Virtual resurrection leveraging 3D modeling for digital preservation of an ancient educational institution

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Abstract

Nowadays, advanced 3D modeling software lets us see, explore and learn about historical sites like never before. Preserving our cultural heritage for future generations means documenting ancient sites accurately and enhancing user experience in virtual visits and education. This paper describes a method to digitally reconstruct and restore Nalanda University, a UNESCO World Heritage site. We collect data from historical records, old maps and photographs, then segregate the ruins based on their importance and features. We use Blender and Maya to create and optimize 3D models to get an accurate virtual representation of Nalanda. This digital model will give us valuable insights into the university's history and culture, a resource for researchers, historians and the public.

Keywords

3D Modeling, Texturing, Sculpting, History, Digital Models, Archaeology, photogrammetry

1. Introduction

Nalanda University was the center of excellence for scholarship and ancient wisdom, founded by Emperor Kumaragupta in the 5th century CE in India[1]. It flourished for almost 800 years and attracted thousands of teachers and students from faraway lands, remaining one of the very first residential universities in the world. The curriculum at the university was vast, while the emphasis on logic, debate, and systematic learning had been so practical that it came to shape the intellectual life of most of Asia. It was not only a center for studying Buddhism but also for many things—fine arts, medicine, mathematics, politics, and military science. Nalanda's golden era came to an end in the 12th century when a Turkish invader destroyed it and set the libraries on fire, resulting in irreplaceable loss of countless manuscripts[2]. The history and architectural importance of Nalanda reinforce the fact that the site must be preserved and recreated at all costs. 3D Modeling and simulation tools

VIPERC2024: 3rd International Conference on Visual Pattern Extraction and Recognition for Cultural Heritage Understanding, 1 September 2024

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today have become powerful tools for preserving cultural heritage sites[3]. For creating such virtual reconstructions, techniques such as photogrammetry and laser scanning have been extensively applied to significant effect in historical sites like Pompeii, Stonehenge, Petra, and Angkor Wat[4]. To achieve a total reconstruction of Nalanda University, we have to integrate various data sources, including historical texts, archaeological findings and academic documents. Advanced technological inputs are yet to find much applicability in most studies associated with Nalanda University[5], most of the inputs are primarily based on archaeological excavation findings and historical analysis. Many sources of data such as archaeological, historical texts and academic data needs to be integrated into the creation of Nalanda.

Digital reconstruction of Nalanda can offer insights into its historical and cultural description, becoming an invaluable source for researchers, historians, etc [6]. Digital models can meet academic purposes: they are always accessible, offering an interactive history of the culture of Nalanda with virtual tours. These models will also help in conservation through the highly detailed documentation that will be present to guide restoration work[6]. This makes a full, valid reconstruction of Nalanda University truly complex but vital through diverse data sources, from the texts of history to archaeology findings and modern technological inputs. The simulation of the influence of environmental factors on ancient constructions and their inevitable degradation, such as weathering and erosion[7], is also an essential tool in the formulation of preservation strategies. The preservation and reconstruction of Nalanda University is not a project on heritage conservation[8]; it's to respect a rich legacy of knowledge and culture. It is made possible that, using technologies such as 3D modeling and simulation, the saga of Nalanda is alive to be told by generations in the future to help posterity understand its glory and architectural splendor in the past[9].

2. Literature Review

Cultural heritage sites worldwide, including the one at Nalanda University, India, are an irreplaceable link to our past[10]. Preserving such sites is vital to the sustenance of cultural identity and the importance future generations will have in relating to and learning from our historical legacies. Significant breakthroughs in cultural heritage preservation have come about over the last few years through technological advancements, with 3D modeling and simulation taking the lead[11]. Most of the most significant adoption of photogrammetry has been in applying photography to measure physical objects for model building. It has had many applications, especially in the preservation of cultural heritage. In the past, researchers have been able to develop very detailed 3D models of historical sites based on photogrammetry, which enables high accuracy in documentation and virtual reconstruction[12]. A high-stakes application case is in Pompeii, the ancient Roman city buried by the eruption of Mount Vesuvius in AD 79. Photogrammetry has allowed researchers to obtain imagery of the ruins, which is processed to acquire accurate 3D models[13]. This helps study the layout of the site, its architecture, and any kind of artifacts without disturbing the physical site itself[14]. Although both photogrammetry and LiDAR provide a powerful tool for the preservation of cultural heritage, applying them to the case of Nalanda University is beset with the following challenges: the state of the existing ruins, environmental conditions, lack of historical documentation, and, last but not least, technical and logistical barriers[15]. All these require a concerted multidisciplinary approach by proper planning to make sure that the rich legacy of Nalanda is preserved for the generations ahead.

3. Methodology

3D modeling for the reconstruction of historical ruins is a multi-step process integrative of archaeology, history, computer science, and digital imaging. The following flowchart (Figure 1) presents an extensive methodology followed to recreate a detailed 3D model of the ruins of Nalanda University, which is not only a UNESCO World Heritage site but also one of the most important centers of learning in ancient India. Data collection, historical record-keeping, old maps, photographs, and textual descriptions create the base for the project. After the collection of data, segregation of various ruins is categorized based on the historical background, structural features, and the present condition of the ruins. This delivers a clear framework within which the modeling will be undertaken. Image Preprocessing is a very important stage where historical photographs are enhanced, their distortions corrected, and images aligned for consistency. This step is followed by Feature Extraction, whereby identification of the architectural details of columns, statues, intricate carvings, etc., is done in processed images and historical records. The next step is the generation of 3D models with the aid of specialized software from the preprocessed images and extracted features. Further, this model is fine-tuned with the help of Model Optimization, comprising noise reduction, enhancing the quality of mesh, and detailing finer details. The Final 3D Model is a rebuilt digital rendition of the ruins, so it is now ready for analysis, interpretation, or virtual exploration. This methodology can be useful in preserving historical information and can help researchers and historians measure the architectural and cultural importance of the site

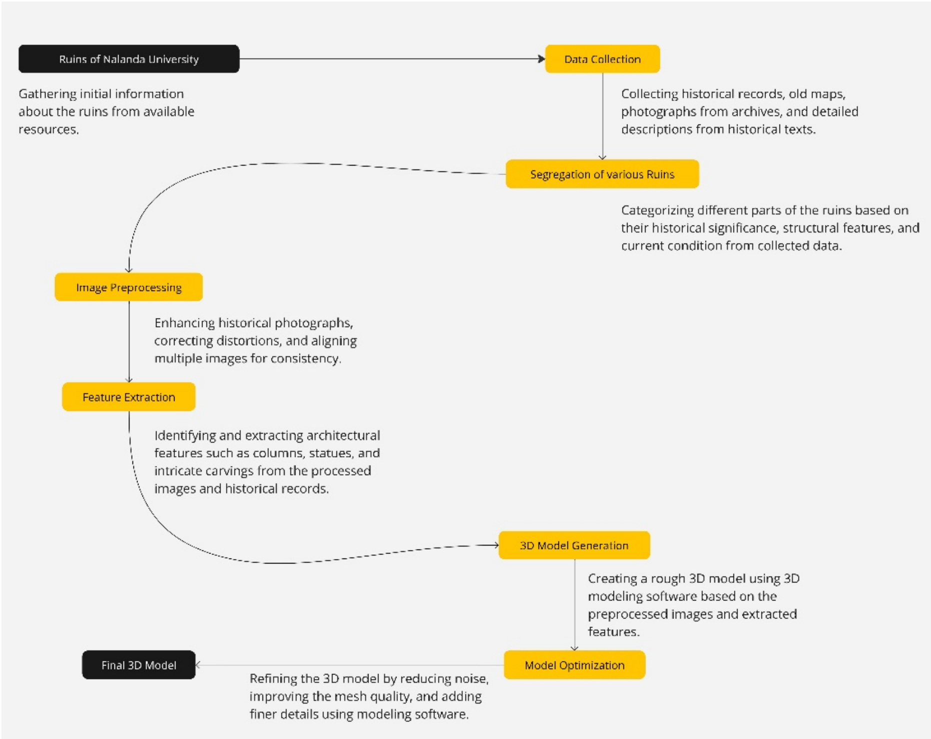

Figure 1: Workflow for 3D reconstruction

3.1. Data Collection

The 3D reconstruction of Nalanda University demands detailed data collection based on diverse historical, archaeological, and architectural resources to keep the 3D modeling and simulation authentic and accurate. Among the most significant sources for historical data, ancient texts, records, and manuscripts describe the form, architecture, and functioning of Nalanda University. Multiple remains of Nalanda University were found during the archaeological excavations carried out in the last century. Such finds represent the viharas, stupas, temples, and many other buildings, including their supporting and structural systems. Detailed reports of excavations, maps, and photographs are invaluable sources that establish the dimensions, layout, and various features related to the construction of ancient buildings. Architectural data is obtained by analyzing the existing structures and comparing them with contemporary buildings of the same period. Key points to measure for exact 3D model creation are the measurements of ruins in all details, including the height, width, and depth of walls, columns, and other architectural elements as illustrated in Figure 1.

3.2. Segregation of various Ruins

Rebuilding Nalanda University requires a careful way of separating out its different parts so as to get a precise idea of the layout and architectural features. This section describes the step-by-step process of classifying and examining the various parts of Nalanda, necessary for a full and accurate restoration. First, we identify and classify the ruins based on their architectural features, historical importance and spatial relationships. This classification is necessary to understand the different roles and purposes of the buildings in the university campus. The viharas which are living and meditation spaces for monks are identified by their layout around a courtyard with rooms around the periphery and a central open space. The focal point of monastic life at Nalanda were these buildings which provided living and meditation spaces for the inhabitants. Characteristics of the viharas are central courtyards, entrance porches, inner cells and verandas. Some viharas may have additional floors which can be identified by the presence of stairs and stronger walls for added structural support. For Buddhist worship and ceremonies stupas and temples are religious buildings in Nalanda. Stupas with their dome shape holding relics and temples with statues and worship spaces played a big role in the spiritual aspect of the university. Stupas have rounded domes, circular foundations and intricate carvings whereas temples have sanctums, prayer rooms and elaborate entrances with sculpted decorations. The lecture halls and classrooms in Nalanda were important for teaching and discussions as they were designed as large spaces to hold many students. These spaces helped disseminate information using designs with large spaces and seating arrangements that allowed for easy viewing and good acoustics for large crowds.

3.3. Image Preprocessing & Feature Extraction

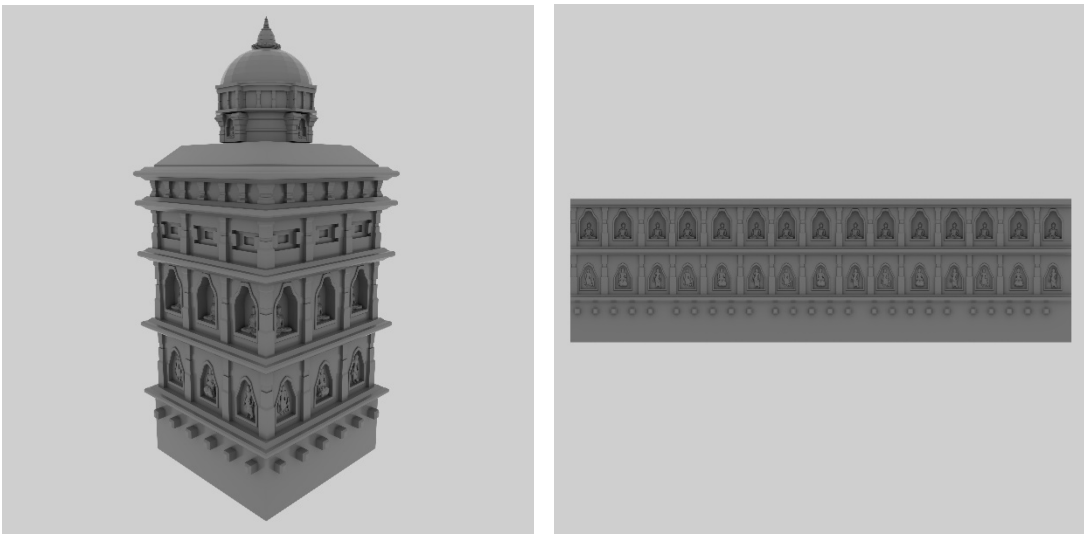

Figure 2 - 3: Model details created using feature extraction

In order to reconstruct Nalanda University in 3D, it is essential to ensure the visual information is precise and uniform. This includes a number of stages. Initially, we collect images from a variety of sources such as vintage photographs, contemporary digital images, and scanned papers. These photos offer important insights, as older ones give a peek into the past while modern high-quality images display the current condition of the artifacts as mentioned as seen in figure 2. We improve scanned historical maps and architectural plans to offer background information. Afterwards, we enhance the image appearance with methods such as reducing noise, adjusting contrast, and correcting colors. This guarantees that the images accurately depict the colors and textures of the original objects. After that, we merge the images together to form complete perspectives, utilizing feature detection methods such as SIFT (Scale-Invariant Feature Transform) or SURF (Speeded-Up Robust Features) to pinpoint important areas in the images that overlap. In the end, we adjust the images spatially and modify them to form smooth panoramas or composites which can help us to develop detailed models as seen in figure 3.

3.4. Software and Tools

The reconstruction of Nalanda University is carried out by some of the software tools available in the market to ensure the highest level of accuracy and detail. The primary tools we use are Blender, Maya, Substance Designer and Painter, Marmoset Tool bag and Unreal Engine 5.3.

3.5. Model Generation and Optimization

To generate the 3D model of Nalanda University, we start by drafting a block-out in Maya based on historical and archaeological data observed by Xuanzang and Yijing as seen in figure 4, Figure 5. This helps us to identify and mark critical structures like monasteries, stupas, and temples. With the initial layout in place, we start by creating basic blockout of each structure such as pillars, sculptures, etc. Then we proceed to create detailed models of each structure, ensuring high precision to maintain historical accuracy. Each structure's geometry is meticulously created with fine details. Following the modeling, we move on to the texturing phase. Using historical references, we develop textures and materials for each model to replicate the original appearance. Once the textures and materials are created, we apply them to the models and all the individual building models are combined into a single cohesive model, aligning them correctly relative to one another based on the historical and architectural data.

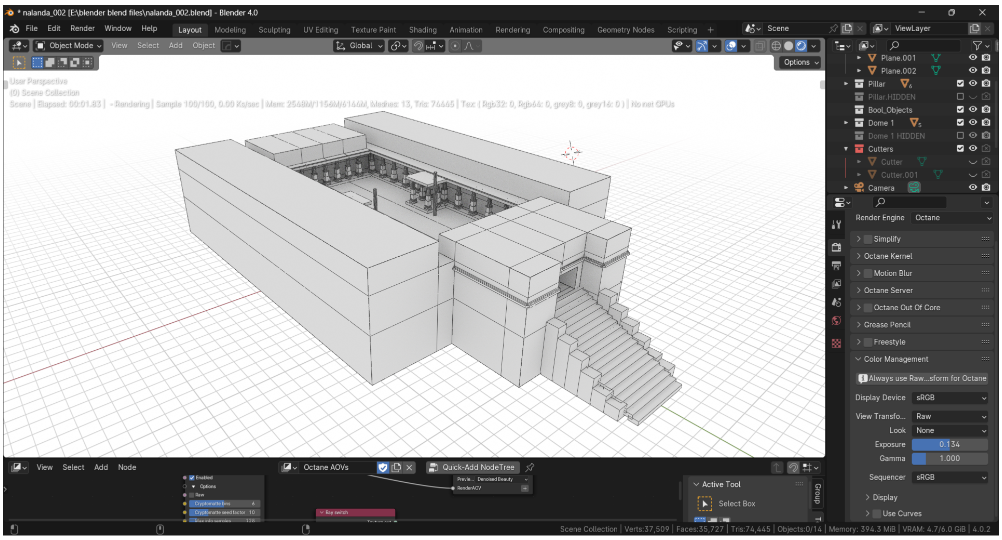

Figure 4: Early Blockout of Monastery - Nalanda University

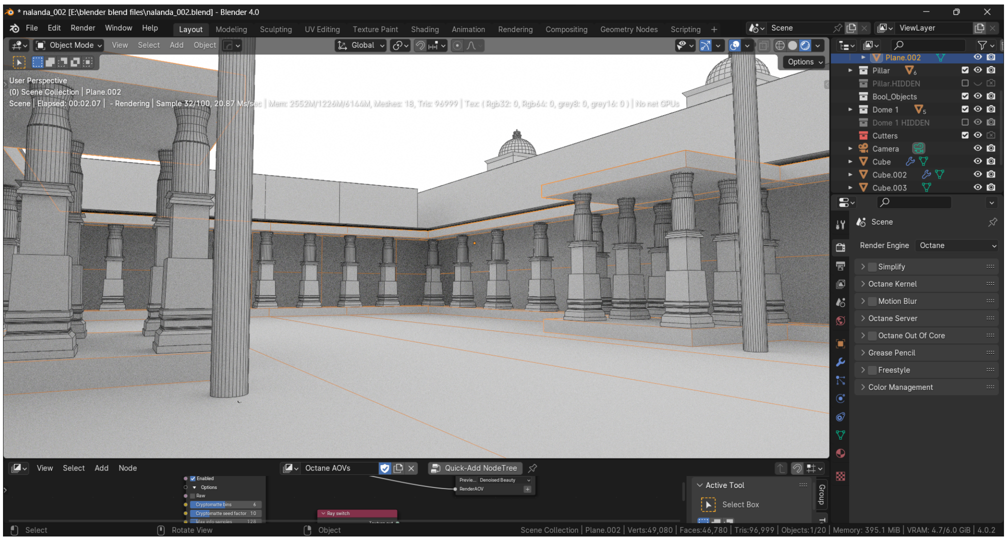

Figure 5: Initial block out of the Monastery - Nalanda University

3.6. Validation

Once the 3D model is completed, the next crucial step is validation to ensure it aligns accurately with historical data. This involves comparison of our reconstructed model with historical descriptions and archaeological findings. By doing this, we verify the model's accuracy and reliability, ensuring it represents the original structures. We check every aspect of the model and cross-reference it with historical records and archaeological reports. Any discrepancies found are carefully analyzed and corrected. This iterative process of comparison and refinement helps us to enhance the model's accuracy further. By continuously refining the models, we ensure that they not only look historically accurate but also maintain the integrity of the original architectural designs. This thorough validation process is essential for creating a reliable and accurate representation of Nalanda University.

4. Implementation

The development of the 3D model of Nalanda University is a multistage process. We take data from different sources and use modern software tools to make a precise, detailed picture of the ancient site. The first plan is developed by superimposing the information from the historical text and archaeological discovery in the initial layout. Important structures, like monasteries, stupas, temples, and lecture halls, are located, and their placements are made per the historical maps and reports of excavations as seen in Figure 6. A base map of the site was created, which outlined the site's boundaries and gave relationships between the different structures. Each structure is modeled in detail using Blender or Maya based on its complexity. Basic geometries are created for walls, columns, roofs, and floors. Historical references guide the dimensions and proportions to ensure accuracy. Elements of architecture, like windows, doors, and decorative features, are also created. These elements are modeled according to descriptions in historical texts and findings from archaeological excavations. We design the textures and Materials by using Adobe Substance Designer and Painter. Textures are created to appear as bricks and mortar within the actual construction. It plays a crucial role in making it look photorealistic and is highly important for valid simulation results. Individual models of different structures are integrated into a coherent whole using Maya. This integration assures proper alignment with spatial relationships between the buildings that tend to give a unified visualization of Nalanda University.

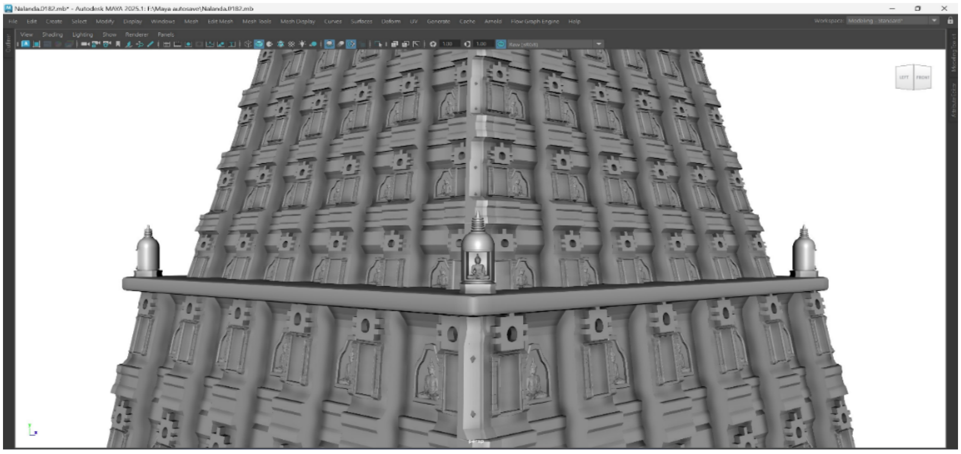

Figure 6: Intricate architecture of Buddhist Pagoda - Nalanda University

5. Results

5.1. 3D Model overview

A detailed 3D model of Nalanda University will be able to restore the ancient site in its entirety as seen in Figure 7, Figure 8. Modelled according to historical and archaeological data, these essential buildings include monasteries, stupas (dome-shaped structures that contain holy relics of the Buddha), temples and lecture halls. The Monastery is reconstructed complete with detailed architectural features, which include courtyards. accommodations and Meditation Halls. A detailed diagram of the brickwork and layout as purported in historical texts. Replicas of stupas and temples, having unique shapes and decorations, are restored very accurately. These findings were mapped with the help of archaeologists and historical records-guided placement & alignment. Lecture halls are designed in buildings to account for the fact that they serve educational purposes, and accommodate a fair number of students at one time.

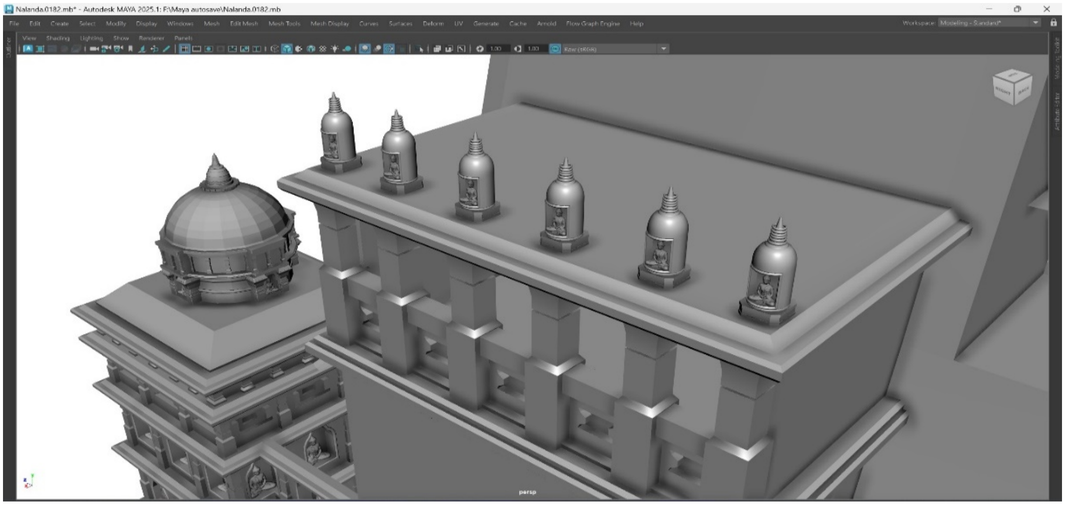

Figure 7: Semi Detailed Model of Nalanda University

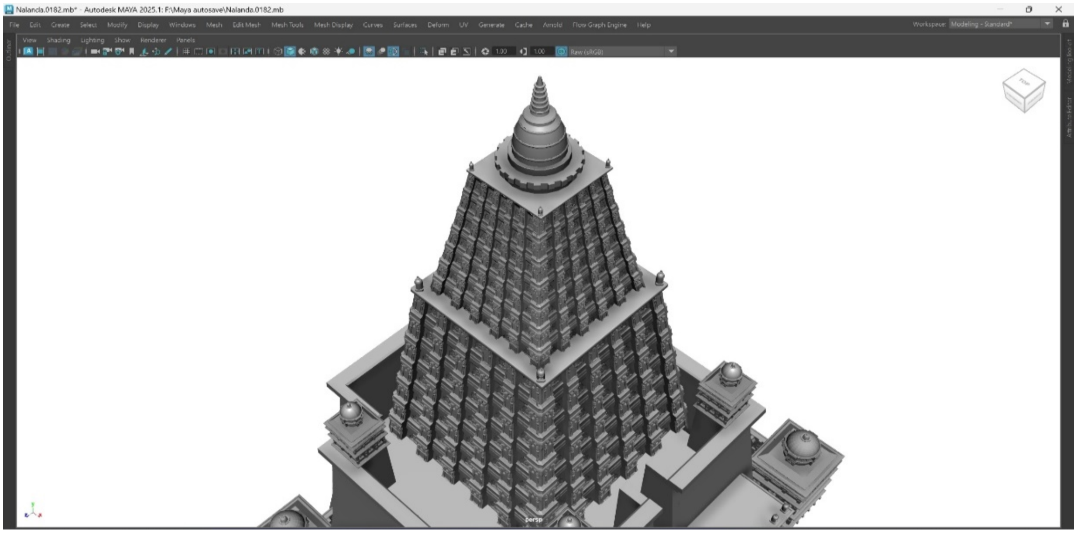

Figure 8: Aerial view of Nalanda University

5.2. Validation Results

The validation process involved a thorough comparison with historical records, expert reviews, and benchmarking against established standards. This rigorous process confirmed the model's accuracy and reliability, ensuring it faithfully represents Nalanda University. The dimensions, layout, and architectural elements of the reconstructed structures closely align with descriptions from historical texts, including those by Xuanzang and Yijing. Resources from the Archaeological Survey of India (ASI) were used to cross-verify the spatial relationships and details of the buildings.

5.3. Comparison with previous case studies

To highlight the significance of this, we compare it with two previous cultural heritage reconstruction projects: The Roman Forum and the ancient city of Pompeii.

5.3.1. The Roman Forum

The digital reconstruction of the Roman Forum, a central architectural and cultural site in ancient Rome, employed similar 3D modeling techniques. The Roman Forum project focused on a single central area, whereas the Nalanda University reconstruction encompasses a broader and more diverse set of structures, reflecting a complex educational institution. Both projects successfully integrated historical texts and archaeological findings. The Roman Forum model has been widely used for educational and tourism purposes, indicating similar potential for the Nalanda model.

5.3.2. The Ancient City of Pompeii

The virtual recreation of Pompeii aimed to preserve and present the city as it existed before it was destroyed. Both projects achieved high levels of detail and accuracy. The Pompeii model focused on residential and public buildings, while the Nalanda model emphasizes educational and religious structures. The Pompeii project utilized advanced technologies like virtual reality (VR) for immersive experiences, which could be a future development area for the Nalanda model. The Pompeii model has significantly contributed to the preservation and understanding of the site, mirroring the anticipated impact of the Nalanda reconstruction on cultural heritage preservation.

5.4. Cultural Heritage Preservation

The successful reconstruction of Nalanda University has several critical implications for cultural heritage preservation. The 3D model is a valuable educational tool, offering insights into ancient Indian architecture and educational practices. The reconstruction aids in preserving Nalanda University's heritage, providing a digital record for future research and conservation efforts. This study demonstrates the effectiveness of modern 3D modeling and simulation techniques in cultural heritage preservation, setting a precedent for similar projects.

6. Conclusion

Nalanda University’s digital reconstruction is a giant leap in preserving heritage. We’ve used 3D modeling and simulation tools to create a detailed and accurate version of this historic site so that it can be passed on to future generations. This project shows the importance of a multi-disciplinary approach – historical, archaeological and technological. The 3D model will support academic research and education and will engage the public through virtual tours and interactive experiences. This is the new benchmark for all future heritage projects – digital technology can transform and celebrate our shared history.

Acknowledgements

The authors would like to express their gratitude to SERB-INAE Online and Digital Gaming Research Initiative, New Delhi, India, for the funding provided to carry out the research work sanctioned under the Immersive Game Prototypes, with a focus on Indian Culture & Values via sanction order no. (2023/DGRI/Cat-2/05) to Karpagam Academy of Higher Education, Coimbatore, India.

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