58, 59].

E. Virtual Navigation in 3D Campus Environment

The system implements a multi-mode virtual navigation feature that allows users to explore the 3D campus environment independently, as shown in Figure XII.



FIGURE XII. VIRTUAL NAVIGATION BUTTONS ALLOWING USERS TO WALK, RUN, AND JUMP

Navigation can be performed through avatar motion controls, allowing walking, running, jumping, and directional changes. Furthermore, the camera system supports two viewing modes: a third-person view, which offers a wider and more contextual perspective, and a first-person view, which provides an immersive character-centered experience. In addition, the system also provides an interactive mini-map that displays the users position in real time, as shown in Figure XIII.



FIGURE 1. MINI-MAP VIEW AT THE TOP-LEFT CORNER AS A REAL-TIME NAVIGATION

This mini-map, located in the top-left corner of the interface, can be expanded to full-screen mode for detailed navigation. Previous studies show that map-based navigation improves user exploration and route knowledge acquisition [25, 60]. By integrating the mini-map with free exploration controls, the system enables users to construct a mental representation of the campus while ensuring flexible navigation.

F. Contextual Information Delivery through Virtual Agents

The system integrates virtual agents or non-player characters (NPCs) to provide contextual information during campus exploration, as shown in Figure XIV.



FIGURE XIV. USER INTERACTION WITH LECTURER NPC TO OBTAIN COURSE-RELATED INFORMATION

NPCs are designed to resemble lecturers and are strategically positioned near faculty buildings, open spaces, and other important campus areas. Interaction occurs through a text-based conversation interface. These NPCs are currently static and limited to predefined backend responses. Nevertheless, they simulate authentic academic encounters similar to those in real campus settings. In addition, the system integrates an AI Companion represented as a “little flying robot” powered by a Generative Pre-trained Transformer (GPT) model. Technically, this companion is embedded into the Unity environment through API-based connections with the GPT service. User queries are entered via a text interface, processed on the server side, and then returned as dynamic responses displayed as on-screen dialogue bubbles linked to the avatar. This implementation allows the companion to provide context-aware answers by maintaining the session history within each exploration, thereby supporting adaptive and personalized interactions during the campus tour.



FIGURE XV. AI COMPANION IN THE FORM OF A “LITTLE FLYING ROBOT” SERVING AS A GPT-POWERED VIRTUAL ASSISTANT

Implementing the AI Companion introduces an interactive layer to the Metaverse-based campus tour by providing personalized and context-aware dialogue. Previous studies have emphasized the crucial role of GPT models in enabling intelligent services for the Metaverse, including natural conversations, narrative generation, and immersive user–avatar interactions [61]. Their strong in-context learning capabilities also demonstrate the ability to deliver adaptive and context-aware responses that enhance personalization and engagement. Similar studies by Sun et al. [62] demonstrate how AI agents can act as storytellers by combining AI- and user-generated content. However, studies by Cao and Jian [63] indicate that embedding static and AI-driven virtual agents aligns with the interactive affordances framework in virtual learning environments, which emphasizes enabling users to actively seek, process, and apply relevant information.

Furthermore, integrating AI Companions in Metaverse environments promotes authentic and engaging interactions that enhance comprehension and user satisfaction [64, 65]. The incorporation of interactive and conversational elements directly promotes student engagement and motivation, resulting in exploration that is both enjoyable and personalized to individual needs [66]. These findings underline the potential of combining GPT-driven companions with immersive platforms to create richer and more user-centered educational experiences.

G. Real-Time Communication and Social

The system incorporates chat and social interaction features to enhance collective virtual campus exploration. Real-time communication is supported through a text-based chat interface for verbal exchanges and an emote system for nonverbal expression. The chat interface is positioned at the bottom of the screen to minimize visual disruption during navigation. In addition, the emote feature is presented via a radial menu on the right side of the screen, enabling quick access to six predefined expressions: upset, sad, uncomfortable, agree, unsure, and happy. These expressions provide a channel for nonverbal communication, enriching interpersonal dynamics in the virtual environment.

This feature fully integrates into the multiplayer environment, enabling synchronous interaction between avatars during campus tours. Such interactions can simulate visiting the campus with peers which helps reinforce social connections and create a more engaging group experience. Previous studies demonstrate that shows that users respond to virtual representations of others in ways similar to real-life interactions, particularly when nonverbal cues are present [67]. Building on these insights, the system integrates text-based chat and expressive emotes to enrich communication and create more engaging shared experiences within the virtual campus.

H. Dynamic Time-Based Rendering

This system features a real-time environment to deliver a dynamic visual experience that mimics the real world. The system adapts to different times of day and moods through a Dynamic Day-Night Cycle and Time Progression Control in “Date and Time”. This feature is commonly referred to as a

Customizable Dynamic Time System, where the virtual world dynamically follows the changing time of day, giving users control to adjust the time of day to suit their exploration or demonstration needs. Users can experience campus tours in the morning, afternoon, evening, and night, either automatically or manually.

The feature extends beyond outdoor scenes to indoor spaces, where lighting conditions in lecture halls and laboratories adapt seamlessly to the selected time of day. Furthermore, the feature provides a realistic feel using dynamic lighting, sky color gradations, and ambient light intensity. This dynamic weather control system allows users to manually toggle between various weather conditions such as clear sky, cloudy sky, rain, fog, and snow (Figure XVI, Figure XVII).



FIGURE XVI. MORNING-TIME ENVIRONMENT SIMULATION WITH ADJUSTABLE SETTINGS

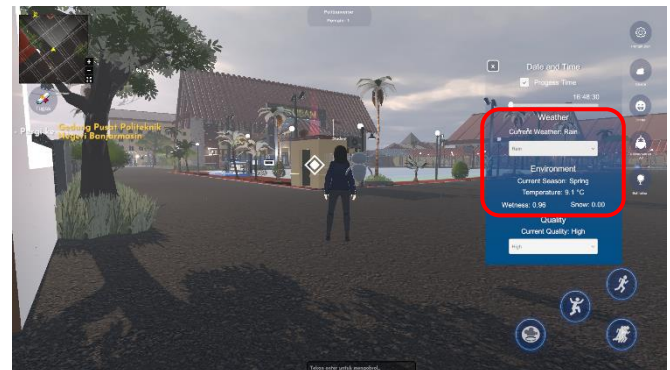


FIGURE XVII. RAIN WEATHER SIMULATION DEPICTING THE CAMPUS ENVIRONMENT DURING RAINFALL WITH DIMMED LIGHTING AND LIGHT RAIN VISUAL EFFECTS

This feature allows the environment to respond to changes in time and weather automatically and manually. In the morning and evening, the system displays bright lighting, blue skies, and sharp shadows. In the afternoon and evening, the lighting dims, the sky changes color, and the campus lights turn on automatically, creating a calmer and more reflective atmosphere. Previous studies have noted that dynamic lighting and environmental transitions enhance the sense of realism and influence how users evaluate comfort and immersion in digital environments [52, 68]. By embedding these temporal changes, the campus tour simulates a more authentic atmosphere, supporting user engagement and reinforcing the impression of experiencing campus life.

I. Gamification

The system integrates gamification features to increase user engagement and foster active exploration of the virtual campus. Users receive missions to explore campus buildings, earn points and rankings based on interactions (with NPCs, exploration, and mission completion), and gain achievement badges when completing tasks, as shown in Figure XVIII.

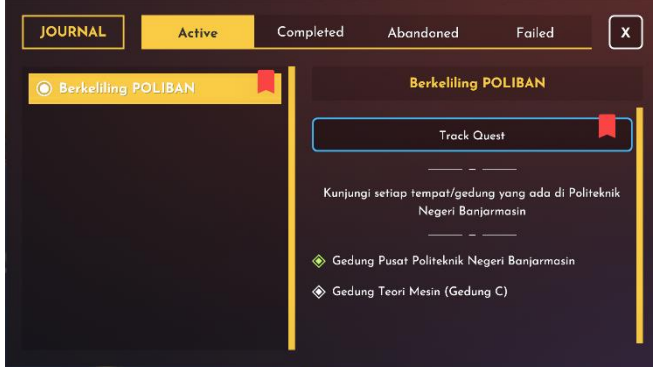


FIGURE XVIII. THE JOURNAL INTERFACE SHOWING THE ACTIVE MISSION

Progress persists across sessions and is displayed in profiles or leaderboards via a backend system. These mechanisms reflect core principles of game-based learning, where goal orientation, feedback, and rewards drive motivation. Prior studies consistently show that gamification elements such as points, badges, and leaderboards can enhance motivation, sustain participation, and deepen exploration in digital environments [69, 70]. By adapting these mechanisms to a Metaverse-based campus tour, the system transforms orientation activities into a more engaging and goal-driven experience, encouraging students to interact with the virtual environment more actively.

J. Metaverse-Based Campus Tour Validation

1. Descriptive Statistics

We report the descriptive statistics for the SUS and the NPS, including mean, standard deviation, median, interquartile range (IQR), and 95% confidence intervals, as presented in Table IV.

TABLE IV. DESCRIPTIVE STATISTICS SUS AND NPS

	Mean	SD	Median	IQR	95% CI	
					Lower bound	Upper bound
SUS	71.6	13.3	73.8	18.1	67.3	75.8
NPS	8.5	1.1	9.0	1.0	8.2	8.8

The SUS results showed a mean score of 71.6 (SD = 13.3), with a median of 73.8 and an interquartile range (IQR) of 18.1. The relatively high mean and median values indicate that most respondents perceived the system as easy to use. However, the considerable score spread, reflected in the standard deviation and IQR, suggests that user experiences were not entirely uniform, as shown in Figure XIX.

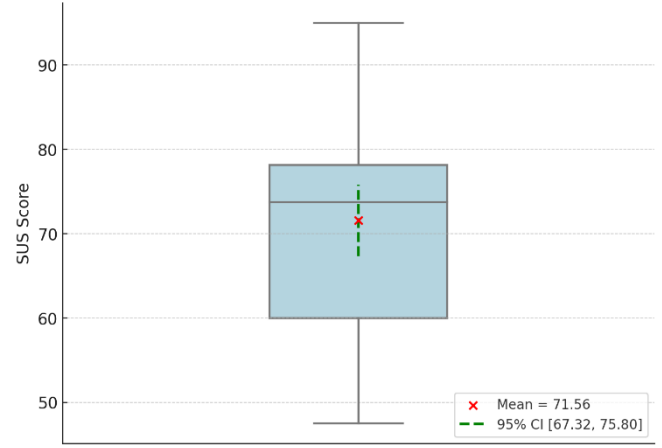


FIGURE XIX. SUS SCORE BOXPLOT WITH MEAN AND 95% CI

The 95% confidence interval (67.3-75.8) further supports that the average usability perception falls within a consistent range, indicating stable usability. Previous studies have emphasized the importance of reporting confidence intervals in usability testing to capture estimation precision and account for variability in user responses [71], [72], [73]. This significant variation warrants further analysis across user groups to assess whether their differences influence usability perceptions.

For the NPS, the mean score was 8.50 (SD = 1.06), with a median of 9.00 and an IQR of 1.00, as shown in Figure XX.

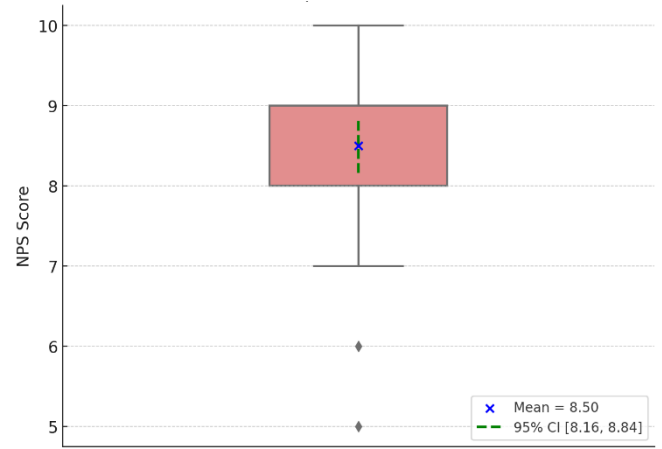


FIGURE XX. NPS SCORE BOXPLOT WITH MEAN AND 95% CI

These results indicate that responses were highly consistent, with most participants providing scores in the 8–9 range. The narrow 95% confidence interval (8.2–8.8) reflects limited variability in the data, reinforcing the consistency of respondents' willingness to recommend the system.

2. SUS

The SUS assesses system usability based on user perceptions. Scores are classified into value ranges that indicate grade, qualitative assessment (adjective rating), and acceptability level. This categorization adapts a widely used framework from [74] and [75] as shown in Table V.

TABLE V. SUS SCORE RANGES WITH CORRESPONDING GRADE, ADJECTIVE RATING, AND ACCEPTABILITY LEVEL

SUS Score (x) Range	Grade	Adjective Rating	Acceptability
$0 < x \leq 51.7$	F	Poor	Not Acceptable
$51.7 < x \leq 62.6$	D	Fair	Nearly Acceptable
$62.6 < x \leq 64.9$	C-	Good	
$64.9 < x \leq 71.0$	C		
$71.0 < x \leq 72.5$	C+	Excellent	Acceptable
$72.5 < x \leq 74.0$	B-		
$74.0 < x \leq 77.1$	B		
$77.1 < x \leq 78.8$	B+		
$78.8 < x \leq 80.7$	A-		
$80.7 < x \leq 84.0$	A	Best Imaginable	
$84.0 < x \leq 100$	A+		

We collected data ($n = 40$) using SUS questionnaires after exploring the Metaverse-based campus tour system. The analysis calculated the SUS score for each respondent based on the questionnaire results to provide an overall view of the systems usability. The analysis followed the standard procedure proposed by [75]. Table VI reports the SUS scores for all respondents.

TABLE VI. SUS SCORES FOR EACH RESPONDENT

Respondents	SUS		
	Odd	Even	Score
R1	18	13	77.5
R2	19	11	75.0
R3	16	15	77.5
R4	17	10	67.5
R5	12	9	52.5
R6	18	14	80.0
R7	8	11	47.5
R8	15	15	75.0
R9	15	13	70.0
R10	12	11	57.5
R11	16	14	75.0
R12	14	16	75.0
R13	14	12	65.0
R14	18	18	90.0
R15	14	10	60.0
R16	15	6	52.5
R17	14	8	55.0
R18	16	15	77.5
R19	16	12	70.0
R20	14	13	67.5
R21	12	7	47.5
R22	14	8	55.0
R23	15	9	60.0
R24	15	14	72.5
R25	17	15	80.0
R26	18	19	92.5
R27	18	19	92.5
R28	18	19	92.5
R29	18	16	85.0
R30	11	12	57.5
R31	16	15	77.5
R32	17	10	67.5
R33	15	15	75.0
R34	20	18	95.0
R35	20	17	92.5
R36	15	15	75.0
R37	16	13	72.5
R38	17	16	82.5
R39	13	8	52.5
R40	15	13	70.0
SUS Total Score (Average)			71.6
Grade			C+
Adjective Rating			Good
Acceptability			Acceptable

The usability evaluation yielded a SUS score of 71.56, which suggests that the system is generally usable and aligns with user expectations, although it does not reach an excellent level. The result indicates that the Metaverse-based campus tour fulfills essential usability requirements and provides a functional experience, but it does not reflect strong performance [39, 76]. Thus, while the platform can be considered acceptable for its intended purpose, further refinement is required to enhance user satisfaction and deliver a more seamless interaction experience.

The moderate score can be attributed to the diverse backgrounds of participants. Users with limited prior exposure to immersive technology and 3D navigation reported greater challenges in ease of use. In contrast, those with higher digital literacy and familiarity with virtual environments provided more favorable evaluations. This pattern aligns with the findings of Xi et al. [77], who emphasized the role of interface familiarity in improving usability ratings, and Lun et al. [78], who demonstrated that repeated interaction reduces the learning curve and enhances perceived usability in virtual environments.

However, these scores do not fully meet initial expectations for the innovation of the Metaverse-based campus tour. So, we analyzed SUS scores by respondent group. Studies by Al-kfairy et al. [79] indicate that usability perceptions can vary significantly across user groups with different backgrounds, experiences, and usage purposes. Segmenting SUS scores helps reveal assessment patterns that may be hidden in aggregate analysis. It also supports identifying targeted improvement priorities, as recommended in the user-centered design approach [80].

Given the relatively wide confidence interval observed in the overall SUS results, a group-based analysis was conducted to explore whether differences across user groups contributed to the variation in usability perceptions. Respondents were categorized into three user groups: prospective students ($n_1 = 5$), lecturers ($n_2 = 4$), and active students ($n_3 = 31$). Table VII summarizes the SUS scores for each respondent and the average score per category.

The results show that prospective students scored an average of 70.0, lecturers 68.1, and active students 72.3. Although all groups fall within the “Good” rating, the acceptability ranges from “Nearly Acceptable” to “Acceptable,” suggesting that users with different backgrounds may perceive the system somewhat differently. The active student group obtained the highest score, indicating that the system was perceived as practical and easy to use. This reflects high satisfaction with usability, likely driven by their familiarity with digital platforms and repeated exposure to academic technology. Such experience reduces cognitive barriers, enhances navigation efficiency, and promotes effective feature use. This result is consistent with Mlekus et al. [81], who found that experienced users adapt more quickly and provide more stable usability ratings than less experienced users.

TABLE VII. SUS SCORES GROUPED BY RESPONDENT TYPE

Respondents		System Usability Scale				
		Score	Average	Grade	Rating	Acceptability
R1	Prospective Student	77.5	70,0	C	Good	Nearly Acceptable
R2		75.0				
R3		77.5				
R4		67.5				
R5		52.5				
R6	Lecturers	80.0	68,1	C	Good	Nearly Acceptable
R7		47.5				
R8		75.0				
R9		70.0				
R10		57.5				
R11	Active Students	75.0	72,3	C+	Good	Acceptable
R12		75.0				
R13		65.0				
R14		90.0				
R15		60.0				
R16		52.5				
R17		55.0				
R18		77.5				
R19		70.0				
R20		67.5				
R21		47.5				
R22		55.0				
R23		60.0				
R24		72.5				
R25		80.0				
R26		92.5				
R27		92.5				
R28		92.5				
R29		85.0				
R30		57.5				
R31		77.5				
R32		67.5				
R33		75.0				
R34		95.0				
R35		92.5				
R36		75.0				
R37		72.5				
R38		82.5				
R39		52.5				
R40		70.0				

The prospective student group achieved a mid-range score, suggesting that the system was generally usable but close to the lower boundary of acceptability. Three factors may explain this outcome: limited prior experience with the campus and its digital systems, the absence of onboarding support in navigating the 3D environment, and high expectations from first-time users regarding information completeness, visual quality, and ease of interaction [82], [83]. In addition, the lecturer group obtained the lowest SUS score among the three groups, at a level suggesting adequate usability but close to the lower boundary of acceptability. This outcome may reflect their higher expectations regarding relevance to teaching needs, completeness of academic content, and integration into learning activities. As experienced professional users, lecturers tend to apply stricter standards when assessing functionality, stability, and efficiency [7].

Meanwhile, previous studies suggest that SUS scores may differ systematically across contexts, reflecting variations in user group characteristics [84]. Furthermore, descriptive statistics were computed for each group to provide a clearer statistical picture of these variations, as presented in Table VIII.

TABLE VIII. DESCRIPTIVE STATISTICS BY USER GROUP

	SD	Median	IQR		Min	Max	95% CI for Mean	
			Q1	Q3			Lower bound	Upper bound
Prospective students	10.6	75.0	67.5	77.5	52.5	77.5	56.8	83.2
Lecturers	14.3	72.5	64.4	76.3	47.5	80.0	45.3	90.9
Active students	13.8	72.5	60.0	81.3	47.5	95.0	67.2	77.3

Table VIII provides the descriptive statistics of SUS scores across the three user groups. The first group is active students ($M = 72.3$, $SD = 13.8$, 95% CI [67.2, 77.3]) reported the highest usability perceptions, ranging from 47.5 to 95.0. Moreover, the second group is prospective students ($M = 70.0$, $SD = 10.6$, 95% CI [56.8, 83.2]) showed slightly lower average scores but a more concentrated distribution. The last group is lecturers ($M = 68.1$, $SD = 14.3$, 95% CI [45.3, 90.9]) obtained the lowest mean, accompanied by the broadest confidence interval due to their small sample size. The distribution SUS scores by group shown in Figure XXI.

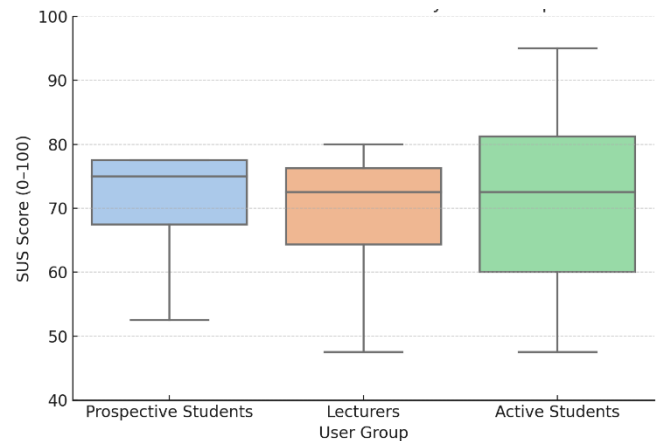


FIGURE XXI. DISTRIBUTION OF SUS SCORES BY USER GROUP

Despite these variations, the central tendency across all groups clustered around mean values ranging from 68 to 72, indicating a generally consistent perception of usability. The wider confidence intervals for prospective students and lecturers reflect their small sample sizes, indicating greater uncertainty and the need for cautious interpretation, as shown in Figure XXII.

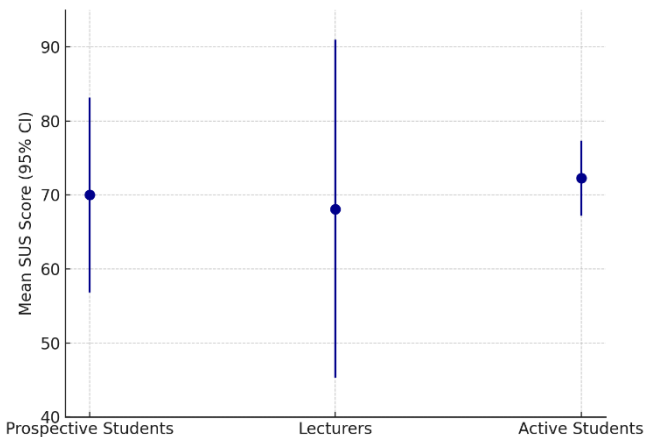


FIGURE XXII. MEAN SUS SCORES WITH 95% CI

Based on Figure XXII, while the group means are relatively close, the wider confidence interval among lecturers indicates greater variability in their responses. In contrast, the narrower confidence interval for active students reflects more consistent perceptions. Although these descriptive results suggest potential differences, statistical testing is required to determine whether the variations are significant. Studies by Sauro & Lewis [37] emphasize that inferential analyses and effect sizes are necessary to complement descriptive statistics in usability studies. Therefore, subgroup comparisons were conducted using Normality tests (Shapiro–Wilk), with effect sizes reported to quantify the differences between groups, as presented in Table IX.

TABLE IX. NORMALITY TESTS USING SHAPIRO-WILK

	n	Shapiro-Wilk p	Interpretation
Prospective students	5	0.088	Approx. normal
Lecturers	4	0.296	Approx. normal
Active students	31	0.181	Approx. normal

Based on Table IX, normality tests indicated no significant deviation from normality in any group. However, given the small sample sizes of lecturers ($n = 4$) and prospective students ($n = 5$), the results were considered unstable. Therefore, the Kruskal–Wallis test was applied for group comparison, which showed no statistically significant differences ($H = 0.19$, $p = .91$), with a negligible effect size ($\eta^2 \approx 0$). This finding indicates that the perceived usability of the system remained consistent with no statistically significant differences despite variations in mean scores across groups. However, Balzerkiewicz et al. [85] recommend integrating quantitative usability measures with qualitative methods to obtain more valid and contextually relevant insights in virtual system.

Furthermore, previous studies have shown that demographic factors significantly influence how users perceive and evaluate usability [86, 87, 88]. In this study, demographic information, open-ended responses, and short interviews provided richer contextual insights into participants' experiences. This approach ensured that the perceptions of smaller groups, such as lecturers and prospective students, were adequately represented despite the limited statistical power.

TABLE X. DEMOGRAPHIC COMPOSITION BY USER GROUP

Category	Prospective students	Lecturers	Active students
Age Range			
17 – 20	5 (100%)	0 (0%)	9 (29%)
21 – 25	0 (0%)	0 (0%)	22 (71%)
>25	0 (0%)	4 (100%)	0 (0%)
Gender			
Male	0 (0%)	3 (75%)	25 (80.6%)
Female	5 (100%)	1 (25%)	6 (19.4%)
Metaverse Experience			
Never	5 (100%)	0 (0%)	18 (58.1%)
Tried	0 (0%)	4 (100%)	11 (35.5%)
Frequent	0 (0%)	0 (0%)	2 (6.5%)

Table X shows that the demographic distribution showed clear contrasts across groups. Prospective students were all females (17–20 years) with no prior Metaverse experience, reflecting a homogeneous novice profile. Lecturers were exclusively older adults (>25 years), predominantly male, and had only trial-level exposure. Active students represented the

most diverse group, spanning age ranges (17–20 and 21–25), mixed genders, and varying levels of Metaverse familiarity, from never to frequent users. The demographic distribution by user group is shown in Figures XXIII–XXV.

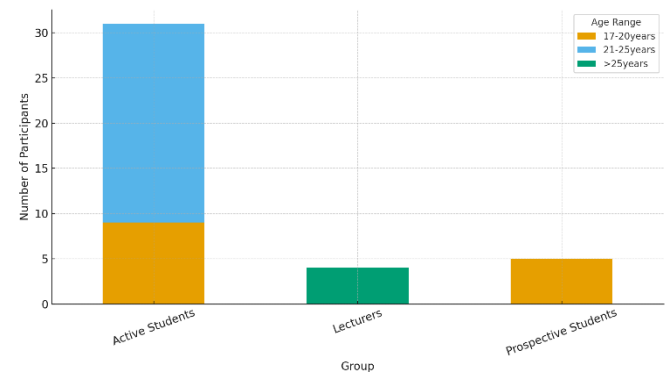


FIGURE XXIII. AGE DISTRIBUTION BY USER GROUP

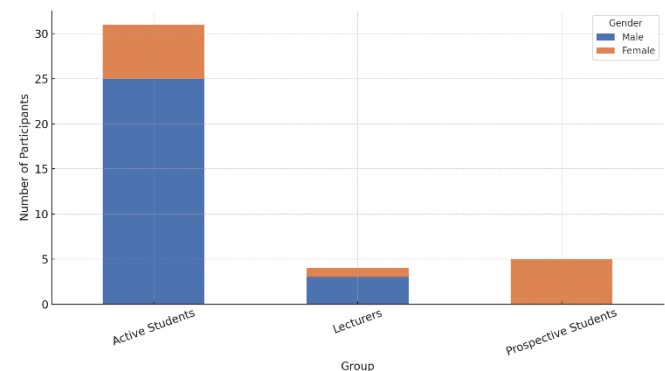


FIGURE XXIV. GENDER DISTRIBUTION BY USER GROUP

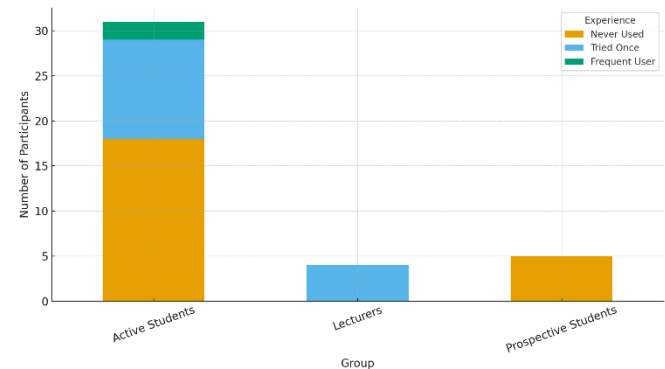


FIGURE XXV. METAVERSE EXPERIENCE BY USER GROUP

In this study, all five prospective students shared similar demographic characteristics: female, aged 17–20, and had no experience with Metaverse platforms. This homogeneity reported lower usability scores. This tendency is consistent with previous research showing that female participants consistently report lower usability scores when interacting with a technology for the first time [89, 90]. Moreover, female participants often emphasize ease of use and require greater clarity in interface design, making initial adoption experiences more challenging [91]. Meanwhile, first-time or novice users typically assign lower usability scores because they lack familiarity and self-efficacy, underscoring the decisive role of prior experience in shaping technology adoption and evaluation outcomes [92, 93]. These findings suggest that the

lower usability scores observed in this group may be partly attributed to gender-related differences in initial adoption behavior and their lack of prior exposure to Metaverse technologies.

The lecturer group obtained the lowest usability scores, a result that can be explained by several interrelated factors beyond the small sample size ($n=4$). Previous studies highlight the generational digital divide, in which older users often encounter greater challenges in adopting new technologies, particularly immersive environments [82], [94], [95]. This difficulty is compounded by the limited prior experience reported by all lecturers, as prior exposure is widely recognized as a strong predictor of perceived ease of use [92]. Furthermore, apparent differences in demographic composition across the three groups are illustrated by the alluvial plot, as shown in Figure XXVI.

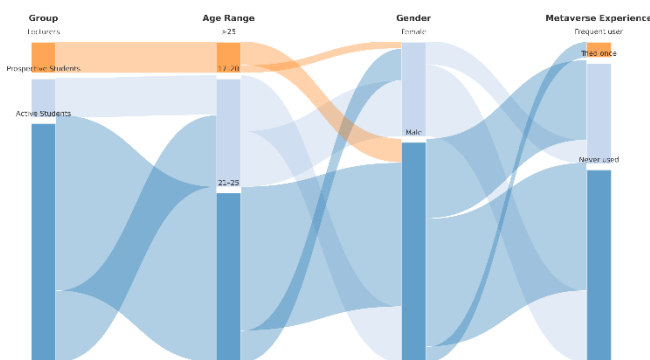


FIGURE XXVI. ALLUVIAL PLOT OF PARTICIPANT DEMOGRAPHICS

Figure XXVI presents the demographic composition across the three participant groups. Prospective students show a homogeneous profile, being exclusively young females with no prior Metaverse experience, which explains their lower and less varied usability scores. Lecturers, in contrast, are older, predominantly male, and report only limited exposure, leading to lower usability ratings. Active students represent the most diverse group, spanning age ranges, genders, and experience levels, providing a broader and more representative basis for usability evaluation. These demographic effects frame the usability outcomes and underscore the importance of complementary qualitative insights from open-ended responses and interviews.

In the open-ended questions, participants were asked, "Please describe any aspects of the system that you found helpful or challenging, along with suggestions for improvement." Thematic coding of their responses revealed recurring concerns as well as positive impressions across the groups, as shown in Table XI.

Prospective students emphasized the importance of onboarding support, with one participant noting, "There should be usage instructions at the beginning to make it easier." Consistent with their demographic profile, this concern reflects their novice status. Furthermore, some responses highlighted positive impressions of the platform's design, such as "The environment looks interesting and makes me curious to explore," indicating that visual engagement and

interactivity can sustain motivation once initial barriers are addressed. Lecturers, in contrast, reflected their older age profile and limited prior exposure by focusing more on questions of pedagogical value. One respondent explained, "I have not yet seen a direct benefit for teaching activities," underscoring the central role of perceived usefulness in shaping their evaluations. However, positive remarks, such as "It can be useful for introducing facilities to new students," suggest that while broader teaching applications remain unclear, the platform is promising for orientation and exposure purposes.

TABLE XI. THEMATIC FOCUS AND REPRESENTATIVE EVIDENCE FROM OPEN-ENDED USER FEEDBACK

	Dominant Focus	Evidence (translated)
Prospective Students	Visual appeal/Engagement	"The environment looks interesting and makes me curious to explore."
	Onboarding/Guidance	"There should be usage instructions at the beginning to make it easier."
Lecturers	Potential for orientation and exposure	"It can be useful for introducing facilities to new students."
	Usefulness/Relevance	"I have not yet seen a direct benefit for teaching activities."

Furthermore, interview results with prospective students reveal a consistent pattern with the demographic profiles, open-ended responses, and quantitative findings. The initial impression of the platform was largely positive, with participants describing it as "fun" and "enjoyable," although some also admitted feeling "confused" at the beginning. Differences in prior exposure to informatics at school further shaped perceptions, as those with relevant backgrounds reported adapting more quickly. Nearly all participants agreed that the system was "very helpful" for campus exploration, confirming its perceived usefulness for orientation purposes. They also noted that the system could serve as an engaging complement to traditional orientation, even though some suggested that offline activities remain necessary. However, the most frequently cited limitation was the absence of clear usage instructions, with participants explicitly stating, "We need guidance to understand more quickly," highlighting onboarding as the most critical factor for improving usability. Despite these challenges, several participants affirmed their willingness to reuse the system, for example, noting, "I would definitely use it again because it is fun and informative." Such reflections underline the high adoption potential, as participants showed strong interest in the system and are likely to achieve higher usability once they become more familiar with its features.

Interview results with lecturers provide further context for their low scores. Their impressions of the platform were positive, with participants describing it as "innovative for campus introduction" and "very useful because it is based on

technology." Strengths were noted in the visual design and the ability to help new users explore campus facilities. However, the most frequently mentioned limitation was the system's restricted functionality, with one lecturer stating, "We are already familiar with the real environment, so virtual exploration feels less relevant." These reflections suggest that lecturers evaluate the platform less on technical usability and more on its pedagogical value and personal relevance. As technology adoption models emphasize, perceived usefulness is central to acceptance [96]. Lecturers acknowledged the system's potential for student orientation but reported limited direct benefit for their teaching practice. This suggests that lecturers may indeed expect stronger links to pedagogical activities, which helps explain their lower usability ratings.

The multi-layered analysis provides a coherent explanation for the observed usability outcomes. The SUS scores revealed notable differences across groups, with prospective students and lecturers rating the system lower than active students. Demographic profiles helped contextualize these differences: prospective students formed a homogeneous group of young, first-time female users, while lecturers were older, predominantly male, and already familiar with the physical campus, both factors limiting their evaluations of the virtual alternative. In contrast, active students represented the most diverse group in age, gender, and prior experience, which was reflected in their higher and more varied scores, indicating broader adaptability and engagement. Open-ended responses clarified the sources of these perceptions, highlighting the importance of onboarding for novices and the relevance of pedagogical value for lecturers. Interview findings deepened these insights by illustrating how prospective students experienced initial confusion but retained strong interest and willingness to reuse the system, and how lecturers recognized its potential for orientation but questioned its integration into teaching.

3. NPS Testing

The NPS measures the extent to which users are willing to recommend a system to others. NPS scores are classified into Negative Sentiment, Good, and Exceptional. Each indicates the level of satisfaction and the potential for continued system use [33, 34, 97]. These categories are presented in Table XII.

TABLE XII. NPS RANGES

NPS Score (Y) Range	Category
$-100 \leq y < 0$	Negative Sentiment
$0 \leq y \leq 50$	Good
$51 \leq y \leq 100$	Exceptional

NPS scores are categorized into three main levels to indicate their willingness to recommend a system or application to others. The "Negative Sentiment" category indicates that most users are dissatisfied with the system or application. This condition reflects serious issues with usability, performance, and the features provided. The "Good" category indicates that users have a generally positive experience. The system or application functions well, but there is room for improvement to increase satisfaction and create stronger user loyalty. The "Exceptional" category describes a very positive user experience. Most users are satisfied and tend to recommend the system to others. This

value reflects the high quality of the user experience and the systems success in meeting or exceeding user expectations.

The NPS test involved all 40 respondents without user categorization, as the metric measures the general tendency to recommend the system to others. The NPS distribution presented in Figure XXVII.

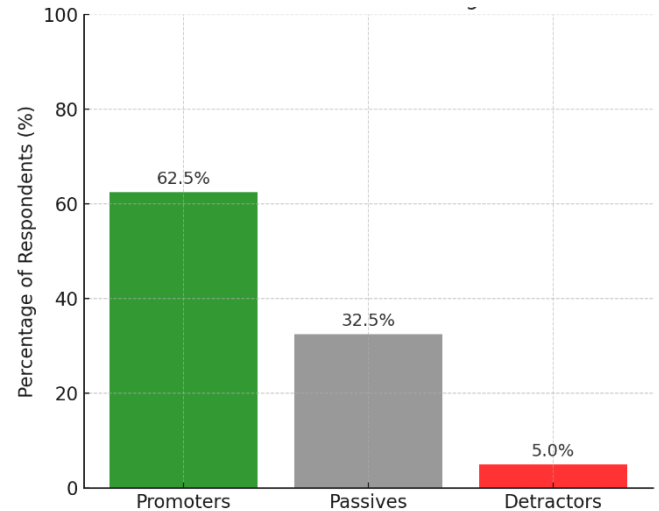


FIGURE XXVII. DISTRIBUTION OF NPS CATEGORIES

Figure XXVII shows that most participants were classified as promoters (62.5%), followed by passives (32.5%) and a small minority of detractors (5.0%). Furthermore, the results for the NPS score are presented in Table XIII.

TABLE XIII. NPS DISTRIBUTION

	Number	Score (%)
Promoters	25	62.5
Passives	13	32.5
Detractors	2	5.0
Total Respondent	40	100.0
Net Promoter Score		57.5

The score obtained was 57.5, which indicates a high level of loyalty and a strong tendency to recommend the system. This finding reflects broad user satisfaction with the Metaverse-based campus tour and signals strong adoption potential among new users. Beyond individual experiences, the result carries strategic significance for educational institutions seeking to enhance branding, expand promotional reach, and strengthen engagement with prospective students. According to Mecredy et al. [98], a high proportion of promoters can have a dual effect: driving organic promotion through digital word-of-mouth and reinforcing institutional credibility through stronger digital presence. Similarly, Agag et al. [99] note that high NPS scores are often positively correlated with sustained adoption rates and stronger brand perception in the public eye. In this context, Metaverse-based campus tours serve as a promotional medium and an interactive channel, creating immersive and emotional experiences that foster long-term engagement with the institution.

VI. INTEGRATED DISCUSSION

A. Systematic Development of the Metaverse-Based Campus Tour (RQ1)

The systematic design of the Metaverse-based campus tour can be understood across four phases: Discover, Blueprint, Develop, and Validate. The focus of each phase, the key contributions derived from the process, and their implications for educational metaverse design are presented in Table XIV.

TABLE XIV. PHASES, KEY CONTRIBUTIONS, AND IMPLICATIONS IN THE SYSTEMATIC DESIGN OF THE METAVERSE-BASED CAMPUS TOUR

Phase	Focus	Key Contributions	Implications for Educational Metaverse
Discover	Identification of transversal requirements through literature and gap analysis	Consolidated key features into a unified requirements framework.	Establishes a holistic foundation that ensures completeness of system features from the outset.
Blueprint	Translation of requirements into design artefacts (storyboards, avatars, 3D models)	Integrated narrative flow, avatar identity, and photorealistic modelling into a balanced design.	Aligns user interaction with institutional branding while maintaining usability and authenticity.
Develop	Implementation through Software-Defined Metaverse architecture [49]	Applied a layered architecture and integrated tools to ensure scalability, interactivity, and adaptability.	Provides a scalable and adaptive framework for real-time multi-user educational environments.
Validate	Empirical assessment of usability (SUS) and loyalty (NPS)	Combined standardized usability (SUS) and loyalty (NPS) metrics to evaluate user experience and adoption potential.	Confirms that systematic design leads to both functional usability and institutional promotional value.

The Discover phase establishes a comprehensive set of transversal requirements through a synthesis of insights from current Metaverse research. Feature selection is based on the needs of Metaverse-based campus tours and addresses gaps identified in previous studies. Consolidating these features into a unified framework ensures that the Metaverse-based campus tour system addresses both functional interactivity and aesthetic fidelity from the outset. This integration aligns with general Metaverse design principles and solidifies the foundation for developing a scalable, engaging, and educationally meaningful platform [100, 101, 102]. This approach emphasizes the Discover phase's role as a strategic synthesis, connecting user needs with emerging trends in Metaverse design. By positioning required features, this phase establishes a clear direction for subsequent design and development phases while ensuring their relevance to technological innovation and higher education practice.

The Blueprint phase translates the consolidated requirements into design artifacts that shape the structure and identity of the Metaverse-based campus tour. The three main

elements of this phase are storyboarding, avatar design, and 3D modeling. The storyboard outlines the narrative flow and sequence of interactions, providing a reality-based framework that maintains coherence between the user experience and the system's features. This phase is consistent with Metaverse design principles, where narrative structure guides immersion while facilitating intuitive exploration [103]. Avatar design is the primary interface between the user and the virtual environment. By integrating institutional symbols such as uniforms and logos, avatars serve as both a medium of interaction and a representation of institutional identity [45, 50, 51]. 3D modeling recreates the physical campus in detail, bringing authenticity and a sense of familiarity to the virtual space. This stage ensures an emotional connection between the user and the virtual environment and strengthening the attachment to the institutional identity that encourages deeper engagement in the Metaverse-based campus tour experience [47]. Furthermore, the integration of storyboard, avatar design, and 3D modelling operationalizes abstract requirements into concrete design artefacts, establishing the foundation for an immersive and user-centered Metaverse system that advances educational objectives and institutional goals.

The Develop phase implemented the design blueprint through a layered architecture that ensured coherence, scalability, and adaptability in the Metaverse-based campus tour. Adopting the SDM framework [49] was central in this process, as layered architectures provide a structured approach for integrating diverse technologies while maintaining stability and interoperability. This study's Application, Control, and Physical layers supported rendering, interaction, data management, and infrastructure. Emphasizing architecture at this stage was critical, since recent Metaverse design research highlights that sustainable platforms require modularity, synchronization, and persistence as foundational characteristics [101]. Equally important was the selection of development tools and services. Unity was the primary engine for photorealistic rendering and interactive features due to its flexibility and cross-platform deployment capabilities. GameCreator2 enabled navigation and interaction flow design through visual scripting, accelerating iteration while reducing coding complexity. Photon Engine provided real-time multiplayer synchronization, ensuring seamless collaborative exploration across users. LootLocker managed authentication and progress tracking, while ReadyPlayerMe supported inclusive avatar personalization. GPT-based dialogue modules enriched NPC interactions, extending user support with context-aware assistance. Each tool was chosen for its ability to address specific functional requirements identified in the Discover and Blueprint phases, ensuring that the final system achieved both technical robustness and user-centered adaptability. This phase combined architectural rigor with strategic tool selection, transforming abstract design artefacts into a synchronized and interactive system. The layered integration advanced beyond static prototypes by enabling real-time collaboration, adaptive features, and intelligent support, reinforcing the Metaverse-based campus tour's educational and institutional functions.

The Validate phase evaluated the Metaverse-based campus tour using usability and loyalty indicators, providing a comprehensive perspective on system performance. Usability is essential in Metaverse environments because ease of navigation, clarity of interaction, and integration of features directly influence immersion and learning effectiveness. The SUS was selected for its reliability and widespread adoption in evaluating interactive systems. It offers a standardized metric to assess user confidence and satisfaction across diverse participant groups [37]. Loyalty measured through the NPS complements usability by capturing users' willingness to recommend the platform to others. In the context of educational Metaverse applications, loyalty reflects satisfaction and the platform's potential to support institutional branding and sustainable adoption. Studies highlight that high loyalty scores correlate with long-term user engagement and positive word-of-mouth, critical for scaling Metaverse initiatives in higher education [104]. The validation framework ensured that the evaluation addressed functional quality and adoption potential. This dual perspective confirmed whether design choices translated into an intuitive experience while indicating the system's capacity to generate institutional value.

B. Interactive and Immersive Features Addressing Limitations of Existing Campus Tour Platforms (RQ2)

Previous campus tour platforms were primarily constrained to static visualizations or linear video presentations, which limited user interaction, reduced opportunities for exploration, and failed to simulate the social and experiential dimensions of campus life. This study demonstrates that integrating interactive and immersive features such as avatar customization, photorealistic environments, structured onboarding, multiplayer interaction, adaptive NPC guidance, dynamic rendering, and gamified exploration effectively addresses these limitations and establishes a holistic framework for engaging and institutionally meaningful campus tours in the Metaverse.

Avatar customization enables users to construct digital self-representations that strengthen presence and identity within the virtual campus. By allowing personalization and institutional branding, avatars foster inclusivity and emotional connection, directly addressing the impersonal nature of earlier platforms. The photorealistic 3D environment replicates real-world campus settings with high visual fidelity, bridging the experiential gap between virtual and physical spaces and enhancing perceptions of authenticity. In addition, a virtual home spawn point supports onboarding by providing a safe and controlled entry zone, reducing cognitive load during initial immersion and improving navigation readiness, a challenge insufficiently addressed in prior systems.

Multiplayer functionality and real-time communication tools transform campus exploration into a shared social experience. Unlike isolated single-user tours, these features enable synchronous interactions, collaborative exploration, and perceptions of co-presence, fostering community building and peer engagement. Virtual navigation controls and an integrated mini-map further allow users to explore the campus

freely and construct spatial knowledge, surpassing linear, pre-scripted navigation models and supporting active learning.

Contextual information delivery is achieved through NPCs and an AI-powered virtual companion, simulating authentic academic encounters and providing adaptive, personalized guidance. The introduction of dynamic environmental rendering includes day-night cycles and weather variations, enhancing realism and immersion while supporting more authentic perceptions of campus life. Gamification mechanisms missions, points, leaderboards, and achievements, encourage active participation and sustained engagement, transforming passive observation into goal-directed exploration.

The integration of nine features embodies the core design principles of educational Metaverse systems and aligns with evidence that presence, authenticity, social co-presence, and sustained engagement determine the effectiveness of virtual campus tours [105, 106, 107]. These interactive and immersive features form a holistic framework that directly addresses the fragmented approaches of previous virtual campus tours. The contribution of this system lies in its integration of personalization, social presence, contextual intelligence, and experiential realism within a single Metaverse platform. By filling these gaps, the developed Metaverse-based campus tour advances beyond traditional models and demonstrates how immersive features can provide engaging, scalable, and institutionally valuable experiences.

C. Reflections on Usability and Loyalty (RQ3)

The findings show that overall usability is favorable but with noticeable variation across users. Most participants perceived the system as easy to use, while a smaller group encountered challenges that introduced variability in their responses. Confidence intervals highlight both the precision of the estimates and the underlying spread in user experiences. When comparing groups, the central tendencies were similar, yet the consistency of responses differed. Active students expressed the most uniform perceptions, lecturers showed more dispersed views due to fewer respondents, and prospective students fell in between. Statistical testing confirmed these insignificant differences, suggesting that variations are modest in practical terms but offer valuable insights for refining future design priorities.

Familiarity and perceived relevance serve as key determinants of usability judgments. The group-level patterns align with theoretical expectations. With broader exposure to digital and Metaverse environments, active students adapted more quickly to 3D navigation and avatar controls, enhancing their perceived ease of use. This is consistent with evidence that interface familiarity increases confidence and efficiency in virtual settings [79, 80]. Prospective students, who were uniformly novice and all female, reported lower scores and emphasized onboarding needs. This mirrors findings that first-time use and lower self-efficacy reduce early usability ratings, and that clear guidance is essential for novices [89-93]. Lecturers emphasized perceived usefulness for pedagogy and content relevance; their lower ratings reflect stricter professional expectations and more limited prior exposure [84, 96, 97]. Qualitative feedback supports these mechanisms:

novices called for clearer first-run instructions, lecturers recognized the value for orientation but questioned direct teaching applications, and active students highlighted practicality and engagement.

Furthermore, user validation demonstrates a strong and consistent pattern of user loyalty. The loyalty profile reveals a community of highly supportive users, with enthusiasm concentrated among those willing to recommend the system actively. Only a small fraction expresses reservations, reinforcing the impression of broad acceptance and confidence in the platform. Such patterns suggest that the system has strong potential to generate positive momentum and build trust as part of institutional engagement strategies. In addition, this profile indicates substantial advocacy potential and a stable willingness to recommend the system. Prior studies link promoter-heavy patterns to stronger electronic word-of-mouth effects and more favorable brand perceptions in institutional technologies [100, 101].

The findings point to a virtuous loop: intuitive controls, smooth navigation, and visually coherent environments (based on SUS) elevate user satisfaction, strengthening the intention to recommend (based on NPS). Compared with the concentrated NPS pattern, the broader dispersion in SUS scores suggests that minor usability frictions do not substantially weaken loyalty. This resilience likely reflects the system's core value proposition: authentic campus exploration, social presence, and engagement, which resonates across user groups. Moreover, subgroup perspectives on usability highlight distinct pathways to loyalty:

- Prospective students (novices): loyalty depends on seamless onboarding and clear wayfinding.
- Lecturers: loyalty is shaped by pedagogical relevance and opportunities for integration.
- Active students: loyalty grows from everyday practicality and enjoyment.

The findings reveal several design implications that can strengthen usability and loyalty in future iterations of the Metaverse-based campus tour. First, onboarding for new users should include a short interactive tutorial, simple on-screen tips, and an optional guided "orientation mission" to help users get started smoothly. Second, flexible control options are useful, such as offering Beginner, Standard, and Advanced modes, with settings that make movement easier and more comfortable. Third, teaching support can be added through orientation kits for lecturers, including location markers, course-related information points, QR-linked handouts, and student visit data to strengthen educational use. Fourth, content priorities should focus on key facilities and program information, while ensuring that 3D assets load quickly so that new users do not face delays. Finally, a continuous feedback process should be maintained with quick in-app prompts ("Was this helpful?"), short surveys and brief interviews, following good practice in evaluating virtual systems. These implications highlight actionable strategies to close the usability gaps identified in subgroup reflections while reinforcing the system's strong loyalty outcomes.

VII. CONCLUSION

The study demonstrates that the Metaverse-based campus tour can be systematically developed through a four-phase Discover, Blueprint, Develop, and Validate framework. This structured process consolidated requirements into a coherent design, transformed them into concrete artifacts, and implemented them within a scalable layered architecture. The validation confirmed that the framework ensures functional usability while advancing institutional branding and outreach goals. The findings highlight the value of a replicable development model that connects emerging Metaverse technologies with the practical needs of higher education.

The study confirms that integrating nine interactive and immersive features, including avatar customization, photorealistic environments, onboarding mechanisms, multiplayer interaction, adaptive NPC guidance, dynamic rendering, and gamified exploration, effectively addresses the limitations of earlier virtual campus tours. These features collectively enhance presence, authenticity, and social engagement, transforming campus exploration from a static and fragmented experience into a holistic and institutionally meaningful platform. The contribution demonstrates how an integrated design approach can deliver scalable, engaging, and contextually relevant Metaverse-based campus tours for higher education.

Users perceived the system as both usable and recommendable. While usability evaluations varied according to familiarity and role-specific expectations, loyalty remained consistently strong across all groups. Active students adapted more smoothly due to prior exposure to digital platforms, whereas prospective students and lecturers emphasized the need for clearer onboarding and pedagogical relevance. Furthermore, these findings indicate that the system delivers meaningful value despite minor usability gaps and demonstrates strong potential for long-term adoption for higher education.

VIII. LIMITATIONS AND FUTURE WORKS

While this study provides valuable insights into the systematic development and evaluation of a Metaverse-based campus tour, it also has several limitations. The most important issue is the imbalance in sample composition, with relatively few lecturers and prospective students compared to active students. Although subgroup analysis yielded useful insights, this imbalance constrains the generalizability of the findings. Future studies should, therefore, recruit larger and more balanced samples to strengthen external validity and capture the perspectives of underrepresented groups more reliably.

Device performance and evaluation setting also presented important limitations. All participants used the same institution-provided PC in a controlled laboratory environment, which ensured consistency but reduced ecological validity. The findings may not fully capture user experience on devices with lower specifications, smaller displays, or mobile platforms, where performance differences such as frame rate, latency, or graphical fidelity could influence usability perceptions. Accessibility considerations

were also not addressed, as the current system lacks features for users with visual, motor, or cognitive impairments. Furthermore, no measures were implemented to mitigate motion sickness, a common challenge in immersive environments that can limit comfort for some users. Future studies should broaden device testing, integrate accessibility and comfort features, and recruit participants with more diverse backgrounds to strengthen inclusivity and external validity.

Another limitation relates to the scope of the evaluation, which was confined to a single institutional context. While this design provided depth in understanding a particular case, it may limit transferability to other settings with different cultural, infrastructural, or pedagogical conditions. Cross-institutional studies are needed to compare implementations across universities or regions, revealing contextual variations in adoption, engagement, and institutional branding.

A further limitation concerns the current implementation of virtual agents. Static NPCs positioned at key campus locations provided predefined information, ensuring consistency but limiting adaptability. Simultaneously, a GPT-powered AI Companion was embedded to deliver context-aware, text-based responses, yet this functionality remains separate from embodied NPCs. Future research could build on this foundation by integrating AI-driven companions into NPC embodiments, enabling them to deliver personalized orientation, adaptive guidance, and domain-specific advising. Such dynamic agents could function not only as navigational aids but also as academic mentors, providing contextually relevant information about courses, curricula, and campus services. These enhancements would deepen immersion, strengthen pedagogical relevance, and create richer opportunities for engagement.

Finally, the evaluation followed a cross-sectional design, capturing user perceptions after initial exposure. Longitudinal studies are required to investigate how usability and loyalty evolve with repeated use and growing familiarity, especially given the learning curve inherent in immersive systems. Integrating subjective measures such as SUS and NPS with objective interaction data, including navigation patterns, error logs, and engagement time, would yield a more comprehensive understanding of how user experience translates into sustained adoption.

ACKNOWLEDGEMENT

The authors would like to thank the Informatics Engineering Study Program, Politeknik Negeri Banjarmasin, Indonesia, for their continuous support in providing facilities and technical resources during the development of this project. Special appreciation is also extended to Muhammad Rizki Murtadha and Ahmad Syafii, who contributed significantly to the system development stages. The authors also acknowledge all participants involved in the evaluation process for their valuable feedback and insights. Finally, appreciation is extended to the Directorate of Science and Technology Talent Development, Directorate General of Science and Technology, Ministry of Higher Education, Science, and Technology, Republic of Indonesia, for its mentoring program that contributed to the refinement of this research.

FUNDING

This research did not receive any outside funding or support. The authors report no involvement in the research by the sponsor that could have influenced the outcome of this work.

AUTHORS` CONTRIBUTIONS

All authors have participated in drafting the manuscript. All authors read and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

DATA AVAILABILITY

The data supporting the findings of this study are available upon request from the authors.

ETHICAL STATEMENT

The study complied with scientific research and publication ethics. Ethical approval was not required under the policies of Politeknik Negeri Banjarmasin, Indonesia, as it involved only voluntary and anonymous survey responses. Informed consent was obtained electronically, and participants were assured of confidentiality and the right to withdraw at any time.

DECLARATION OF AI USAGE

No AI tools were used in the creation of this manuscript. However, AI functionalities were employed within the Metaverse-based campus tour, specifically through the AI Companion to generate automatic responses to enhance interactive with user queries.

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