LiDAR Scanner and Virtual Reality: A Post-Processing of Scanned Physical Objects to Create 3D Immersive Virtual Environments

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Abstract. Nowadays, there has been significant development of virtual reality (VR) as a medium for visualizing information and enhancing user experiences. Virtual reality involves the creation of three-dimensional visual representations through computergenerated simulations of real-world objects. With the specific VR equipment, users are immersed in the immersive virtual environments, allowing them to feel a direct and physical connection with the simulated surroundings. Although, there is a potential way to produce a 3D immersive virtual environment by using LiDAR Scans approach. This technique allows to scan a large-scale of physical object into a 3D representation model. Thus, the raw scanned data have to be processed in post-processing mode to produce a proper asset for 3D immersive virtual environment. This study aimed to review the post-processing workflow to produce a LiDAR-based 3D virtual environment by making use of image analysis tools and visualization software.

Keywords: Virtual Reality, LiDAR, Immersive.

1 Introduction

In recent years, virtual reality (VR) has grown rapidly as a medium to visualize information in terms of user experience. In general, virtual reality is a visualization of three-dimensional images, made by a computer to perform realistic image simulation from real-world objects with certain equipment, which makes the user feel as if they are directly physically involved with the environment [1]. Therefore, users can perceive the physical environment around them, along with virtual elements that are displayed simultaneously through advanced VR systems such as Oculus Rift, HTC Vive, and PlayStation VR. The implementation of virtual reality can be found in various areas, such as engineering, education, science, even games and entertainment. Technically, the virtual objects that will be displayed in the VR systems are designed by 3D modeling. This is necessary to display images that are realistically close to realworld objects in detail, especially in designing immersive virtual reality environments (IVREs).

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Immersive virtual reality environments (IVREs) are a representative artificial environment model that replaces users' real-world surroundings. Moreover, besides the basic ability to

visualize space in 3D, virtual environments are characterized by the component of immersion, which considerably intensifies the visual communication of spatial information. Thus, immersive spatial representations allow people to perceive virtual space in a way that is more similar to the perception of real-world space. Visual and auditory spatial information can be perceived from a 'close-to-natural perspective' [2]. Typically, user engagement will vary accordingly on individual differences. Meanwhile, the 3D assets design for an immersive virtual environment has basic requirements, firstly the system can display 3D objects as complete and realistic as possible, and secondly, the system can respond to several user actions interactively.

In order to obtain a complete and realistic result of virtual reality environment design, technological advancements have made it possible to create a large scale of 3D objects in a simplified manner, with the LiDAR Scanning procedure. LiDAR refers to Light Detection and Ranging, which is a distant sensing technology that emits sharp, focused beams of light, and measures the time it takes for the reflection to be detected by the sensor, and it is used to examine the surface of the earth [3]. This scanning procedure can be done by utilizing UAV Lidar Sensor with close-range scanning or even long-range scanning methods. Although, LiDAR scanning procedures can simplify the complex modeling process to generate high-polly 3D objects, as well as load several supporting data such as textures and surface contours. Yet this technique is not commonly used in Indonesia, so that is needed to study virtual reality production based on LiDAR Scans post-processing techniques, especially to create immersive virtual environment.

Moreover, the scanned data will be transformed into a point cloud which is composed of connected dots to construct the details and dimensions of the scanned object. The resulting data have to be processed by the post-processing stage, using several 3D software, as well as a game engine to generate point cloud data into a final reproduction of 3D artwork. The application of LiDAR Scanning has the benefit to simplifies the modeling process, including performing 3D modeling production of an environmental character or scene, with accurate visual results and able to achieve hyper-realistic effects on the final results of digital compositions through visual effects. Therefore, LiDAR scanning can be applied in various fields, such as engineering, architecture, and science. Also, it has the possibility to be applied in the visual design area.

2 Three types of Virtual Reality

There are 3 major components of VR systems categories. These components are nonimmersive VR Systems, Semi-Immersive VR Systems, and Fully-Immersive VR Systems [4]. This classification defines a VR system that requires a 3D immersive virtual environments (IVREs) design. Among others are:

- ∞ Non-Immersive VR system: This type called Desktop VR system. Non-immersive VR requires an extended medium to display visual elements through a tv or screen-based monitor. It allows the user to stay aware and keep control of their physical environment. A daily life example of this type can be found in a video game or interactive media with a desktop computer.

- Semi-Immersive VR Systems: This system allows the user partially participated in a virtual environment to perceive being in a different reality when they concentrate on the digital imagery. However, users also remain connected to their physical surroundings. Semi-immersive technology achieves realism by utilizing 3D graphics, also referred to as virtual reality depth, and the level of immersion is enhanced with more intricate graphics. This type of VR is frequently applied for educational, sports, or training purposes and relies on high-resolution displays, high-end computers, projectors, or realistic simulators that partially replicate the design and functionality of real-world mechanisms.
- Fully-Immersive VR Systems: These simulations offer a highly authentic simulation experience with visual and auditory elements. In order to engage with and interact within a fully immersive virtual environment, users require a proper virtual reality equipment such as glasses or a head-mounted display (HMD). Virtual reality headsets deliver visually detailed contents with a wide field of view. The visual display is typically divided between the user's eyes, creating a stereoscopic 3D effect, and combines with input tracking to establish a captivating and realistic experience.

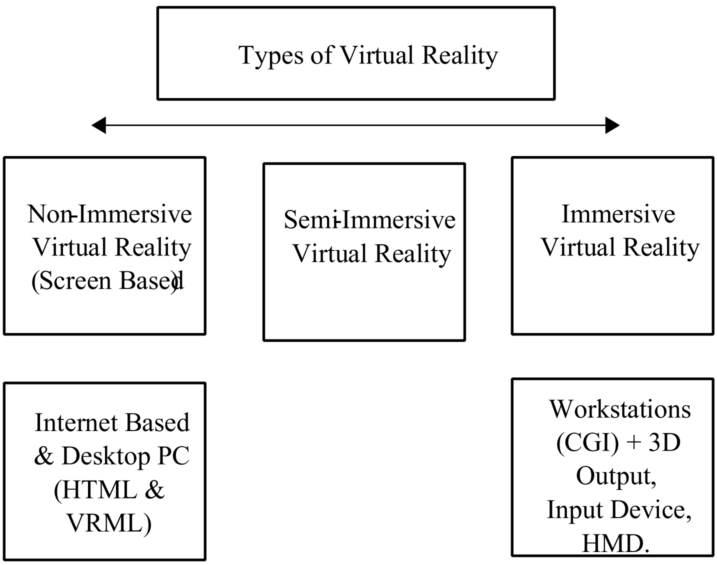

Fig. 1. Three types of Virtual Reality.

2.1 The Components of Immersive Virtual Environment

Visual perception: It has significant advantages over conventional 3D displays generated by desktop computers. The virtual elements provide a perceptual experience to users as if they are directly in a large-scale environment such as in a large room, building, and open outdoor space. The displayed elements are purposed as a stimulation to the user, so that they can feel the sense of being surrounded by virtual elements around them [5]. This is a type of digital simulation where real object elements are packaged into virtual form and displayed continuously through HMD. However, there is a weakness that significantly affects the user's perception of close-up object visualization. This weakness occurs because the virtual elements that are displayed have a fixed distance, so it affects the user's natural viewing conditions which is called the accommodative distance. This is a condition where human vision finds it difficult to maintain a focus point when dealing with objects that are so close to the human eye, while the object is placed based on distance perception which is simulated into a distance comparison scale in virtual space.

Spatial cognition: Spatial cognition is a part of cognitive psychology that studies how people acquire and use knowledge about their environment to determine where they are, how to obtain resources, and how to find their way home [6]. The attractiveness of Virtual Environment Technology (VET) largely lies in its ability to easily create intricate environments for participants to explore. It is widely acknowledged that spatial navigation relies on two distinct processes: piloting and path integration. Piloting involves determining one's position by using environmental cues, such as landmarks. On the other hand, path integration entails continuously updating estimated current position by integrating self-motion information. Therefore, a potential approach to comprehending human navigation ability involves initially examining the functional characteristics of the two processes separately and subsequently investigating them together.

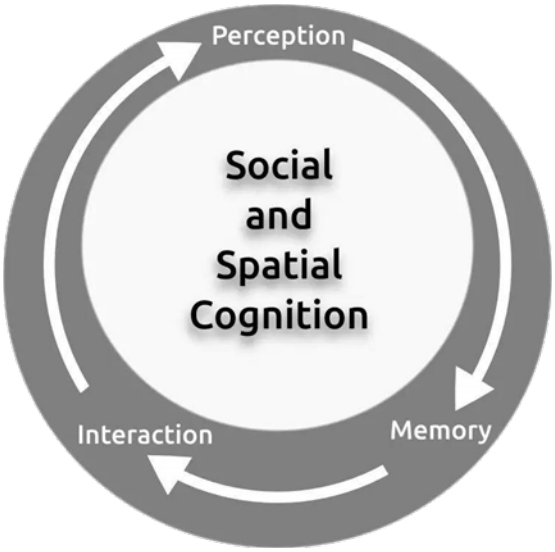

Fig. 2. Waller & Nadel., Spatial cognition cycles.

For instance, in order to investigate path integration relying on visual input, an IVREs can be employed to provide accurate optic flow information for perceiving self-motion, while simultaneously eliminating any environmental cues regarding position. A previous study was conducted to assess participants' capability to navigate back to a target location indicated by multiple visible landmarks. To disrupt any reliance on path integration through physical walking, the virtual environment was systematically rotated and conducted relative to the physical direction in each trial, rendering any estimation of the current location ineffective. Similar research examining self-localization utilizing landmarks has been conducted using desktop Virtual Environments (VEs).

Social Interaction: Immersive Virtual Reality Environments (IVREs) technology has demonstrated its value in perception and spatial cognition research, its methodological potential extends to other realms of psychology and behavioral science, including the intricate domain of social behavior. Experimental social psychologists and researchers explore social interactions through various means, often utilizing one of two techniques to develop interaction scenarios. The most common approach involves using a genuine participant alongside a non-simulated individual user. In such cases, the presence of other interactants is typically simulated through verbal or written information via human actors.

IVREs technology presents a convincing solution to the challenges of simulating others using conventional techniques. It enhances the experimental realism of manipulations by offering more powerful and impactful interventions compared to methods such as vignettes, audio recordings, or videotapes. By immersing participants in immersive virtual worlds through IVREs technology, researchers gain precise control over the behaviors and appearances of simulated individuals. For example, using Virtual Environment Technology (VET), studies on interpersonal attraction can be conducted, incorporating a diverse range of lifelike simulated individuals varying in characteristics that are hypothesized to influence the attraction of various users.

2.2 LiDAR Scanning and Post-Processing Overview

Light Detection and Ranging or LiDAR is a method that uses laser pulses to measure distances and create detailed height map of the scanned environment. It is commonly used in various fields such as remote sensing, autonomous vehicles, geospatial research, and archaeology [7]. The process begins with a LiDAR scanner emitting rapid laser pulses toward the target surface. These pulses bounce back when they encounter objects, and the sensor records the time it takes for the pulses to return. By multiplying this time by the speed of the traveling pulse, the distance between the scanner and the object can be calculated. The scanner collects millions of data by distance measurements, resulting in a large set of 3D coordinates in the form of a point cloud. Each point represents a specific location in space and carries information about the distance to the object.

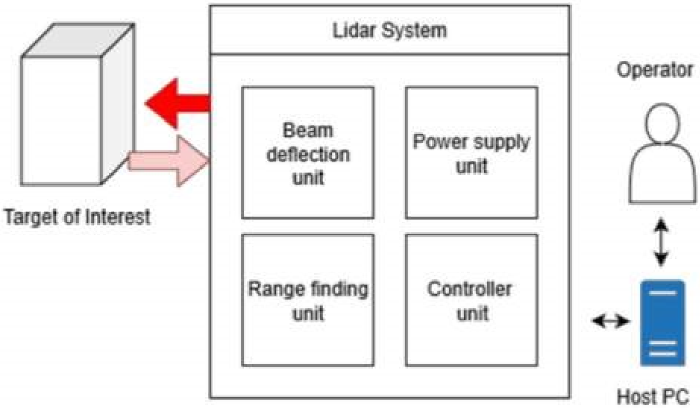

Fig. 3. LiDAR Scanning framework.

To create a more detailed representation of the scanned area, post-processing techniques are applied to the point cloud data. This stage involves connecting points to form vertices, edges, and planes, which are used to create a 3D geometric mesh. A geometric mesh is a collection of vertices, edges, and faces that define the shape and structure of a 3D object. Once the geometric mesh is generated, it can be further processed and manipulated to create a more refined 3D model. Depending on the specific case, this model can be used for visualization, analysis, simulations, or various applications. LiDAR technology offers precise and accurate measurements, making it valuable in applications where detailed 3D information is required. Its versatility and ability to capture large-scale environments make it a powerful tool in various industries [8].

2.3 Principle of Long-Range LiDAR Scanning

The LiDAR operates based on the Time-of-Flight (ToF) measuring principle. By measuring the ToF, the sensor can calculate the distance between the sensor and the target using a specific equation [9].

$$d = tToF \cdot c/2$$

The explanation for this calculation is, where d is the distance between the target and the LiDAR sensor, tToF is the time of flight, and c is the speed of light.

2.4 Virtual Reality Production with Unreal Engine4 Panoramic Capture

The Panoramic Capture plugin for Unreal Engine 4 (UE4) enables users to capture still images or movies that can be later viewed or played back in mono or stereo. This functionality creates the perception that the rendered world is happening in real-time. In the subsequent sections, the user will be able to explore the process of setting up and utilizing the Panoramic Capture plugin.

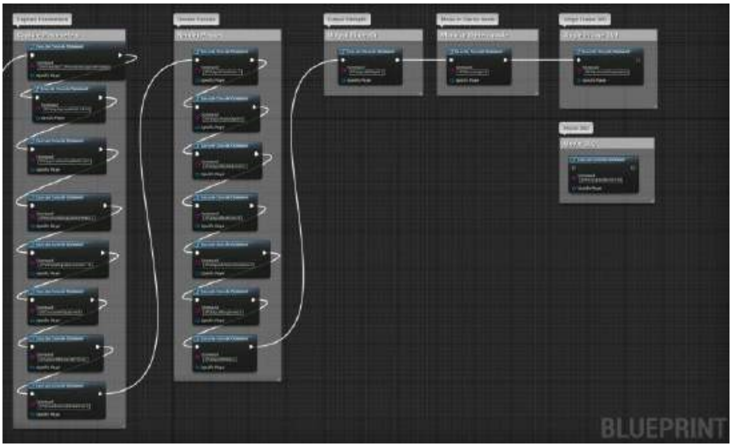

Fig. 4. Interface of Panoramic capture nodes with Unreal Engine4.

The final stage for virtual reality media has to be rendered in panoramic mode with the blueprint nodes. The data will be rendered into a panoramic mode to produce a 360-degree visualization. The panoramic capture also has a video rendering feature, so that the resulting output could be rendered into a video format that can be played through various devices. Although it could be divided into two models, that is the stereoscopic for non-interactive output and monoscopic for interactive output.

Fig. 5. Unreal Engine4 monoscopic image render.

3 Methodes and Procedures types of Virtual Reality

Post-processing techniques significantly enhance the usability and applicability of LiDAR scans, by refining the data and extracting valuable information for the post-processing stage. The specific methods utilized depend on the intended applications and requirements of the data analysis. The software for processing LiDAR data can be categorized into two main types based on their capabilities [10]:

- **Analysis tool**: This category of software enables users to visualize LiDAR data and also offers additional functionality for deriving specific topographic information. This software's most used feature is generating digital elevation models, profiles, and other topographic components. These packages provide advanced analysis tools to extract understandable information from LiDAR data. The most common software for LiDAR data analysis software is ArcGIS.

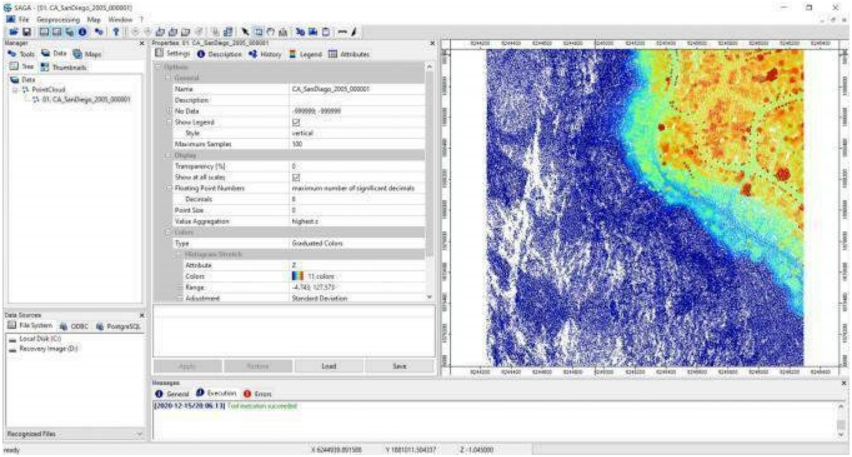

Fig. 6. Interface of ArcGIS height map analysis.

A Geographic Information System (GIS) is a computer system that analyzes and displays geographically referenced information. It uses data that is attached to a specific location [11].

- **Visualization tool**: These packages are designed for viewing LiDAR raw datasets. Visualization software provides tools and features for visualizing point cloud data in a comprehensive and user-friendly manner such as Unreal Engine4 software.

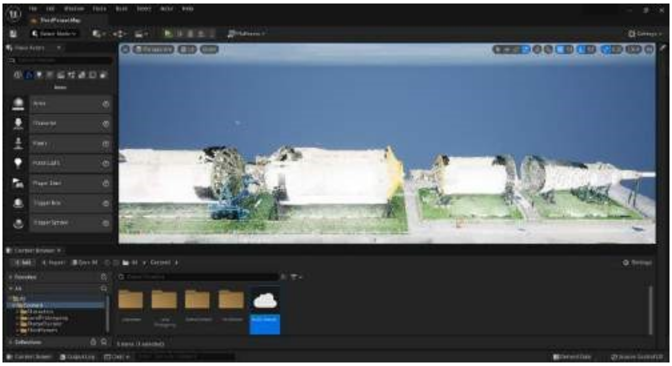

Fig. 7. Interface of Point cloud plugin with Unreal Engine.

3.1 Post-Processing Procedures

In this case, the study is focused to create 3D immersive environment for virtual reality by implementing LiDAR Data post-processing procedures including;

1. Filtering: Filtering techniques are used to remove noise, outliers, and unwanted points from the LiDAR data. Common filtering methods include statistical outlier removal, density-based filtering, and morphological filtering. These techniques help improve the overall data quality and remove artifacts that may affect subsequent analysis.
2. Ground extraction: Ground extraction is a crucial step in LiDAR data processing, especially in applications such as terrain modeling and mapping. Various algorithms, such as progressive morphological filters or height-based methods. Ground extraction allows for the creation of accurate digital elevation models (DEMs) and terrain representations.
3. Point cloud registration: Point cloud registration involves aligning multiple LiDAR scans acquired from different positions or time instances. Registration is necessary when creating larger and more comprehensive point cloud datasets. Iterative Closest Point (ICP) algorithms and feature-based matching techniques are commonly used for registration, ensuring accurate alignment and minimizing errors between overlapping point clouds.
4. Segmentation: Segmentation refers to the process of partitioning the LiDAR point cloud into meaningful regions or objects based on certain criteria. Segmentation can be performed using various techniques, such as region growing, clustering, or geometric feature extraction. This allows for the identification and isolation of individual objects or areas of interest within the point cloud.
5. Surface reconstruction: Surface reconstruction techniques are used to generate continuous and smooth representations of the LiDAR point cloud, such as mesh models or TIN (Triangulated Irregular Network) surfaces. These representations can be utilized for visualization, analysis, and simulation purposes. Surface reconstruction algorithms, including Delaunay triangulation and Poisson surface reconstruction, are commonly employed to create detailed surface models from the LiDAR data.

4 Case and Application

The LiDAR scanning process is performed at Bandung Institute of Technology (ITB) environment, led by FSRD ITB professor Deny Willy Junaidy, and the team in 2022. The purpose of this activity is to digitalize the buildings, landmarks, and other several sections of the campus area in terms of realistic 3D documentation. The scanning process was carried out with a UAV LiDAR Sensor drone to capture large areas along with contour data of the surface. In addition, there are several procedures that must be considered to conduct a scanning activity, as well as calibration settings, area marking, also distance measurement for the longrange scanning method.

Fig. 8. Area of Aula Timur and the main structure.

In this application, a type of virtual model is needed: The East Hall area. Thus, the area will be scanned as 3D imagery along with the surrounding elements of the building. In this case, the shape of the East Hall building has unique characteristics, so the exterior orientation of the LiDAR sensor has to be equal and aligned to the target object. Then, the sensor calibration and adjustment in the scanning process have to be done properly to capture the entire structure. Therefore, the collected data can be used to provide stimulation of the spatial cognition components to create perceptual information, by defining users' positioning, orientation, and direction. A depiction of landmarks as an immersive virtual environment can be useful to create the sense of being surrounded through a virtual reality visualization. Moreover, by reproducing identical visual information of the real-world objects, users will perceive that they are directly involved into a realistic virtual environment.

4.1 Data Analysis

The computations were used with ArcGIS Pro to define the topographical information from each surface. The control points for the entire building are measured automatically by the local coordinate system which is displayed in the form of a height map. The adjustment technique is used to calibrate the sensor and generate the necessary points to build the reproduction of a 3D model. Additional ground points are measured in each image, and they can be identified by the colors. These images show captured height map data.

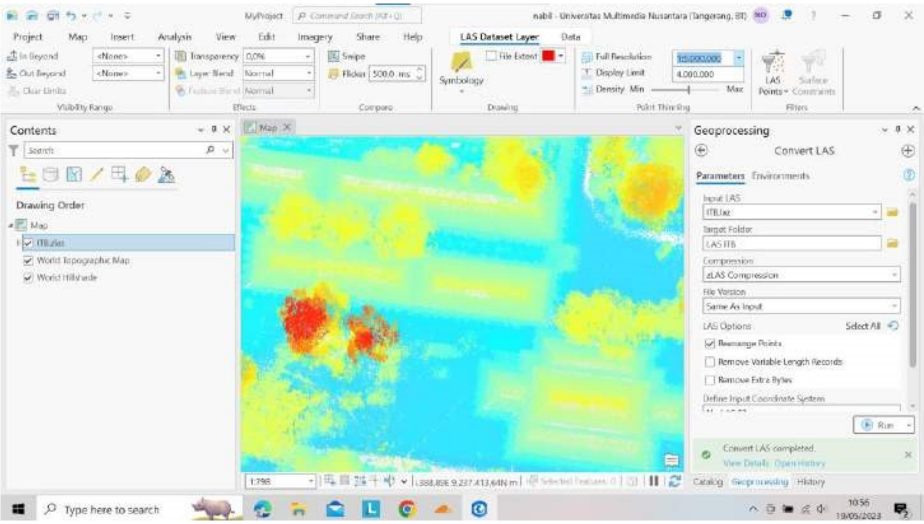

Fig. 9. Height map of Aula Timur Area.

The visualization shows the contour and visual information of the East Hall area. It can be seen that in this area there are several objects that have different heights. The ground surface is highlighted in blue colors, while buildings and trees are highlighted in yellow. The higher the object, the data will show a different color from yellow to the red.

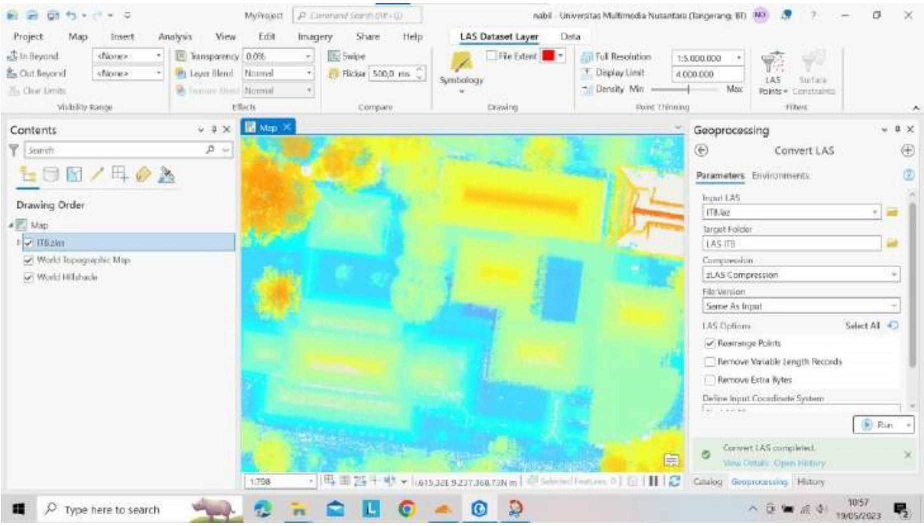

Fig. 10. Height map of FSRD Buildings.

In the second area, visual information shows a yellow surface that can be interpreted as a building layout. Based on this area, the data visualization is displayed using a world topographic map with a display limit of 4,000,000 cloud points per square meter. The scanning activity through the UAV LiDAR Sensor will produce raw data that needs to be analyzed, including color grouping for topography data interpretation, integration of geometric objects, and format conversion that is needed for the data visualization stage.

4.2 Data Post-Processing and Visualization

The height map data from the analysis tool have to be processed with post-processing software, by using Unreal Engine4. The converted Height map data from ArcGIS is then imported to Unreal Engine4, as well as textures and color information of the target objects into a 3D representation artwork. The height map data is transformed into a 3D point cloud format, where the data is visualized as interconnected points to create a three-dimensional object. In this stage, the visualization tool works with a total of 55,111,109-point clouds within a single file. The utilization of LiDAR Scanner technology allows imagery creation that captures the actual characteristics of the object and simplifies the modeling process for large-scale buildings with certain details. These are the processed data with the visualization tool:

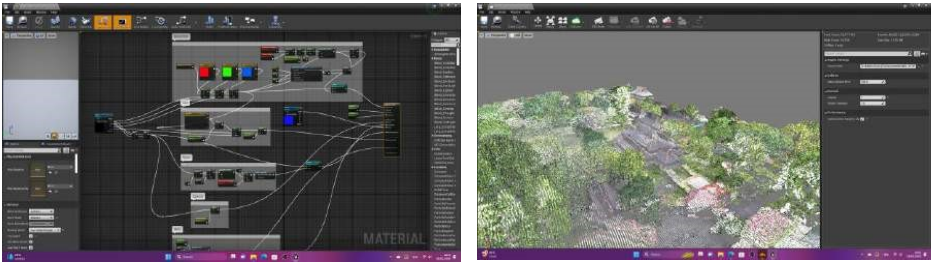

Fig. 11. Material instance nodes and point cloud editing.

At figure 11, the processed height map of the East Hall area is integrated to generate a 3D landscape composition according to the actual environment. The spatial information and buildings contained in the height map data can be represented in sufficient detail. Unreal engine post-processing requires height map data in LAS format, so the data can be transformed into a point cloud along with life-like elements within the spatial information contained in height map data. The coloring process also can be accomplished by importing texture information from the height map, or using third-party painting tools.

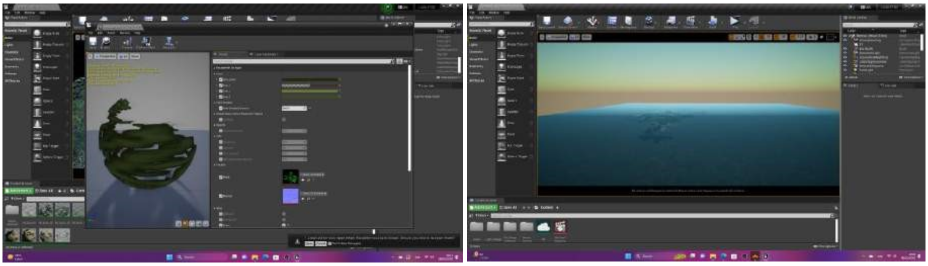

Fig. 12. Foliage UV tilling, lighting, and atmospheric compositing.

In figure 12, several elements need to be added to create a proper immersive virtual environment, such as; foliage, lighting, atmospheric elements, and the 3D objects' composition. These additions contribute to achieving a visually appealing and realistic representation of the environment that closely resembles to the actual setting.

Fig. 13. Composition of Aula Timur area.

The creative process can also be explored to generate a unique visualization concept to create a realistic immersive virtual environment. The roof structures of the buildings require realistic visualization to obtain an identical impression to real-world objects, enabling the audience to perceive a realistic immersive virtual environment. Moreover, spatial experiences that are identical to large-scale dimensions and individual user experiences can help derive new theories for evaluating spatial experiences [12]. This image represents a final composition of the East Hall area:

Fig. 14. Final Artwork of Aula Timur 3D environment design.

4.3 Panoramic Capture for Virtual Reality

Point cloud data's large volume and high resolution make it suitable for LoD management and rendering. The data model that determines the logical structure of a database will determine in which manner the data can be stored, organized, and manipulated [13]. The composed LiDAR data is then rendered in 360 degrees to produce a complete visualization for virtual reality display. In this case, the results of the environment composition are rendered stereoscopically to make it compatible and fit to virtual reality devices. Generally, the 3D rendering process refers to packaging a three-dimensional or two-dimensional image of a model or design to subtly illustrate the final appearance [14].

Fig. 15. Stereoscopic render of Aula Timur environment.

Meanwhile, 3D composition data can also be rendered using a monoscopic technique for a screen-based VR device. There are several significant differences between monoscopic and stereoscopic rendering, where monoscopic rendering is aimed directly at both eyes, which has a resemblance to landscape videos in general. While the stereoscopic rendering the image is divided into two sides between the right and left. In addition, a stereoscopic display adopts the perspective of how the human eye works to see the world.

Fig. 16. Monoscopic render of FSRD area environment.

5 Discussion

The integration of the East Hall LiDAR data into a 3D post-processing facilitates the accurate placement and arrangement of objects, buildings, and landscapes within the virtual environmental design. This has the potential to be implemented as an alternative way to create a virtual reality environment in different procedures. The LiDAR scans also enable the creation of a precise and realistic representation model of physical spaces, allowing for better understanding and visualization of the captured areas. Based on post-processing techniques, the model of the East Hall building can be represented in a way close to its original form. The area's details, colors, and characters can be seen from the structure of the building, including the shape of the roof and the surrounding elements of the building. Conventional methods of 3D modeling obtain a degree of approximation or estimation, which may lack precision or require significant time of production. In contrast, LiDAR scans offer a precise level of fidelity that contributes to a more realistic and immersive VR experience, enabling users to navigate and interact with the virtual world in a way close to the physical world. Further research is needed to conduct a user test to measure the experience of the virtual reality produced with LiDAR Scans. This is needed because the accurate representation of spatial information through LiDAR scans potentially has a direct impact on spatial cognition.

Spatial cognition refers to the mental processes involved in perceiving, interpreting, and organizing spatial information. This condition could develop a better sense of the virtual environment's layout, distances, and proportions, to allow intuitive understanding of space. Also, this can stimulate mental maps and cognitive models of the virtual environment, which in turn enhances spatial awareness and navigation, so the users can feel a resemblance to the actual environment. The data that has been scanned in the east hall has several important points to create basic imagery of spatial cognition to the user, including; a). geometric details of the East Hall structures. The visual information shows the realistic shape of the entire structure and also with the surroiunding elements. b). Assesing location in depth. The generated environment has a precise location with the actual world, so the user could navigate and explore the environment based on their perceptional information about the actual area. c). Determining the orientation of lines and objects. Every visual component of the virtual environment such as buildings, trees, and even façade of the structures have a precise alignment between one and another. So that, the 3D model of the scanned area can be displayed correctly within the whole structure and the surrounding elements along with vegetation and atmospheric elements of the area. This level of precision ensures that the virtual reality environment design through LiDAR Scans closely resembles its real-world counterpart, enhancing the sense of immersion for users. Moreover, the composition of the virtual environment generates a resemblance of perception to its actual environment and potentially has a significant spatial impact for the user that are familiar with the East Hall area.

In addition, raw height map data requires a complex interpretation and analysis to produce precise spatial information about the scanned area. This has its own difficulties because the resulting height map data generates a 2D image with an aerial view perspective. Meanwhile, the height map data is needed as a database to build 3D visualizations along with the dimensions and details of the scanned area. However, it is important to note that the successful integration of LiDAR data into an immersive virtual environment, requires expertise in post-processing techniques in order to create a seamless point cloud composition design. Moreover, it can be concluded that the post-processing technique allows raw LiDAR data to be processed into a new output to create immersive virtual reality environment assets. Thus, the rendered final environment composition with panoramic capture enables users to explore the virtual environment using a VR device, providing a unique experience as if they are truly immersed in the virtual world.

This process fulfills several components of the immersive virtual environment, including visual perception and spatial cognition. Furthermore, the use of LiDAR scanning enables virtual elements to accurately represent the characteristics of a real-world object. However, there are limitations to the LiDAR Scans' post-processing stage, such as data noise and occlusions. These limitations can be addressed by reducing the point size, connecting output nodes on the event graph, and reassuring the correct assignment of data to the source color. Also, there are several procedures that need to be evaluated to create a LiDAR-based immersive environment design for virtual reality. The airborne scanning produces an aerial perspective that causes the object is covered by trees or buildings, so it is not scanned properly. This resulting unconnected point clouds with the incomplete shape of the object, and it can be prevented by using a ground-based terrestrial LiDAR device, so the sensor could be aligned properly to the target object.

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