

**BACHELOR OF ARTS IN MULTIMEDIA STUDIES**  
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**UNIVERSITY OF THE PHILIPPINES  
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**BACHELOR OF ARTS IN MULTIMEDIA STUDIES**

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**Exploration of 3D Reconstruction Techniques for the UPOU FMDS' Perma  
G.A.R.D.E.N.: Contributing to Its Digital Twin Development**

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02 October 2024

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### EXPLORATION OF 3D RECONSTRUCTION TECHNIQUES FOR THE UPOU FMDS' PERMA G.A.R.D.E.N.: CONTRIBUTING TO ITS DIGITAL TWIN DEVELOPMENT

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## Acceptance Page

This paper prepared by **CHAN, JOSEPH ISAIAH M.** with the title: “**EXPLORATION OF 3D RECONSTRUCTION TECHNIQUES FOR THE UPOU FMDS’ PERMA G.A.R.D.E.N.: CONTRIBUTING TO ITS DIGITAL TWIN DEVELOPMENT**” is hereby accepted by the Faculty of Information and Communication Studies, U.P. Open University, in partial fulfillment of the requirements for the degree Course.

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## **Biographical Sketch**

Joseph Isaiah M. Chan was born in Caloocan City, Philippines, and grew up in Bulacan with two older sisters. He excelled academically in elementary school but later found himself distracted by the creative aspects of life. His early interest in computer-generated imagery (CGI) and visual effects (VFX) was evident from an early age. He was captivated by behind-the-scenes clips of "Jurassic Park" (1993), his childhood favorite film, and fascinated by the CGI and VFX processes that brought the dinosaurs to life. This fascination extended to his hobby of photo manipulation, where he would cut out pictures of dinosaurs and incorporate them into his own photographs. Later, he also developed a keen interest in video editing.

Aligning his academic pursuits with his passion for multimedia production, he chose the Humanities and Social Sciences (HUMSS) strand in Senior High School at Jesus Is Lord Colleges Foundation, Inc. He graduated with Honors and received a HUMSS Service Award for his active involvement in the HUMSS Media Information Technology Committee. Following his graduation, he sought admission to the Bachelor of Arts in Multimedia Studies program at the University of the Philippines Open University (UPOU). His application was successful. During his final term as a freshman, he applied for a position as a Student Assistant at the UPOU Multimedia Center (MC). His application was approved and worked directly with then-Director aProf. Luisa Gelisan and then-Information Systems Researcher II, Mr. Lexter Mangubat. His two years as a Student Assistant enhanced his technical skills in graphic design, video editing, and website management, deepening his interest in multimedia production and emerging technologies.

## **Acknowledgement**

I would like to extend my appreciation to my adviser, Dr. Roberto B. Figueroa Jr., for not only providing me with technical insights but also offering words of motivation as I navigated this project amidst moments of doubt.

I would also like to thank the members of the Faculty of Management and Development Studies (FMDS) for the financial assistance and accommodation, and the Center for Open and Digital Teaching and Learning (CODTL) for the technical assistance and support. My gratitude extends to Dean Joane V. Serrano, Dr. Jabez Joshua M. Florez, Ms. Jessa Perez, Ms. Mary Jane Reondanga, and all those who contributed their assistance in various ways.

Special thanks to my parents, Mrs. Chona Rizza M. Chan, and Mr. June C. Chan, for providing me with life. To my *Lola*, Ms. Dely S. Cruz, who has been serving me the right food and providing me with the care I needed. To my eldest sister, Ms. Christine Chan, you already know it. Lastly, to my sister, Mrs. Crizelle Chan-Torres, and her family, for their aid whenever I needed it.

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## Abstract

This project aims to explore emerging 3D reconstruction techniques applied to the UPOU FMDS' Perma G.A.R.D.E.N., in contribution to its digital twin development. The objectives include providing a simplified overview of how the explored 3D reconstruction methods work, testing these techniques to the garden, and assessing their output models in terms of visual accuracy and usability. The project also addresses and acknowledges various issues, explores an optimal methodology, and includes prototyping and recommendations to provide insights for future developers and researchers working on the garden's digital twin. Among the three explored techniques—Photogrammetry, Neural Radiance Fields (NeRF), and Gaussian Splatting—Gaussian Splatting was found to be the most suitable for the garden, based on visual accuracy and usability. The optimal methodology utilized the Nerfstudio framework with its “splatfacto” method, which is its Gaussian Splatting procedure. For prototyping, PlayCanvas was used with its support for editing and integrating Gaussian Splatting 3D models. Various issues were addressed and acknowledged during these phases. The insights from this project could benefit future developers and researchers involved in the garden's digital twin project by demonstrating the differences between the 3D reconstruction methods and their application to the garden. The prototypes provided, which are available as open educational resources, could inspire the enhancement of the current digital twin of the garden, which is its 360-degree photo-based Virtual Reality (VR) tour, by integrating walkability through a 3D model, thus increasing its immersive experience. The prototypes can be accessed through the following links: [“perma-center” Prototype](#), [“perma-right” Prototype](#), and [“perma-bridge” Prototype](#).

## I. INTRODUCTION

### Background

#### **UPOU-FMDS Perma G.A.R.D.E.N.**

In celebration of the International Day of Forests and the International Women's Day, the University of the Philippines Open University (UPOU) Faculty of Management and Development Studies (FMDS) launched the FMDS Perma G.A.R.D.E.N. (Growing Appreciation toward Resilience, Development, Entrepreneurship and Nutrition) to the public in March 2023. This project, spearheaded by Dean Joane Serrano and was developed with the aid of Dr. Jabez Joshua Flores, a UPOU alumnus and permaculture expert, is an initiative to contribute to the Sustainable Development Goal (SDG) 2: Zero Hunger, aiming for the long-term goal of fostering growing appreciation of communities towards sustainability and nutrition (Alazada, 2023). Such gardens can enhance the availability and consumption of fresh vegetables and diverse, healthy foods for low-income households (Alazada, 2023), while also promoting sustainability using organic and recyclable materials, thereby responding to SDG 2.

#### **Actualized Digital Twin: A 360-degree Photo-based Virtual Reality (VR) Tour**

With the collaboration of FMDS and UPOU Immersive Open Pedagogies (IOP) Program, a Virtual Reality (VR) tour of the garden was produced and made available for accessing online. The scenes of the VR tour were created using 360-degree photographs, a method executed by Dr. Roberto B. Figueroa Jr., IOP Program Director, and Dr. Joane V. Serrano, FMDS Dean, and was constructed and housed by Hiroshi Taniguchi, Adjunct Professor, and Ms. Joshze Rica Esguerra, an IOP Research Associate (Figueroa Jr., 2023). Additionally, the FMDS Research

Associates, Rhea Ariele Pascua, Nathalie Ross B. Panting, and Janele Anne Belegal, assisted for providing other related materials and information for the project (Figueroa Jr., 2023).

The VR tour, which can be accessed through this link: <https://iop.upou.edu.ph/vrtours/permagarden/>, offers immersive features and interactive elements. The VR tours, such as this, allow users to acquire a sensation of presence in a technology-enhanced environment (Heeter, 1992, as cited in Figueroa Jr, Gil, & Taniguchi, 2022). The VR tour of the garden allows users with moderate immersion—those who use smartphones and laptops without VR goggles (Figueroa Jr, Gil, & Taniguchi, 2022)—to control their viewing location with a mouse or navigating via touch through their smartphones. When accessing the tour on a mobile device, users have the option to switch to VR goggle view. Moreover, integrated into the photographic scenes are interactive hotspots that provide information about the plants in multiple formats, including text, audio, and images. The hotspots are also designed to allow users to proceed or return to different photographic scenes or areas of the garden.

### **Digital Twin Development**

In response to UPOU FMDS' initiative to explore immersive technologies and spatial computation with IOP, through the establishment of ISTAR (Immersive Spatial Technology and Reality) Labs (Perez & Macaldo, 2024), this project will explore 3D reconstruction techniques to contribute to the faculty's broader plan to develop a digital twin of the Perma G.A.R.D.E.N. Given that virtual representation is an essential component of a digital twin (AIAA Digital Engineering Integration Committee, 2020),

and considering the complexity of the garden's physical attributes—such as dense vegetation, as opposed to the simpler mechanical objects often replicated and developed as digital twins—this exploration of 3D reconstruction techniques aims to help future developers and researchers gain a basic understanding of 3D reconstruction methods that may address these complexities. It also intends to evaluate the effectiveness of the 3D reconstruction models, in terms of visual accuracy and usability, for creating a visual representation of the garden.

### **Objectives**

This project falls under the category of **Creative Multimedia and Emerging Technology Explorations**. To ensure the project aligns with its goals, the following objectives are outlined for this exploration:

- Explore the emerging 3D reconstruction techniques and provide a basic overview of how they work.
- Assess sample processed 3D models for each technique in terms of visual accuracy and usability, in the context of the Perma G.A.R.D.E.N. as the physical asset.
- Present the optimal methodology explored.
- Provide the sample output and prototype from the selected technique and optimal methodology.
- Offer recommendations for future developers and researchers of the Perma G.A.R.D.E.N.'s digital twin development and other related projects.

## Scope and Limitations

To provide further clarity on the extent and constraints of this project, the following scope and limitations are outlined:

- **Visual Representation:** The focus of this exploration is on virtual representation, specifically visual representation, excluding simulations. Thus, among the components of digital twin modelling, this falls under virtual modelling. Other elements of digital twins, such as those concerning the physical space and information flow, as well as components of modelling, including physical, connection, data, and service modelling, are not covered.
- **Visual Accuracy and Usability:** This exploration focuses on assessing the visual accuracy, based on perceptual observation, and usability of the output models. It does not cover aspects related to precise geographical modelling, measurement errors, computational comparisons, or other unmentioned related factors.
- **Technical Constraints:** The assessment is limited to the visual output of the selected 3D reconstruction techniques and methodologies using the devices and machines made available to the researcher. This exploration may not address all technical challenges.

## II. REVIEW OF RELATED LITERATURE

### Digital Twin

Hawkinson (2022) explains that digital twins are virtual models of organisms—whether living or inanimate—that facilitate the exchange of data between physical entities and their computer-generated counterparts. It involves generating a digital replica of physical objects, locations, individuals, and environments to facilitate simulations (Hawkinson, 2022). The basic components of a digital twin, as outlined by To et al. (2021), include: a) a “**physical space** (p. 3)” (real object), b) a “**virtual space** (p. 3)” (digital model), and c) the “**information flow** (p. 3)” (connectivity) between the physical and virtual space. These components are termed by AIAA Digital Engineering Integration Committee (2020) as “**virtual representation** (p. 5)” (digital model), “**physical realization** (p. 5)” (asset), and “**transfer of data** (p. 5) (connectivity).” To et al. (2021) proposed the components involved in digital twin modelling, which includes “physical modelling, virtual modelling, connection modelling, data modelling, and service modelling (p. 3).”

### Features

Digital twins offer various features across industries, such as real-time data synchronization, sophisticated modeling and simulations, integration with other digital twins, predictive analytics, remote monitoring and control, dynamic updates, improved VR experiences, collaborative learning, engagement with stakeholders, enhanced accessibility, defect detection, design modifications, environmental analysis, and recording and management. These capabilities,

among others, highlight the broad range of benefits digital twins provide (Hawkinson, 2022; To et al., 2021).

## **Applications**

In the field of tourism, it is utilized as VR tours, which enable students to explore significant locations for learning without the necessity of physical travel (Alizadeh & Hawkinson, 2021, as cited in Hawkinson, 2022). Advanced applications of digital twins, with the presence of simulations and/or connectivity between the digital model and physical asset, include urban planning, traffic management, and crop harvesting, among others (Li et al., 2022, as cited in Hawkinson 2022). In the context of distance education and e-learning, digital twins are utilized in the STEM field to enhance student understanding by simulating engineering and biological concepts (David et al., 2018, as cited in Hawkinson, 2022). Furthermore, it is being applied in the medical domain by analyzing physiological and contextual data to gain a deeper understanding of the human body, which can aid in preventive strategies and predictive measures (Ravi et al., 2017, as cited in Hawkinson, 2022).

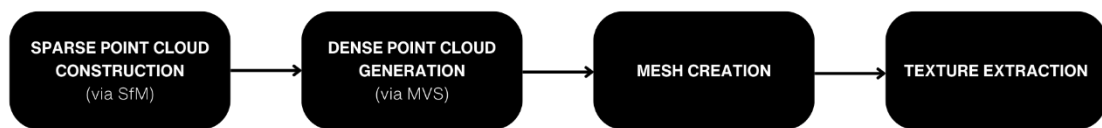
## **3D Reconstruction Techniques**

3D reconstruction techniques have been utilized in digital twin modeling to create virtual representations of actual objects or scenes (To et al., 2021). 3D reconstruction techniques can be divided into non-contact, which do not involve direct interaction with the object or the emission of signals, and contact method, which require direct interaction with the object (Croce et al., 2024).

The explored techniques fall under non-contact methods, which include Photogrammetry, Neural Radiance Fields (NeRF), and Gaussian Splatting.

## Photogrammetry

Photogrammetry is an established 3D reconstruction technique that uses a series of photographs from different viewpoints to generate a dense point cloud, which is then converted into a mesh (Croce et al., 2024). This method produces a mesh-based 3D model (Croce et al., 2024).



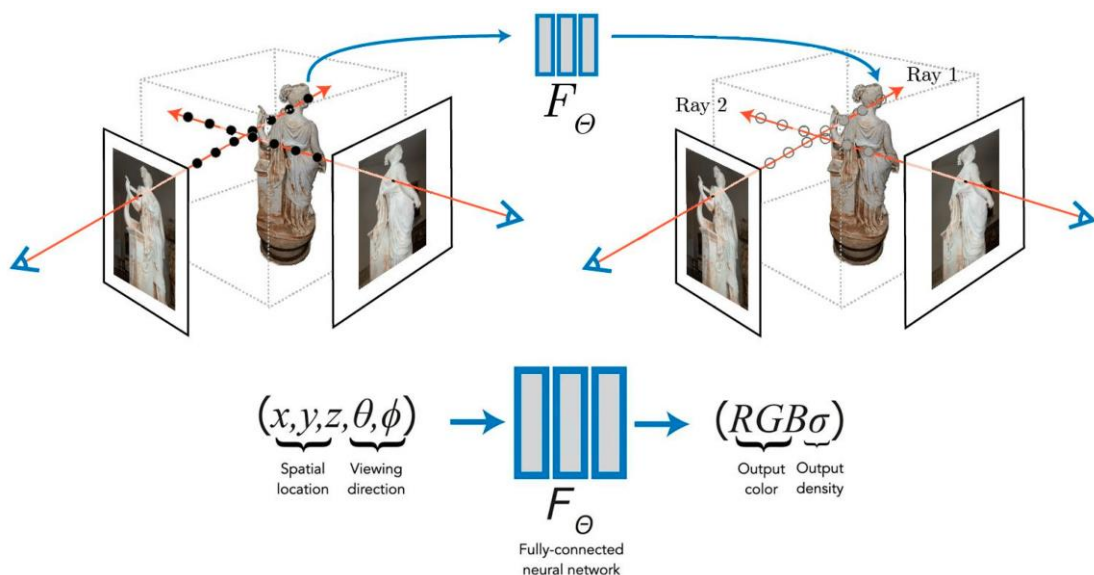
**Figure 1:** A simplified overview of the photogrammetry method. It begins with constructing a sparse point cloud from the estimation of camera parameters (Croce et al., 2024) using the Structure-from-Motion (SfM) algorithm, which extracts 3D points from the input data (University of Cambridge, 2008). Next, a dense point cloud is generated using multi-view stereo (MVS) algorithms, which rely on the SfM parameters to further build the model representation (Furukawa & Hernández, 2015). The process then continues with converting the point cloud data into a mesh and generating textures for a realistic representation (Croce et al., 2024).

While the technology has been around for some time, recent improvements in accessibility and affordability have expanded its use, including its availability on mobile phones. By 2022, advancements had made

photogrammetry highly sophisticated and accessible to a broad range of users, including video game and film developers, as well as those interested in immersive experiences (Lumen & Forge, 2022).

## Neural Radiance Fields (NeRF)

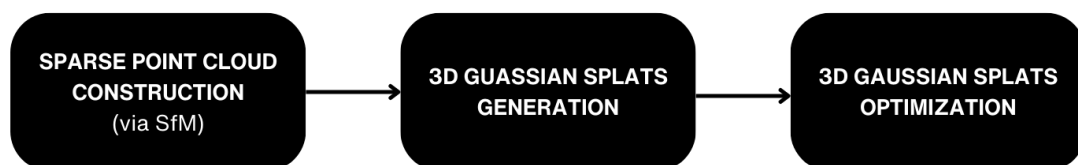
Neural Radiance Fields (NeRF)-based reconstruction is a new 3D reconstruction technique pioneered by Mildenhall et al. (2021) (Croce et al., 2024). In response to advancements in technology and artificial intelligence (AI), NeRF offers a promising alternative to the well-established photogrammetry (Croce et al., 2024). This technique utilizes a fully connected neural network or Multi-Layer Perceptron (MLP) to generate novel views of scenes or objects based on overlapping input images or data (Croce et al., 2024). NeRF models prioritize photorealism, and unlike photogrammetry and Gaussian splatting, which produce discrete outputs (mesh and splats, respectively), NeRF generates a continuous volumetric scene function (Croce et al., 2024).



**Figure 2:** A simplified overview of the NeRF-based reconstruction method, adapted from Croce et al. (2024) and based on the original NeRF paper by Mildenhall et al. (2021). The process begins by synthesizing the spatial location and viewing direction through camera ray sampling. The resulting 5D coordinates are then input into a fully connected neural network (MLP) to generate output color and density values. Using volume rendering techniques, these values are composited into an image (Mildenhall et al., 2021).

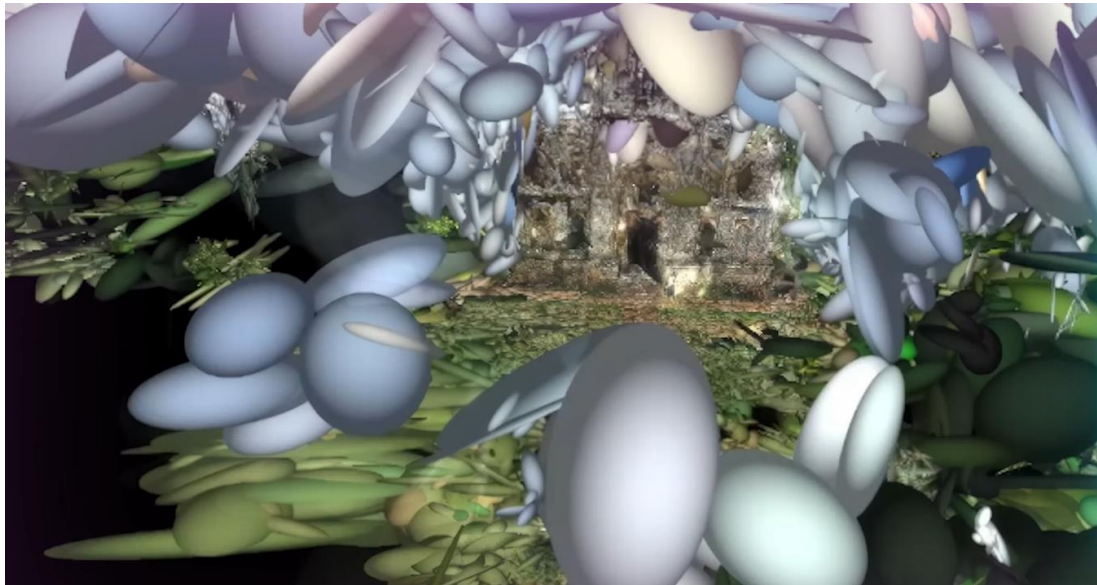
### Gaussian Splatting

Gaussian Splatting, an evolution of NeRF, is a recent 3D reconstruction method that incorporates photogrammetric techniques. Like photogrammetry, it also uses SfM algorithms to define the initial 3D representation of space, thereby avoiding the high computational demands associated with neural networks used in NeRF (Basso et al., 2024). The output model of this technique is a discrete representation through “splats” (see Fig. 4), which are ellipsoids distributed in 3D space that hold color attributes and compose the scene representation (Basso et al., 2024).



**Figure 3:** A simplified overview of the Gaussian Splatting method. Like photogrammetry, Gaussian Splatting uses SfM algorithms to create a sparse point cloud by estimating camera parameters. From this sparse point cloud, 3D Gaussian splats are generated (Basso et al., 2024). However, Gaussian

Splatting does not require the generation of dense point clouds; the sparse point clouds are sufficient. The method then employs 3D Gaussian optimization to adjust the size and parameters of the splats to effectively fill in the scene (Basso et al., 2024).



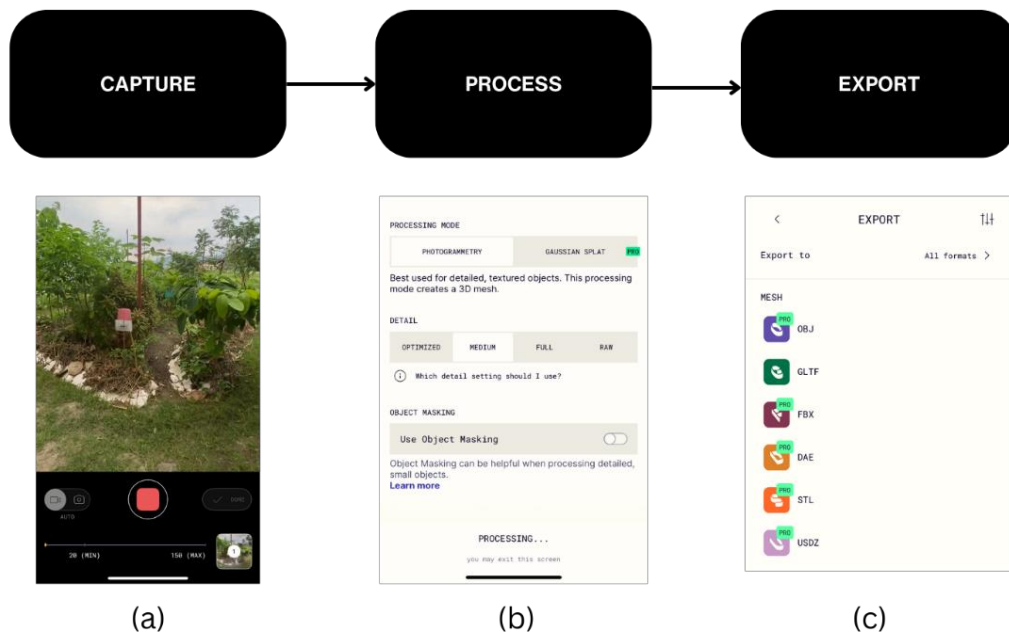
**Figure 4:** A simplified visualization of modified 3D Gaussian “splats” in 3D space from an online video by Sidhu (2023). This illustration shows the shapes of the splats, described by Basso et al. (2024) as like blobs in space, and how their sizes vary to fill the scene because of their optimization, along with their chromatic representation. The size of the splats depends on the complexity and requirements of reconstructing an object (Sidhu, 2024). For example, more splats are used for complex objects like trees or buildings compared to simpler scenes like the sky. This concept is reflected in the figure, which shows fewer, larger blue splats for the sky compared to the denser splats used for the building.

### III. METHODOLOGY

#### A. Testing the 3D Reconstruction Techniques

The tests were conducted using an iPhone 11 for data collection and 3D scanning, utilizing the mobile-based 3D scanning applications Polycam and Luma AI. Polycam supports photogrammetry, while Luma AI supports both NeRF and Gaussian Splatting methods. These applications offer tier-based subscriptions that provide additional options for input data density and export features, as well as free versions with limitations in these areas. The free versions were used for these tests.

##### i. Photogrammetry

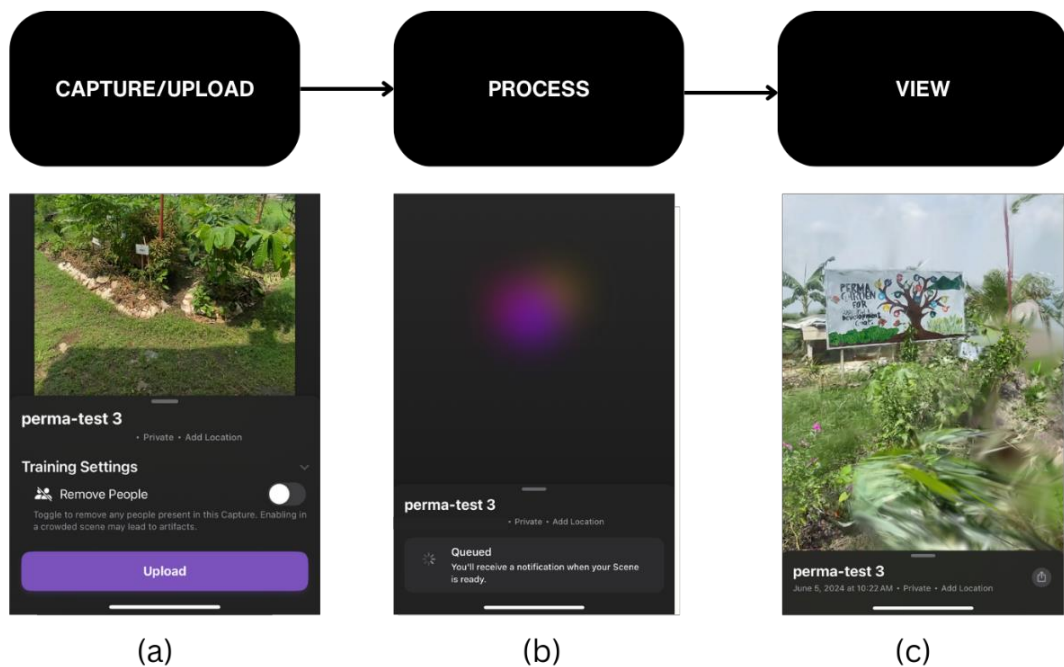


**Figure 5:** The process of using Polycam to test the photogrammetry method in the garden involves capturing the scene either through a series of photos or a video (a). The video setting functions as an automatic shutter, capturing still images rather than

actual video footage. The free version has a frame number limit of 150. Users can upload photos from their camera roll, though the frame limit applies. After capturing the scene, the software processes the images (b). It provides options for the method, detail level, and masking. The photogrammetry method was selected, detail was set to full, and object masking was toggled off. Finally, after processing, the model was exported (c). The free version only supports export in GLTF format.

*Note: The capturing process was not documented, but to get an idea of how the researcher scanned the scene, refer to this [video](#).*

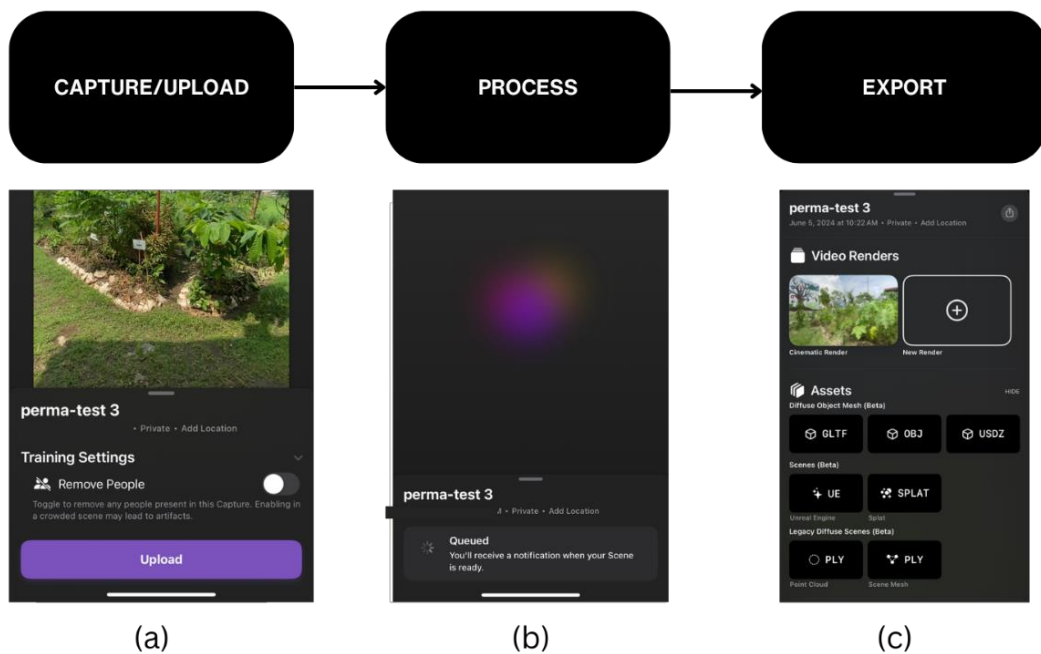
## ii. NeRF



**Figure 6:** The process of using Luma AI to test the NeRF method in the garden involves uploading a video of the garden (a). Alternatively, you can capture the scene directly within the application. In the free version, there appears to be no duration limit for the input. The video is

then processed within the application (b). Finally, the model can be viewed (c). There is no export option for NeRF models. While there is an option for it to be exported as a mesh-based model, this will compromise the visual accuracy of the NeRF model.

### iii. Gaussian Splatting



**Figure 7:** The process of using Luma AI to test the Gaussian Splatting method in the garden is like that of the NeRF method. It begins with uploading a video of the garden (a). Next, the video is processed within the application (b). The main difference is that you can export the model in Splat format (c), which uses the .ply file extension for Gaussian Splat models.

**Note:** The tests for NeRF and Gaussian Splatting were conducted multiple times. Please refer to [this folder](#) for some of the input videos used in both the NeRF and Gaussian Splatting tests. Note that not all videos were tested.

## **B. Assessing the 3D Models**

After acquiring the processed output from the techniques, the 3D models were assessed for visual accuracy based solely on perceptual observation. This approach addresses the advancements in 3D reconstruction techniques, which primarily focus on visual accuracy and managing complex scenes like the Perma G.A.R.D.E.N. The usability framework used was based on Christensen's (2004, as cited in Barve, 2007) requirements for digital formats in digital documents. These principles include criteria such as ease of understanding and implementation, independence from specific hardware, operating systems, or private software, and resilience against isolated nodes of failure. These criteria ensure that the digital object is practical, adaptable, and durable over time. To address these criteria, the editability and flexibility of the models was assessed.

File formats or extensions are crucial for digital twin development, particularly for features like VR tours. The file format should be adaptable enough to be integrated into a platform for development and visitor use, support recording and management of the garden's past conditions through archiving, and facilitate design change planning.

## **C. Developing an Optimal Methodology**

Once the technique has been chosen, the issues encountered from the initial methodology used to test the 3D reconstruction techniques were acknowledged. These issues limit efficiency in data collection and processing. After acknowledging these issues, further exploration was conducted to

address them. This included additional testing and exploration of available devices for data collection and tools/frameworks for data processing.

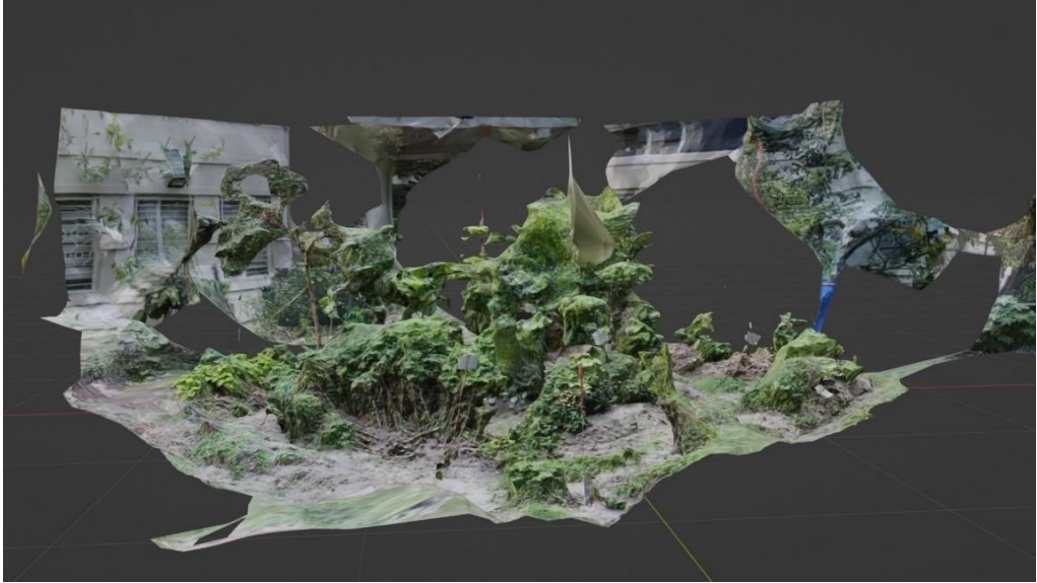
#### **D. Prototyping**

To validate the usability of the models, they were tested for integration into a platform after being acquired using the optimal methodology and most suitable 3D reconstruction technique. PlayCanvas, a web-based gaming engine, was found to support the chosen 3D reconstruction technique, facilitating development, and enabling interactivity and accessibility through a browser.

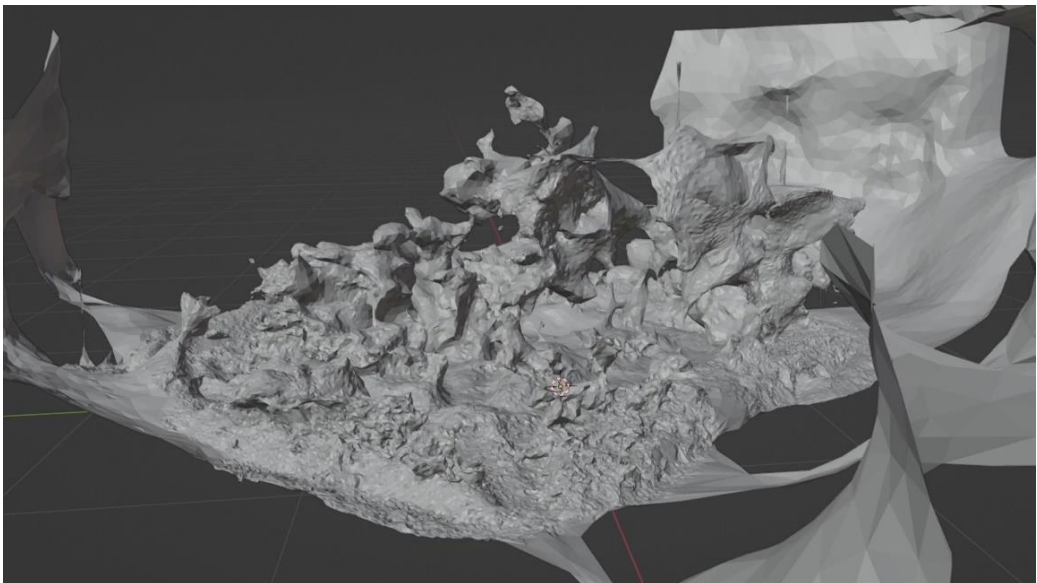
## IV. RESULTS AND DISCUSSION

### A. Test Results and Observations

#### i. Photogrammetry



**Figure 8:** The 3D output model processed using the photogrammetry method via Polycam, then imported and viewed in Blender.



**Figure 9:** The 3D output model without textures, processed using the photogrammetry method via Polycam, then imported and viewed in Blender.

**Note:** The video demonstrations can be viewed through [this link](#).

## Observations

Using a smartphone as the data collector limits the scene coverage, resulting in an incomplete 3D model and restricted viewpoints. Although the textures may appear sharp, the 3D mesh generated exhibits distortions and inaccuracies. This method struggles with handling complex scenes, making it challenging to accurately reconstruct intricate details such as the fine features of the garden, including the grass, leaves, and branches. It tends to overlook the miniscule spaces between foliage, producing a mesh that resembles corals.

### ii. NeRF



**Figure 10:** The 3D output model processed using the NeRF method via Luma AI, viewed in the Luma AI Fields Dashboard.



**Figure 11:** The 3D output model processed using the NeRF method via Luma AI, viewed in the Luma AI Fields Dashboard.

***Note:** The video demonstration can be viewed through [this link](#). The interactive scene via Luma AI Fields Dashboard can be accessed through [this link](#). No account is needed.*

## **Observations**

Again, using a smartphone as the data collector limits the scene coverage, resulting in an incomplete 3D model and restricted viewpoints. Despite this limitation, the generated output effectively captures the intricacies of the vegetation, outperforming mesh-based photogrammetry. Its continuous representation fills in gaps with chromatic details. It also achieves a photorealistic depiction of the plants. Consequently, the method demonstrates strong performance in handling complex scenes, representing the garden's detailed features with greater visual accuracy.

### iii. Gaussian Splatting



**Figure 12:** The 3D output model using the Gaussian Splatting method processed via Luma AI, imported, and viewed in PlayCanvas' SuperSplat.

*Note:* The video demonstration can be viewed through [this link](#).



**Figure 13:** The 3D output model using the Gaussian Splatting method processed via Luma AI, imported, and viewed in PlayCanvas' SuperSplat, showing the splats' outline and size.

### **Observations**

Once again, this issue is also observed: using a smartphone as the data collector limits the scene coverage, resulting in an incomplete 3D model and restricted viewpoints. Despite this limitation, the generated output, like NeRF, effectively captures the intricacies of the vegetation, outperforming mesh-based photogrammetry. Although, with its discrete representation through splats, it is not able to efficiently fill in the whole scene, even with a simple chromatic representation as with NeRF. But again, like NeRF, it also achieves a photorealistic depiction of the plants. Therefore, the method also exhibits strong performance in handling complex scenes, representing the garden's detailed features with almost the same level of visual accuracy as NeRF.

### **B. Assessment Sheet**

The assessment of the models from the 3D reconstruction techniques, tested for visual accuracy and usability (through flexibility and editability) based on the researcher's observation from the tests, was presented through this assessment sheet.

Factor	Photogrammetry (Mesh)	Neural Radiance Fields (Continuous Volumetric Representation)	Gaussian Splatting (Splats)
<b>Visual Accuracy</b>	Low visual accuracy	High visual accuracy	High visual accuracy
<b>Flexibility</b>	Output in standard 3D mesh formats (.obj, .glb, a.o.) and texture maps; universally supported	Output typically involve rendered images and videos and may require conversion to meshes; conditionally supported	Output in volumetric or point-based data format (.ply, .splat); it may require add-ons; limitedly supported
<b>Editability</b>	Directly editable meshes and textures; straightforward to modify in standard 3D modeling tools	Requires conversion to meshes for modification	Point-cloud data editing, which is limited to deleting certain splats; requires add-ons or specific tools

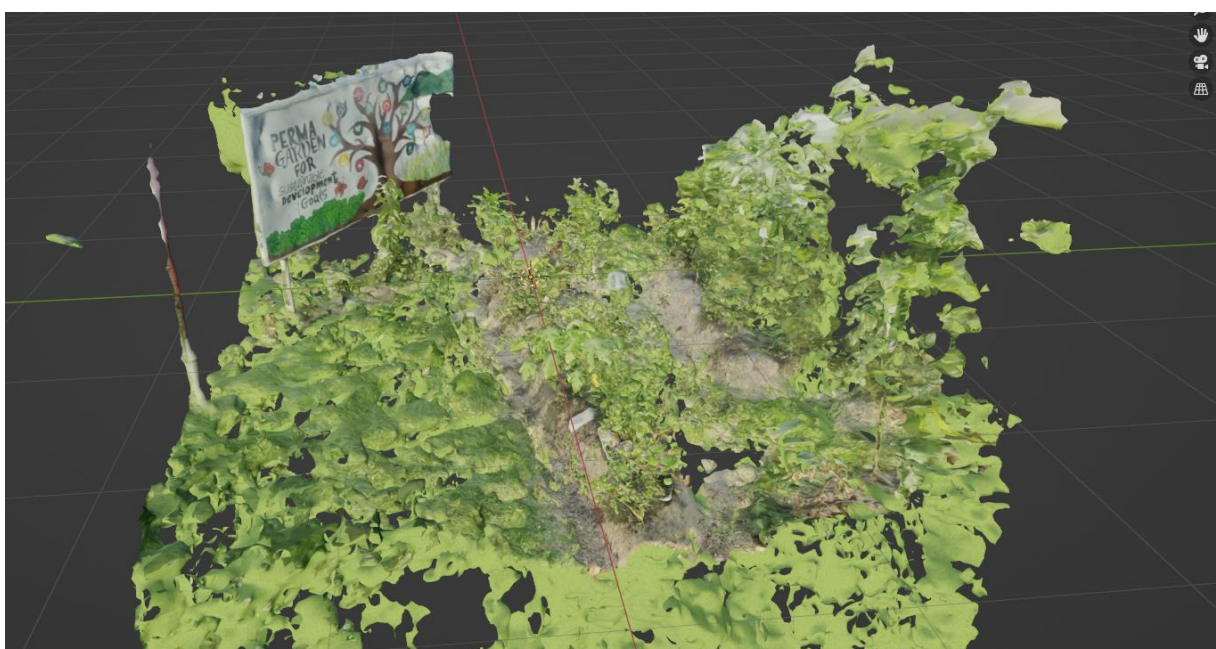
**Figure 14:** The assessment sheet of the 3D model outputs in the context of the Perma G.A.R.D.E.N. This indicates the low visual accuracy of photogrammetry with its mesh-based output, and the high visual accuracy of both NeRF and Gaussian Splatting, with their continuous volumetric representation and splats, respectively. In terms of flexibility and editability, photogrammetry, being a well-established technique, offers high flexibility and editability with its standard 3D mesh-based models. This allows for universal access in most 3D editing tools and platforms, enabling direct editing of meshes and textures. NeRF, on the other hand, allows for video or image exports but may require conversion to meshes before it gains support and editability in a 3D workspace, so it was labeled as conditional. Gaussian Splatting, with its photogrammetric method and point-cloud-based output, has limited support and editability. It requires add-ons for common 3D workspace tools like Blender. Specific tools like PlayCanvas' SuperSplat enables splat editing, which is limited to deleting splats.

With this assessment, photogrammetry was excluded due to its low visual accuracy. Both NeRF and Gaussian Splatting were highly accurate

visually, placing them in contention, with the decision primarily relying on their usability. NeRF's requirement to be converted into a mesh for flexibility and editability compromises its visual accuracy (see Figs. 15 and 16). Therefore, Gaussian Splatting is more preferable than NeRF as it maintains visual accuracy while offering some degree of flexibility and editability with discrete splat representation and .ply format, which is integrable in various web-based viewers (Nerfstudio, n.d.).



**Figure 15:** NeRF model viewed in the Luma AI Fields Dashboard.

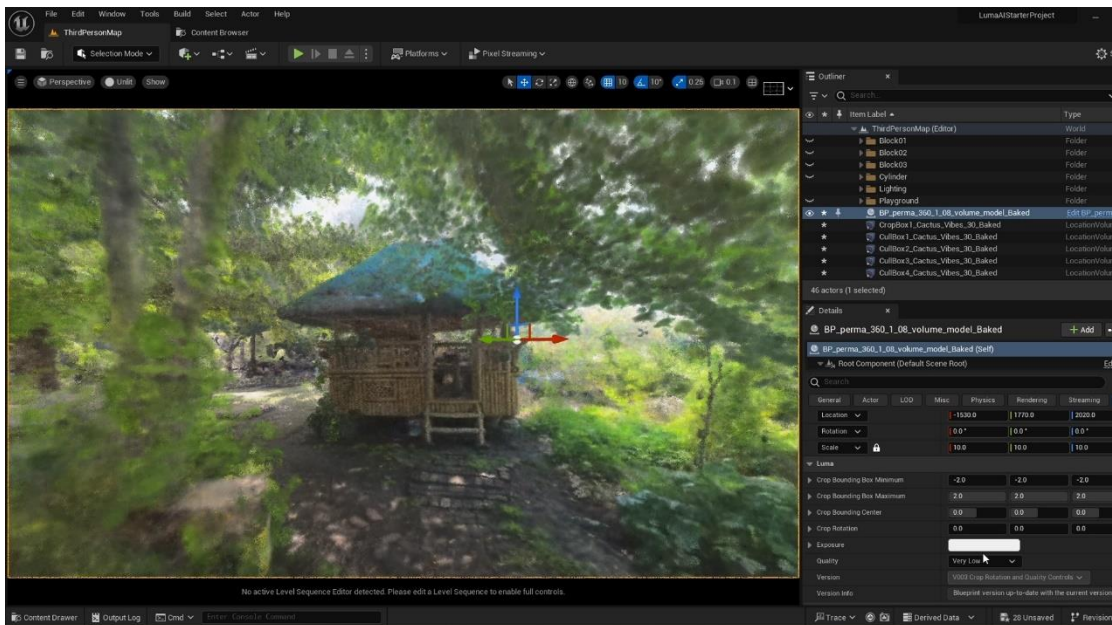


**Figure 16:** The same NeRF model from Fig. 15 exported as mesh via Luma AI, then imported and viewed in Blender.

### **C. Explored Optimal Methodology**

In furthering this project, an optimal methodology was explored for more efficient data acquisition and processing. A recurring issue in data collection is the use of smartphone, which results in limited camera coverage and leads to partially built 3D models. In response to this, a 360-degree camera, specifically Insta360, was utilized to address concerns on coverage and efficiency.

Regarding the application tested for Gaussian Splatting, namely Luma AI, it was observed that the application has export limitations for models processed from 360 data. A test was conducted using input from Insta360 on Luma AI; however, the output is limited to a Luma Field file—a fully volumetric representation from point clouds—that is only viewable and editable in Unreal Engine, a gaming engine tool, and requires the Luma Unreal Engine Plugin (Luma AI, n.d.). The application does not offer a .ply export format for models obtained from 360 data. The Luma Field file was tested in Unreal Engine (see Fig. 17). The test confirmed that using 360-degree video input results in a broadly scoped model. However, its usability was hindered by its exclusive reliance on Unreal Engine and the required plugin. To address this, further exploration led to the Nerfstudio framework.

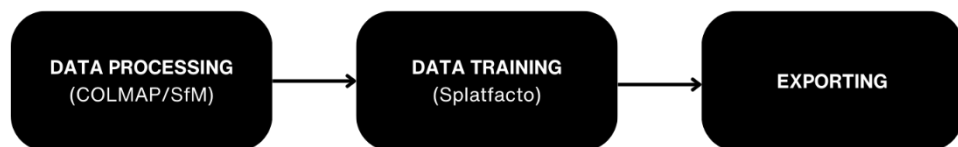


**Figure 17:** Luma Field model imported into Unreal Engine

*Note:* The video demonstration can be viewed through [this link](#).

#### i. Framework: Nerfstudio

NerFStudio is a command-line interface (CLI) application offering a Gaussian Splatting method, called “splatfacto” (Nerfstudio, n.d.), allowing for 360 data processing and export.



**Figure 18:** A simplified overview of the Gaussian Splatting method in the Nerfstudio framework. The process begins with data processing, which involves generating sparse point clouds via SfM using COLMAP, an SfM and MVS tool. The processed data is then trained using the splatfacto method, and finally, the trained model is ready to be exported.

The installation process, following Stephens' (2024) guide, includes installing prerequisites such as CUDA, Git, Visual Studio 2022, and Conda; dependencies such as PyTorch; and finally, Nerfstudio. All steps are performed using the command prompt.

## ii. **Data Sectioning**

Due to the hardware limitations available to the researcher, specifically a GPU with approximately 6GB of memory capacity, the input data—an equirectangular 360-degree video (see Fig. 19)—had to be segmented into chunks. The 360-degree video, which captured the entire garden except for the "Adopt-A-Plot" area, was split into three sections: "perma-center," covering the central part of the garden; "perma-right," covering the right side of the garden; and "perma-bridge," covering the left side of the garden, including the bridge and *bahay kubo*. The names served as file names for each section and model used throughout the process. Each segment was trimmed to a 30-second duration.



**Figure 19:** A snapshot from the 360-degree equirectangular video used as input data, covering the Perma G.A.R.D.E.N.

*Note:* The video can be viewed through [this link](#).

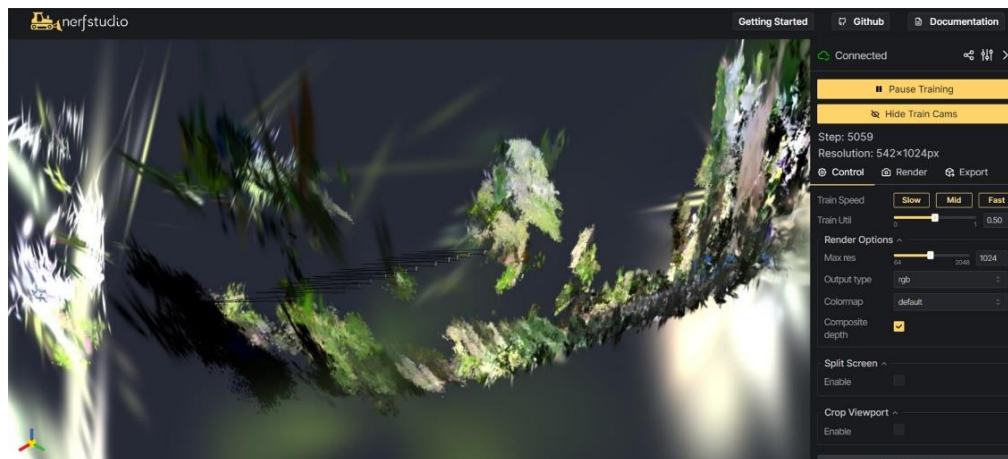
### iii. Data Processing

A simplified overview of the data processing method includes extracting frames from the 30-second video input, extracting frames from each equirectangular frame, and performing feature matching and bundle adjustment in COLMAP. This process is part of the sparse point cloud construction step.

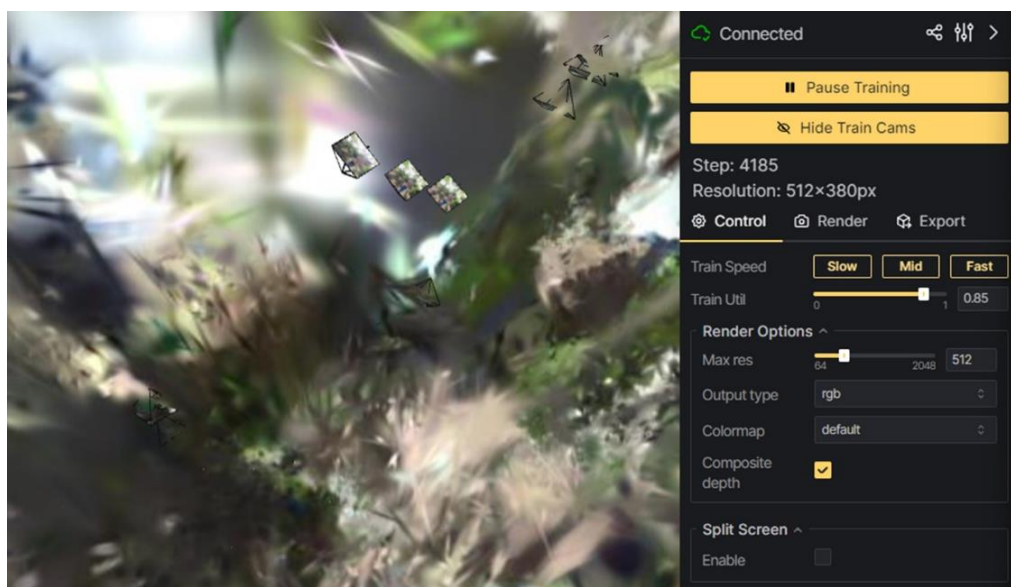
```
(nerfstudio) C:\Joshua\miniconda\envs\nerfstudio\process-data video --camera-type equirectangular --images-per-equirect 14 --num-frames-target 400 --data "C:\Joshua\miniconda\envs\nerfstudio\data\perma-center\perma-center.mp4" --output-dir C:\Joshua\miniconda\envs\nerfstudio\data\perma-center
Number of frames in video: 1850
Number of frames to extract: 525
C:\Joshua\miniconda\envs\nerfstudio\lib\site-packages\torch\functional.py:4236: UserWarning: Default grid_sample and affine_grid behavior has changed to align_corners=False since 1.3.0. Please specify align_corners=True if the old behavior is desired. See the documentation of grid_sample for details.
warnings.warn('
Generating Plane Images 100% 1.00 equirect frames/s 04:31
[22:07:24] # Done copying images with prefix 'frame_' process_data_utils.py:236
[22:08:53] # Done generating images process_data_utils.py:278
[22:35:08] # Done extracting COLMAP Features colmap_utils.py:130
[22:37:12] # Done matching COLMAP Features colmap_utils.py:158
[22:38:46] # Done COLMAP bundle adjustment colmap_utils.py:172
[22:38:23] # Done refining intrinsics colmap_utils.py:283
[22:39:39] # # # all DONE # # # video_to_nerfstudio_dataset.py:137
Starting with 1850 video frames video_to_nerfstudio_dataset.py:140
We extracted 525 images with prefix 'frame_' video_to_nerfstudio_dataset.py:148
We downscaled the images by 2x, 4x and 8x video_to_nerfstudio_dataset.py:168
COLMAP matched 7350 images video_to_nerfstudio_dataset.py:168
COLMAP found poses for 1000.00% of the images. video_to_nerfstudio_dataset.py:168
```

```
ns-process-data video --camera-type equirectangular --images-per-equirect 14 --num-frames-target 400 --data "C:\Joshua\miniconda\envs\nerfstudio\data\perma-center\perma-center.mp4" --output-dir C:\Joshua\miniconda\envs\nerfstudio\data\perma-center
```

**Figure 20:** The command line for data processing specifies the camera type of the input data (equirectangular) and the number of images to extract per frame, with two options available: 8 or 14, dividing the frame accordingly. While 8 images were tested, this setting produced a low-quality, indistinguishable model (see Fig. 21). The total number of frames to be extracted for the entire clip is set to 400. Trials were conducted with 90, 200, 300, and 400 frames. Using 90-300 frames resulted in a low percentage of matched poses, also leading to a low-quality, indistinguishable model (see Fig. 22).



**Figure 21:** The trained Gaussian Splatting model processed with the number of images per equirectangular frame set to 8.



**Figure 22:** The trained Gaussian Splatting model processed with the number of target frames set to 90.

*Note: The 3D model can only be visualized during the data training period. Figs. 12.1 and 12.2 are from this period and serve as references for what the final 3D model looks like with the specific settings used during the data processing step.*

#### iv. Data Training

This step involves Gaussian Splatting generation and optimization. After processing the data, the resulting structure was trained using the 'splatfacto' method to obtain the Gaussian Splatting 3D model. To manage computational demands and address the 'out of memory' errors encountered, adjustments were made to the data training settings (see Fig. 23).

```
29910 (99.78%) 35.050 ms 3 s, 154.485 ms 19.05 M latfacto.py:514
29920 (99.73%) 32.680 ms 2 s, 607.983 ms 19.99 M latfacto.py:514
29930 (99.77%) 33.380 ms 2 s, 331.088 ms 19.42 M latfacto.py:514
29940 (99.88%) 33.480 ms 2 s, 4.811 ms 19.35 M latfacto.py:514
29950 (99.82%) 34.080 ms 1 s, 699.997 ms 19.02 M latfacto.py:514
29960 (99.87%) 34.048 ms 1 s, 361.911 ms 19.03 M latfacto.py:514
29970 (99.98%) 33.848 ms 1 s, 15.435 ms 19.16 M latfacto.py:514
29980 (99.93%) 32.780 ms 653.993 ms 19.86 M latfacto.py:514
29990 (99.97%) 32.480 ms 323.997 ms 20.00 M latfacto.py:514
29999 (100.00%) latfacto.py:514
```

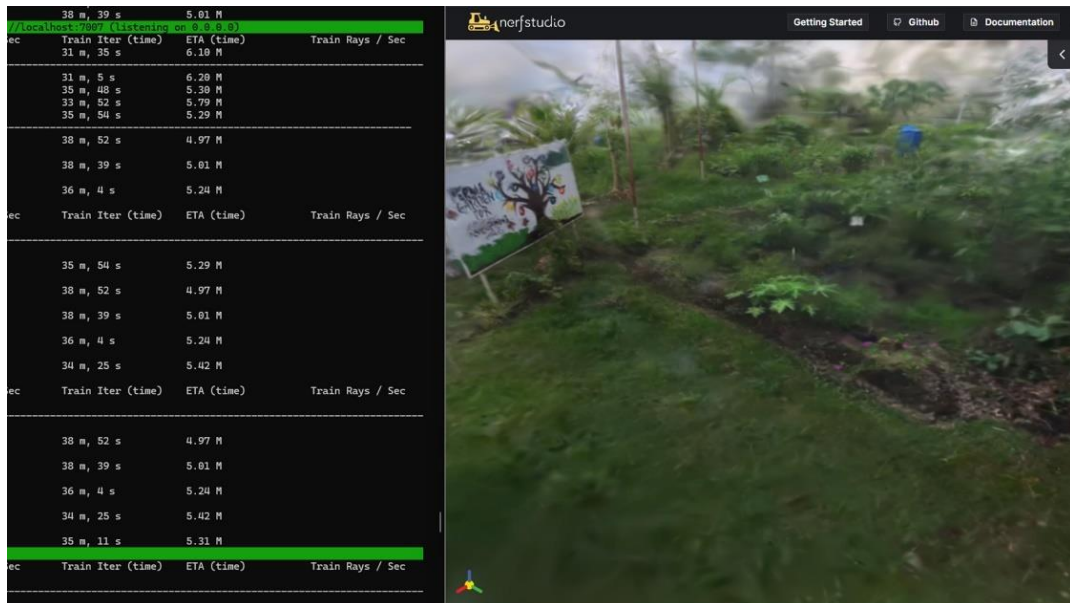
```
Viewer running locally at: http://localhost:7007 (listening on 0.0.0.0)
Training Finished
Config File | outputs\perma-center-hq\splatfacto\2024-07-07_212556\config.yml
Checkpoint Directory | outputs\perma-center-hq\splatfacto\2024-07-07_212556\nerfstudio_models
```

```
ns-train splatfacto --data
C:\Joshua\miniconda\envs\nerfstudio\data\perma-center --viewer.num-
rays-per-chunk 100 --pipeline.datamanager.camera-res-scale-factor
0.25
```

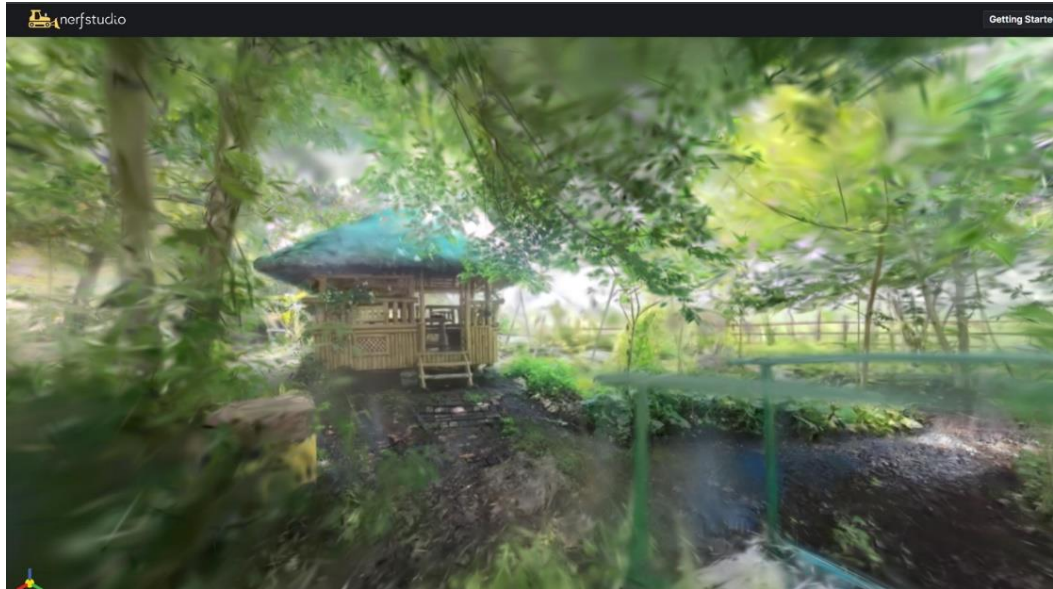
**Figure 23:** The command line for data training specifies the file directory of the processed model to be trained. To address computational demands that led to an 'out of memory' error, the number of rays per chunk was set to 100. A lower number of rays means fewer samples, which can reduce both quality and computational load. Initial

random tests were conducted with 1000 rays, but 100 rays provided a balance between quality and performance. The camera resolution scale factor was set to 0.25, meaning the input images were downscaled to 25% of their original quality to manage computational demands. Tests were also conducted with scale factors of 0.75 and 0.5. The “perma-bridge” model was able to manage the 0.5 scale factor, which is 50% of the original quality, while “perma-center” and “perma-right” could only handle the 0.25 scale factor.

This modification to the training settings was suggested by ChatGPT, an AI language model developed by OpenAI.



**Figure 24:** The training process of “perma-center” and its visualization.



**Figure 25:** The training process of “perma-bridge” and its visualization.



**Figure 26:** The training process of “perma-right” and its visualization.

#### v. **Exporting**

After successfully completing the training of the models, they were exported using the following command line: “*ns-export gaussian-splat --load-config <config> --output-dir exports/splat*” (Nerfstudio, n.d.). This

command specifies the config.yml file, which is an output from the training process and guides the system to the trained model and its configurations. After exporting, it generates a .ply file, ready for use.

### Observations

Due to the need for downscaling, the quality of the final 3D models was compromised. Vegetation farther from the camera in the video input appears abstract and blurry, with details rendered at a lower quality. However, the “perma-bridge” model stands out with higher quality among the three, as it managed a downscale factor of only 0.5. There are also noticeable visual traces of the researcher in the final model (See Fig. 27), as he was visible in the video input.



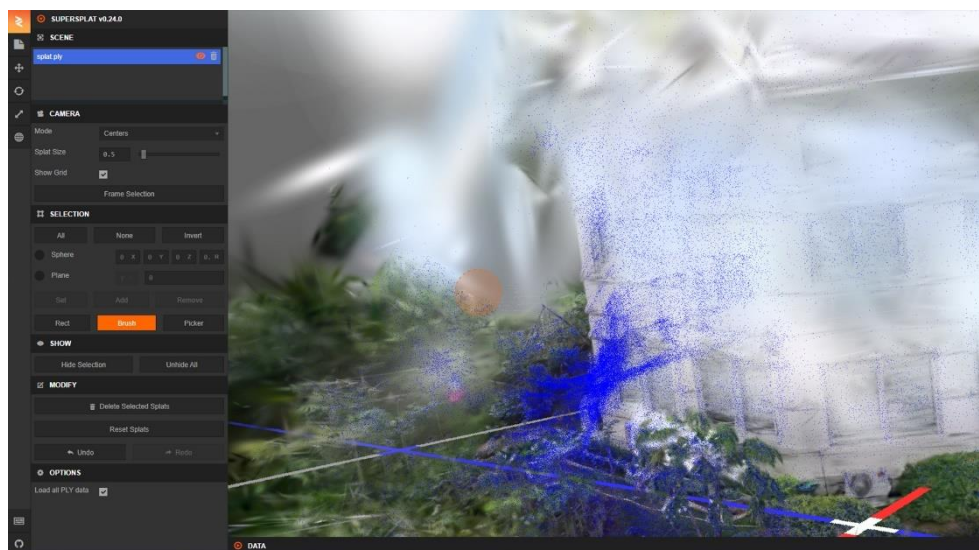
**Figure 27:** A visual artifact or trace of the researcher in the final 3D model.

## D. Prototyping

To validate the models' usability, they were implemented in a game development tool for prototyping. The platform used is PlayCanvas, a web-based development environment. It supports editing of Gaussian Splatting models through its SuperSplat platform and accepts these models for import as objects or assets. PlayCanvas also allows integration of user interface (UI) elements, such as buttons, images, and text. Additionally, it provides flexibility in scripting, physics settings like collisions, and arranging first- or third person viewing controls.

### i. Model Editing

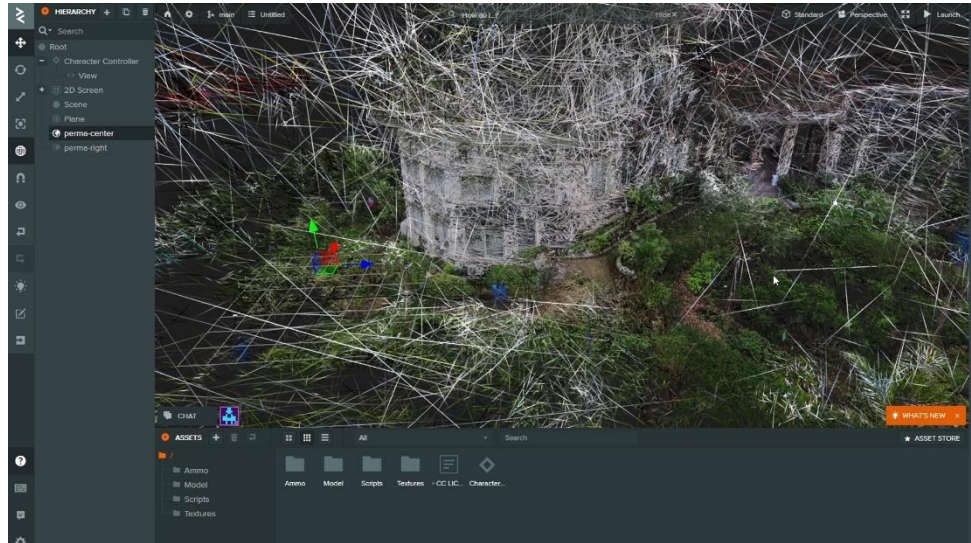
The models were minimally edited using SuperSplat. Efforts were made to address the visual artifacts in the models (see Fig. 27), but removing splats can compromise detail and create gaps. Therefore, the editing was not exhaustive in eliminating the unwanted splats.



**Figure 28:** Editing of splats via SuperSplat. The blue dots represent the splats, which can be selected and deleted.

## ii. Model Integration

After making minor edits to the models, they were imported and integrated into a PlayCanvas project (see Fig. 29).



**Figure 29:** The 3D Gaussian Splatting models imported into PlayCanvas and integrated. The wireframe view, which displays the models through lines, is used to help with alignment.

**Note:** The video can be viewed through [this link](#).

## Issues

Integrating the models presents challenges in alignment (see Fig. 30) and results in merging 3D Gaussians that obstruct the user's view and create confusing viewpoints (see Fig. 31).



**Figure 30:** The misalignment in the building is visible. This view shows the merged “perma-center” and “perma-right” models.



**Figure 31:** The view between the 'perma-center' and 'perma-right' models, resulting from their merging, causes confusing viewpoints and splats that obstruct the user's view.

While the use of 360-degree video improved coverage, the scope remains compromised due to the downscaling and sectioning of the models.

### iii. Prototypes

Considering the acknowledged issue, the prototypes are separated for each 3D Gaussian Splatting model. These prototypes are integrated with first-person viewer controls for users. To access the prototypes, click the link embedded in the text below via the web. A PlayCanvas account is required, which is free.

### [“perma-center” Prototype](#)



**Figure 32:** A screenshot from the “perma-center” prototype.

### [“perma-right” Prototype](#)



**Figure 33:** A screenshot from the “perma-right” prototype.

### [“perma-bridge” Prototype](#)



**Figure 34:** A screenshot from the “perma-bridge” prototype.

**Note:** Click anywhere on the screen to control the viewing directions and use either the arrow keys or the “A, S, D, W” keys to move. Press “Esc” to exit control of the arrow keys and viewing directions.

**Additional Note:** The screen-recorded walkthrough videos can be viewed through [this link](#).

The prototypes are licensed under [CC BY 4.0](#).

## **V. SUMMARY, CONCLUSION, AND RECOMMENDATIONS**

### **Summary and Conclusions**

This project explored emerging 3D reconstruction techniques for the UPOU FMDS' Perma G.A.R.D.E.N., contributing to its broader digital twin development project. The aim is to assist future developers and researchers involved in this project. The techniques explored include photogrammetry, a well-established technique that has recently become more sophisticated, as well as NeRF and Gaussian Splatting, which are both novel technologies in the field. The objectives include providing a basic overview of how each technique works, assessing sample 3D models from each technique in terms of visual accuracy and usability, presenting the optimal methodology employed, and providing prototypes of the models in use. After conducting initial tests, the 3D models were assessed based on their visual accuracy and usability. The most fitting technique was then subjected to further exploration to refine its optimal methodology, addressing issues encountered during the initial tests, and prototyping.

Gaussian Splatting was determined to be the most fitting technique for the garden in terms of visual accuracy and usability. The optimal methodology explored included using a 360-degree camera for data collection and utilizing the Nerfstudio framework with its "splatfacto" method. To address computational demands, data sectioning and adjustments in data processing and training were necessary. As for prototyping, PlayCanvas was explored as a platform that supports the editing and integration of Gaussian Splatting models, allowing for UI functionalities and scripting.

Due to device limitations that resulted in insufficient memory errors, certain compromises had to be made. These issues affected the quality of the models and posed challenges in their integration. Furthermore, while the use of a 360-degree camera improved coverage, it still shows limitations in scope with the final models, which could be areas for future researchers to address.

This project could serve as a reference for future researchers and developers working on the garden's digital twin development by providing a basic overview of the techniques used. With its focus on visual accuracy, the methodology and prototypes could enhance the current digital twin of the garden. Specifically, the VR tour, which uses 360-degree photos, could be improved with 3D Gaussian Splatting models to enable walkability and enhance the immersive experience. In more advanced digital twin applications, features such as defect detection, design modifications, and recording and management (To et al., 2021) may be effectively addressed through visual accuracy in the context of the garden. While many projects in the field focus on metric accuracy, visual accuracy could offer significant advantages in closely monitoring vegetation.

## Recommendations

In terms of technical constraints and addressing the issues presented in the optimal methodology explored, these could be mitigated by using higher-performance devices or hardware. This would reduce the need for data sectioning and downscaling, which compromised the quality of the models and presented challenges in their integration. Additionally, exploring other data collection devices, such as drones—which have been evaluated by other researchers—may also be beneficial and could help address the issue concerning scope.

To access the more advanced features and applications of digital twin, components such as “real-time replication” (To et al., 2021, p. 3), simulations (Hawkinson, 2022), “transfer of data” (AIAA Digital Engineering Integration Committee, 2020, p. 5), and other related functions require advanced research and further exploration. Unexplored areas such as metric or geographical accuracy and Geographic Information Systems (GIS) integration, or other related functions, necessitate further study.

Further research into usability and computational comparisons is recommended. Additionally, a systematic assessment of visual accuracy could provide extended insights. Integrating metric accuracy with visual accuracy may offer significant benefits as well. Finally, given the rapidly evolving nature of technology, adaptation and ongoing research are advised. On an inspirational note, have fun exploring!

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# APPENDICES

## APPENDIX A

### Request to Visit Perma G.A.R.D.E.N. Sent via Email to FMDS

Request to Visit Perma G.A.R.D.E.N. for MMS200 Project Implementation External Inbox x ✕ 📧 📧

**Joseph Isaiah Chan** <jimchan1@up.edu.ph>  
to jserrano, robertojr.figueroa ▼ Wed, Apr 3, 2:04 PM ☆ ↶ ⋮

Dear Dr. Serrano,

I am Joseph, enrolled in the BAMS program. I am writing to inform you that for my MMS200 project, I will be developing a digital twin of the Perma G.A.R.D.E.N. under the supervision of Dr. Roberto Figueroa.

I am planning to visit and stay at the headquarters during the second or third week of May 2024. This visit will allow me to commence the implementation of my project and gather all necessary assets. I kindly request your approval for this arrangement.

Thank you for your attention to this matter.

Best Regards,  
Joseph Isaiah Chan

---

**Joane Serrano** <jserrano@up.edu.ph>  
to Mary, Raizza, Jabez, me, Joane, Roberto ▼ Thu, Apr 11, 8:07 PM ☆ ↶ ⋮

Dear Joseph,

Apologies for the late reply.

This is approved. I've cc'd Jane and Raizza to accommodate your request.

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**Joseph Isaiah Chan** <jimchan1@up.edu.ph>  
to Joane, Joane, Roberto, Mary, Raizza, Jabez ▼ Thu, Apr 11, 9:12 PM ☆ ↶ ⋮

Thank you, Dr. Serrano!

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**Raizza Anna Alforja** <raizzaanna.alforja@upou.edu.ph>  
to Joane, me, Mary ▼ Fri, Apr 12, 1:21 PM ☆ ↶ ⋮

Acknowledging this request. Will coordinate with Mr. Chan regarding this matter.

Thank you.

Regards,  
Raiz

\*\*\*

# APPENDIX B

## Request for Financial Assistance During Implementation Stage to FMDS

Request for Financial Assistance External Inbox x ⌵ 📧 📧

**J** Joseph Isaiah Chan <jmchan1@up.edu.ph> to Roberto ▾ May 27, 2024, 10:28 PM ☆ ↶ ⋮

Good day, Prof. Rob.

I hope this email finds you well. I am writing to request for financial assistance for my accommodation at the UPOU Academic Residences. I am planning on staying for a total of five days, from 3rd to 7th of June 2024. My stay at the UPOU Headquarters is crucial for my special project for the Perma G.A.R.D.E.N., as it will allow me to visualize the space, 3D scan and gather the necessary assets, and seek your guidance, as my adviser, in doing so.

Thank you for your time and consideration.

Regards,  
Joseph

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**R** Roberto B. Figueroa Jr <rfigueroa@up.edu.ph> to FMDS, Jessa, josephine.macale, wyomia.pradas, me ▾ May 28, 2024, 9:43 AM ☆ ↶ ⋮

Dear Joseph,

Dean Joane Serrano of FMDS kindly offered to host you during the period since this will be part of the Metaverse-project of their Peram GARDEN. Thank you Dean and FMDS colleagues!

Including Ms. Mia and Ms. Josephine here.

Joseph, please start coordinating with Ms. Jessa so that we can be productive during the scanning period. Dean Joane, is there anybody else from the PermaGARDEN project that you'd like to include to the loop?

Thank you!

Best Regards,  
Rob

\*\*\*

**ROBERTO B. FIGUEROA JR., PH.D. (フィゲロワロベルト) [HE/HIM]**  
[Associate Professor](#) at the Faculty of Information and Communication Studies.  
Director of the Immersive Open Pedagogies Program, and  
Deputy Director at the Center for Open and Digital Teaching and Learning  
[University of the Philippines - Open University](#)

Program Chair,  
[Mixed Augmented and Virtual Realities in Learning SIG](#)  
[Japan Association for Language Teaching](#)

*Highlighted Publications:*

**Figueroa, R. B.** Immersive Capability and Spatial Presence in Virtual Reality Photo-based Tours. *Asian Association of Open Universities Journal* 18 (3). <https://doi.org/10.1108/AAOUJ-12-2022-0171>

**Figueroa, R. B., Palma Gil, F. A., Taniguchi, H.** 2022. Piloting Virtual Reality Photo-Based Tours among Students of a Filipino Language Class: A Case of Emergency Remote Teaching in Japan. *Avant: trends in interdisciplinary studies* 13(1). <https://doi.org/10.26913/avant.202208>

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**F** FMDS Dean <fmds-dean@upou.edu.ph> to Raizza, Mary, Jabez, Roberto, me, Jessa, josephine.macale, wyomia.pradas ▾ Tue, May 28, 1:33 PM ☆ ↶ ⋮

I've cc'd Raiz and Jane to assist Joseph in scanning and Sir Jabez for advice.

\*\*\*

**JOANE V. SERRANO, PHD (She/Her)**  
Dean and Professor  
Faculty of Management and Development Studies  
University of the Philippines OPEN UNIVERSITY  
Los Banos, Laguna, Philippines 4031

[upou.edu.ph/home](http://upou.edu.ph/home) 

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**R** Roberto B. Figueroa Jr. <rfigueroa@up.edu.ph> to FMDS, Roberto, me, Jessa, josephine.macale, wyomia.pradas, Raizza, Mary, Jabez ▾ Tue, May 28, 2:22 PM ☆ ↶ ⋮

Thank you, Dean.

I will also be there to help next week.

Cheers,  
Rob  
Roberto Figueroa, PhD  
フィゲロワロベルト  
Associate Professor and Director of the Immersive Open Pedagogies Program, University of the Philippines - Open University

On May 28, 2024, at 13:33, FMDS Dean <fmds-dean@upou.edu.ph> wrote:

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## APPENDIX C

### [3D Gaussian Splatting Models](#)

My Drive > MMS 200 > Perma 3DGS Models ▾

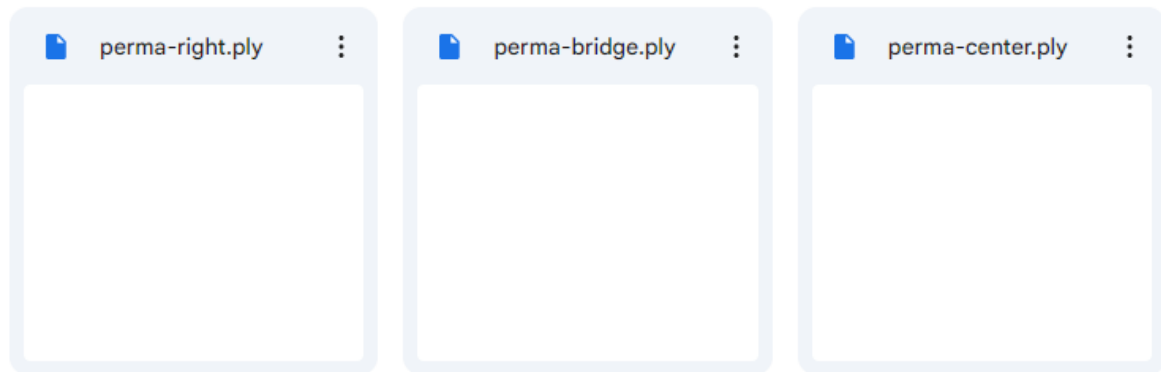
Type ▾

People ▾

Modified ▾

🔊 New! Keyboard shortcuts Drive keyboard shortcuts have been updated to give you first-letters navigation

Files



## APPENDIX D

### [Prototypes Available on the IOP Website](#)

Immersive Open Pedagogies

Home About Us Portfolio ▾ News Resources ▾ Events ▾

#### Perma GARDEN 3D Prototypes

Created by: Joseph Isaiah Chan, UPOU Student  
Guided by: Roberto B. Figueroa Jr., Immersive Open Pedagogies  
Jabez Joshua Flores, Faculty of Management and Development Studies

- [Perma-center](#)
- [Perma-right](#)
- [Perma-bridge](#)

In partnership with the Faculty of Management and Development Studies.

