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CS 25-309 Pumphouse

Preliminary Design Report

Prepared for

Mac Wood

Friends of the Pumphouse

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Under the supervision of

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Date: 10/2/24

Executive Summary

This capstone project, titled "3-D Modeling of Byrd Park Pump House," aims to advance the digital representation of the Byrd Park Pumphouse, building on the previous year's virtual reality (VR) model of the main pumphouse room, developed for the Meta Quest 3. The project is a collaboration between the Friends of the Pump House and a dedicated team of computer science students, with guidance from experienced mentors and faculty advisors.

Our primary objective is to expand the existing VR model to encompass the entire pumphouse, integrating augmented reality (AR) features and enhancing the VR environment through improved sound and lighting effects. This year, we will focus on creating detailed assets for the Hydroelectric Pump Generator and the Boiler Room, which are integral components of the pumphouse's functionality.

To ensure the project remains organized and accessible, we have structured our GitHub repository to be self-contained, with dedicated directories for documentation, notes and research, project deliverables, status reports, and source code. This organization will facilitate a clear understanding of the tools and techniques employed in the project, while also allowing the Linux Foundation OMP Mentorship program to track our progress and address any challenges encountered during development.

Our team consists of Mac Wood from the Friends of the Pump House as both a mentor and technical advisor, alongside faculty advisor John Leonard, and student team members Cesar Colato, Mohammad Garada, Zemas Zeamnauel, and myself, Nicholas Casey.

As we move forward, we will continually update the executive summary to reflect the project's progress and insights gained, particularly in preparation for the Preliminary Design Report due in December 2024. This ongoing documentation will ensure all stakeholders have a clear understanding of our objectives, deliverables, and the timeline of our work.

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Section A. Problem Statement

The Byrd Park Pump House, a historical landmark located in Richmond, Virginia, is not only a significant architectural structure but also a crucial part of the local water supply system. Despite its importance, the Pump House has faced challenges in terms of public engagement, preservation, and education about its historical and engineering significance. The need to modernize the representation of this structure through advanced digital modeling techniques has become increasingly evident.

Understanding the Problem

The primary stakeholders facing this issue include the Friends of the Pump House, local community members, historians, and educators. These groups recognize the importance of the Pump House but often lack engaging tools to convey its historical significance and operational functionality to a broader audience. The problem is widespread, as many historical structures across the country face similar challenges in public engagement and educational outreach. The frequency of the issue is particularly pronounced during public tours and community events, where outdated or limited representations can detract from the learning experience.

The potential costs associated with inadequate representation of the Pump House extend beyond mere economic factors; they encompass societal and environmental concerns as well. Poor public engagement can lead to a lack of awareness and appreciation for historical landmarks, ultimately jeopardizing funding for maintenance and preservation efforts. Furthermore, environmental education regarding the Pump House's role in the local ecosystem is critical, particularly in an age of increasing climate change awareness.

Project Client and Stakeholders

The project client is the Friends of the Pump House, a community organization dedicated to preserving and promoting the history of the Pump House. Key stakeholders also include local government agencies, educational institutions, and community members who benefit from enhanced educational resources about the Pump House's historical and engineering significance.

Field of Study and Contribution to Technology

This project falls under the fields of computer science, engineering, and digital media, specifically focusing on 3D modeling and virtual reality (VR) technologies. By leveraging advanced digital representations, this project contributes to the current technology in heritage conservation and educational outreach, offering innovative solutions to bridge the gap between historical significance and modern engagement techniques.

Historical Perspective and Prior Solutions

Historically, various attempts have been made to digitally represent historical structures through 3D modeling and VR. For example, past projects have successfully utilized VR to enhance visitor experiences at museums and historical sites, increasing engagement and understanding of the subject matter. However, these projects often fell short in incorporating interactive elements and comprehensive representations of complex systems, such as the Hydroelectric Pump Generator and Boiler Room in the Byrd Park Pump House.

Current competitive designs focus on standalone VR applications, yet they lack the integration of augmented reality (AR) features that can provide contextual information in real-world settings. Our project aims to improve upon these previous efforts by not only creating a fully integrated 3D model of the entire Pump House but also incorporating interactive AR elements to enhance user engagement and learning outcomes.

Figures can often help aid in the discussion and understanding of technical subject matter. Examples of figures may include a labeled, detailed mechanical drawing, 3D rendering, photograph, schematic, process flow chart, etc. All figures should include a figure number and title located below each figure, and a reference number if necessary. The introduction should include a minimum of 5 cited references. More are encouraged. All references should be cited in-text and on a reference page at the end of the report using the APA citation format [1]. Figure 1, illustrating the engineering design process, provides an example of properly labeled and cited images. Given the level of investigative detail required for this design report, it is expected that the introduction will consist of several pages.

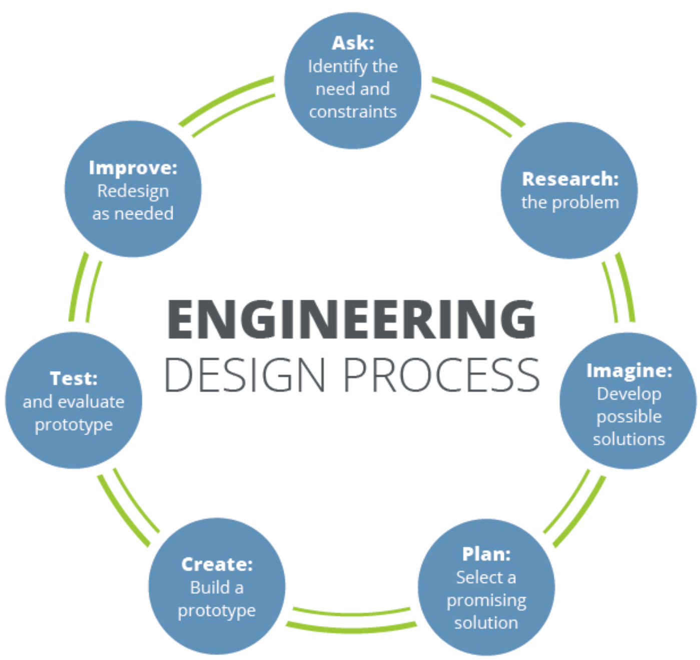

Figure 1. The iterative nature of the engineering design process [2].

Section B. Engineering Design Requirements

This section outlines the goals and objectives of the "3-D Modeling of Byrd Park Pump House" project, along with the constraints that guide the design process. The design requirements stem from the needs articulated by the project client, the Friends of the Pump House, as well as feedback from stakeholders, and they have been refined through extensive research.

Goals and Objectives

1. **Comprehensive 3D Model**: Develop an accurate and detailed 3D model of the Byrd Park Pump House, including both the interior and exterior structures, focusing on the Hydroelectric Pump Generator and the Boiler Room.
2. **Integration of AR and VR**: Enhance the user experience by integrating augmented reality (AR) features alongside virtual reality (VR) elements, allowing users to interact with the model in real time and gain contextual information about the historical and engineering significance of the Pump House.
3. **Educational Outreach**: Create a user-friendly platform that promotes education and awareness of the Pump House's role in the local water supply system, ensuring accessibility for diverse audiences, including students and community members.

Constraints

The design is bound by several constraints that have been identified through stakeholder discussions and research into existing technologies:

1. **Budget**: The project must remain within a specified budget, limiting expenditures on software licenses, development tools, and potential hardware requirements for VR and AR experiences.
2. **Technical Feasibility**: The model must be compatible with existing platforms such as Meta Quest 3, ensuring that the VR and AR features function effectively within the parameters of the hardware and software.
3. **Timeline**: The project must adhere to a predefined timeline, with milestones for each phase of development, ensuring that deliverables are met promptly for reporting and stakeholder engagement.
4. **User Accessibility**: The final product must be designed with usability in mind, ensuring that it can be easily navigated by individuals with varying levels of technical proficiency.

5. **Stakeholder Input**: Continuous feedback from stakeholders, including the Friends of the Pump House and local educators, will be essential to ensure that the model meets the needs of its intended audience.

Research Methodology

The requirements outlined above were established through a combination of stakeholder interviews, literature reviews, and benchmarking against similar projects. By analyzing existing solutions and their effectiveness in engaging audiences, we were able to identify key areas for improvement. For example, a review of projects that utilized VR for historical education revealed common challenges in user engagement and interactivity . This insight guided the decision to incorporate AR features, which have shown to enhance learning outcomes by providing contextual information directly in the user's environment.

Considerations

1. **Design Efficacy**: The effectiveness of the model in educating users about the Pump House will be a primary metric for success. User testing will be conducted to assess the clarity and engagement level of the model.
2. **Cost**: A detailed budget will be created to track all expenses associated with software, hardware, and development costs, ensuring that we stay within financial constraints.
3. **Safety**: While the project primarily focuses on digital representations, attention will be paid to data security and user safety, particularly regarding the use of AR technology.
4. **Reliability**: The final model must be robust and free of technical issues, ensuring smooth operation across various devices.
5. **Usability**: User experience testing will be conducted to ensure that the navigation and interaction with the model are intuitive and straightforward, allowing users to engage without technical difficulties.
6. **Risk Management**: Potential risks, such as software incompatibility or budget overruns, will be continuously monitored and addressed throughout the project lifecycle.

Updates and Revisions

As the project progresses, the design requirements will be revisited and updated to reflect any new insights gained or changes in stakeholder needs. Regular reviews will ensure that the objectives and constraints continue to align with the overall goals of the project.

B.1 Project Goals (i.e. Client Needs)

The primary goals of the "3-D Modeling of Byrd Park Pump House" project are derived from the specific needs of the Friends of the Pump House. These goals reflect the desire to enhance public engagement, education, and preservation of this historical landmark. The following goals outline what the client aims to achieve through this project:

- To enhance public awareness of the Byrd Park Pump House's historical significance and operational functionality.
- To create an engaging educational resource that fosters learning about the local water supply system and the Pump House's role in it.
- To provide a visually compelling representation of the Pump House that attracts visitors and encourages community involvement.
- To utilize modern technology to bridge the gap between historical education and contemporary digital engagement.
- To promote preservation efforts by increasing public interest and support for the ongoing maintenance of the Pump House.

These goals will guide the project's development and ensure that the final outcomes align with the client's vision for promoting and preserving the Byrd Park Pump House.

B.2 Design Objectives

The following objectives outline what the "3-D Modeling of Byrd Park Pump House" design will accomplish. Each objective is crafted to be Specific, Measurable, Achievable, Realistic, and Time-bound (SMART):

- The design will create a comprehensive 3D model of the Byrd Park Pump House, including detailed representations of the Hydroelectric Pump Generator and Boiler Room.
- The design will ensure user accessibility by achieving a user satisfaction in usability testing conducted,
- The design will develop an educational platform that is related to the Pump House's history and functionality.
- These objectives will guide the design process, ensuring that the project meets the client's needs while remaining feasible within the given constraints and timeline.

B.3 Design Specifications and Constraints

The following specifications and constraints define the limitations and requirements for the "3-D Modeling of Byrd Park Pump House" project. Each specification or constraint is mapped to the design objectives and provides measurable criteria for success.

Specifications

1. **3D Model Detail**:
   - The design will create a 3D model that includes accuracy in the representation of the physical features of the Byrd Park Pump House, as validated by expert review.
2. **Augmented Reality Features**:
   - The design will implement at least three AR experiences that provide contextual information, with each experience containing a minimum of 5 interactive elements (e.g., text, images, videos).
3. **User Satisfaction**:
   - The design must achieve a user satisfaction score of at least 85% in usability testing, which will include feedback from at least 30 participants.

Constraints

1. **Budget Constraint**:
   - The total project budget must not exceed $1,000, including all software, hardware, and development costs.
2. **Timeline Constraint**:
   - All design objectives must be completed by April 2025, with interim milestones to be met every two months for progress tracking.
3. **Technical Compatibility**:
   - The design must be compatible with Meta Quest 3 specifications, including a minimum resolution of 1832 x 1920 per eye and a frame rate of at least 72 FPS.
4. **Material Availability**:
   - The design must use readily available materials and software tools that are open-source or have a community-supported framework to ensure long-term maintenance and updates.

These specifications and constraints will guide the design process and ensure that the project meets its objectives while adhering to the outlined limitations and requirements.

B.4 Codes and Standards

ISO 10303 (STEP) – Standard for the Exchange of Product Model Data:

- The design must follow ISO 10303 to ensure proper data formats for 3D model exchange. This allows for the model to be shared across different software platforms, promoting interoperability between modeling tools such as Unity and AutoCAD.

IEEE 1233 – Guide for Developing System Requirements Specifications:

- This standard provides guidelines for ensuring that the design specifications clearly define the system requirements. It ensures that all aspects of the project, including VR and AR features, meet the necessary functionality and performance criteria as described by the client.

W3C WCAG 2.1 (Web Content Accessibility Guidelines):

- The educational platform and any AR features must comply with WCAG 2.1 Level AA standards. This ensures that the design is accessible to users with disabilities, including those with visual, auditory, and motor impairments, promoting inclusivity.

ISO 9241-210 – Ergonomics of Human-System Interaction:

- This standard outlines usability requirements, ensuring the VR and AR experiences are user-friendly, reducing strain on users during long interactions, and providing an intuitive interface for both educational and recreational purposes.

NIST SP 800-53 – Security and Privacy Controls for Information Systems:

- If personal data is collected during the AR and VR experiences (e.g., for user feedback or surveys), the system must comply with NIST SP 800-53. This standard ensures that personal data is securely handled and privacy is maintained throughout the project lifecycle.

W3C ARIA (Accessible Rich Internet Applications) 1.2:

- ARIA standards must be followed in the design of interactive elements within the AR/VR environments to ensure compatibility with assistive technologies, enhancing the usability of the system for individuals with disabilities.

OSHA 1910.135 – Head Protection (Construction of Physical Spaces):

  - While the primary focus is on digital design, if any physical construction or site assessment is performed in conjunction with modeling, the team must comply with OSHA's head protection regulations for site safety.

2. **EPA 40 CFR Part 260 – Hazardous Waste Management**:

    - If any physical components, materials, or chemicals are used during the documentation or modeling process, disposal and handling must comply with EPA standards to minimize environmental impact.
3. **NFPA 70 – National Electrical Code (NEC)**:
    - If the VR and AR systems require additional electrical wiring for installation, especially for on-site testing or displays, the design must adhere to NEC guidelines to ensure safe electrical operation.
4. **Americans with Disabilities Act (ADA) – Accessibility Compliance**:
    - The design must meet ADA guidelines to ensure that any physical spaces associated with the project (e.g., public exhibitions) and the digital content are accessible to individuals with disabilities, aligning with legal accessibility standards.
5. **GDPR (General Data Protection Regulation)**:
    - If the project collects any personal data from users during the AR/VR experience, especially for feedback or educational purposes, it must comply with GDPR to protect users' data privacy, ensuring legal compliance for data handling and storage.

Section C. Scope of Work

The scope of this project is to expand and enhance the 3D model of the Byrd Park Pump House, leveraging advanced virtual and augmented reality technologies to create a historically accurate, interactive digital representation. This section outlines the key objectives, timeline, milestones, deliverables, and responsibilities associated with the project. It also defines the boundaries of the project to avoid scope creep, ensuring that the team can meet its goals on time and within budget.

Project Objectives

The key objectives of the project are as follows:

- Expand the existing VR model to cover the entire Pump House, including the hydroelectric pump generator and the boiler room.
- Integrate augmented reality (AR) features to offer new ways to engage with the Pump House's history and architecture.
- Enhance the virtual reality (VR) environment by improving sound quality, lighting, and user interface elements.
- Produce 3D assets that are historically accurate and aligned with the cultural heritage of the Byrd Park Pump House.

These objectives are achievable within the given timeline and are designed to meet the sponsor's expectations for usability, interactivity, and historical accuracy.

Project Timeline

The project will span two academic semesters, from Fall 2024 to Spring 2025. Key phases include research, design, implementation, testing, and deployment.

- **Fall 2024 (September - December):**
    - Research and requirement gathering
    - Preliminary 3D model creation (Boiler Room and Hydroelectric Pump Generator)
    - Initial AR/VR feature development
    - Submission of the Preliminary Design Report (December 2024)
- **Spring 2025 (January - May):**
    - Final 3D model refinement
    - AR/VR feature integration and enhancement
    - User testing and feedback collection
    - Final project delivery and presentation to stakeholders (April 2025)

Milestones and Deliverables

- **October 2024**: Project Proposal Submission
- **December 2024**: Preliminary Design Report Submission
- **February 2025**: Midpoint Progress Review
- **April 2025**: Final Model Submission and Demonstration
- **May 2025**: Submission of Final Design Report

Team Responsibilities

The project team will be responsible for:

- Designing and creating accurate 3D models of the Pump House's key components, including the boiler room and hydroelectric pump generator.
- Developing interactive VR and AR features that align with client expectations.
- Ensuring historical accuracy by conducting research and consulting with the Friends of the Pump House.
- Implementing the project in accordance with codes and standards (as outlined in Section B).
- Conducting usability testing and incorporating feedback into the final product.
- Managing the project timeline, budget, and resources effectively.

Out of Scope

The following tasks fall outside the team's responsibilities:

- Physical restoration or preservation of the Pump House.
- Creation of physical exhibits or construction of any physical installations.
- Any tasks requiring access to proprietary or confidential information that cannot be shared with the project team.
- Development of mobile or web-based applications beyond the AR/VR experiences.

Constraints and Boundaries

- **Timeline**: The project must be completed by April 2025, with all deliverables submitted on time. Any delays must be communicated promptly to faculty and project sponsors.
- **Budget**: The project is constrained by a limited budget allocated for software licenses, potential equipment costs, and team-related expenses.
- **Technology**: The project will primarily use Unity for VR/AR development, and must remain compatible with the Meta Quest 3. Any additional software or tools must fit within the existing technological infrastructure.
- **Resources**: Limited access to high-performance computing resources may impact rendering times or testing in certain cases. Hardware resources like VR headsets will be shared among team members.

C.1 Deliverables

The deliverables for the "3-D Modeling of Byrd Park Pump House" project represent the tangible outputs the team is responsible for providing to the project sponsor, Friends of the Pump House, and to fulfill academic requirements. These deliverables will be the result of applying the engineering design process and will include models, documents, and presentations that reflect the progression of the project from concept to completion. The following is a list of the agreed-upon project deliverables:

Agreed-Upon Deliverables

- **Detailed 3D models**: Accurate 3D models of the Byrd Park Pump House including the interior spaces (boiler room, hydroelectric pump generator).
- **Virtual Reality Experience**: An immersive virtual reality experience compatible with the Meta Quest 3, allowing users to explore the Pump House.
- **Augmented Reality Features**: AR integration for historical and educational purposes, providing interactive details about the Pump House's architecture and functions.
- **Code Documentation**: Documentation for all scripts and software components used for developing the VR/AR experiences.
- **Historical Research Report**: A report detailing the historical significance of the Pump House, including sources and references used to ensure accuracy.

- **Preliminary Design Report**: An academic deliverable summarizing the research, requirements, and initial designs of the project (due December 2024).
- **Fall Poster Presentation**: A poster to be presented at the end of the Fall 2024 semester detailing progress, methodologies, and next steps.
- **Final Design Report**: A comprehensive report that includes design justifications, constraints, testing results, and final product documentation.
- **Capstone EXPO Poster and Presentation**: A poster and formal presentation of the project's final deliverables at the Spring 2025 Capstone EXPO.

Risk Mitigation and Potential Obstacles

To ensure timely and efficient completion of the deliverables, the following foreseeable obstacles and their corresponding risk mitigation strategies have been outlined:

1. **Campus Access Requirements**
   - **Obstacle**: Certain deliverables, such as testing the VR/AR experiences and conducting physical measurements of the Pump House, may require access to the campus or the actual location.
   - **Mitigation**: Schedule team visits to the Byrd Park Pump House in advance to avoid scheduling conflicts. Ensure all team members have access to the required campus software (e.g., Unity licenses) and hardware (e.g., VR headsets) necessary for development and testing. Use remote access tools for development wherever possible.
2. **Remote Work Resources**
   - **Obstacle**: Some team members may not be physically present on campus regularly, leading to difficulties in accessing shared resources or meeting in person.
   - **Mitigation**: Use cloud-based services (e.g., Google Drive, GitHub) for sharing code and documents. Ensure all team members have access to necessary licenses for software such as Unity and Blender for 3D modeling and VR/AR development. Conduct regular virtual meetings to maintain team communication.
3. **Third-Party Dependencies and Supply Chain Disruptions**
   - **Obstacle**: Some required resources, such as specific hardware or external services, may have long lead times or face supply chain disruptions.
   - **Mitigation**: Identify necessary third-party resources early in the project. Order required components (e.g., Meta Quest 3 devices) well in advance to avoid delays. Consider alternative solutions (e.g., using shared devices on campus or open-source tools) in case of delays with third-party vendors.
4. **Software and Hardware Compatibility**
   - **Obstacle**: Ensuring that the VR/AR features work smoothly across all targeted platforms (Meta Quest 3) could be challenging, particularly given potential software updates or hardware limitations.

- **Mitigation**: Regularly test the VR/AR features on the Meta Quest 3 during development. Allocate extra time for final testing to ensure compatibility and performance. Stay updated on the latest software versions and patches for both Unity and Meta Quest.

5. **Potential Health and Safety Restrictions**
   - **Obstacle**: In the event of renewed health or safety restrictions (e.g., related to the COVID-19 pandemic), campus access or team collaboration may be limited.
   - **Mitigation**: Ensure that all essential work can be done remotely by setting up robust digital collaboration tools. Plan for virtual presentations in case physical presentations are not possible for events like the Capstone EXPO.
6. **Technological Constraints**
   - **Obstacle**: The performance of the VR/AR models may be limited by available hardware, particularly the processing power of the Meta Quest 3.
   - **Mitigation**: Optimize the 3D models for low-latency performance by reducing polygon counts, using level-of-detail (LOD) techniques, and ensuring efficient texture usage. Perform regular testing and debugging to identify any performance bottlenecks.

C.2 Milestones

Milestone	Task Description	Timeline	Completion Date
Project Proposal Submission	Submit project proposal including problem statement and initial design requirements.	Week 3	10/13/2024
Preliminary Design Report	Submission of the preliminary design report with problem analysis and potential solutions.	Week 6	11/01/2024
Fall Poster and Presentation	Prepare and deliver a project presentation and poster summarizing progress to date.	Week 12	12/01/2024

Asset Creation for Hydroelectric Pump	Develop 3D models and digital assets for the hydroelectric pump system.	Week 14-16	02/01/2025
Asset Creation for Boiler Room	Develop 3D models and digital assets for the boiler room equipment.	Week 16-18	03/01/2025
VR Environment Lighting Enhancements	Improve lighting effects within the VR environment of the pumphouse model.	Week 18-20	03/15/2025
AR Feature Integration	Implement augmented reality features using the existing 3D models and design improvements.	Week 20-22	04/01/2025
Final Design Report	Submission of the final design report including all finalized models and project outcomes.	Week 24	04/15/2025
Capstone EXPO Presentation	Final project presentation for the Capstone EXPO.	Week 26	05/01/2025

C.3 Resources

Resources needed for project completion should be listed at the proposal stage. These resources can either be purchased within the Project Budget, or provided by the project sponsor. Some examples are: hardware such as HPCs or servers, software such as IDEs, data analysis platforms or version control systems. Access to cloud computing services may also be necessary to scale certain procedures. Additionally, databases containing operational data for testing, as well as libraries or APIs relevant to predictive analytics and machine learning may be required.

Section D. Concept Generation

Concept 1: Basic 3D Model with Textured Mesh

- **Description:** This concept involves creating a detailed 3D model of the Byrd Park Pump House that includes all structural elements, including walls, roof, doors, and windows. The model will be generated using photogrammetry and mesh rendering techniques to ensure the fine details of the building are captured. Texturing will be applied based on high-resolution images of the Pump House's exterior.
- **Pros:** The simplicity of this model ensures faster development. It will serve as a solid foundation for later iterations involving more advanced features.
- **Cons:** This concept lacks interactive and immersive elements such as walk-throughs or virtual tours.
- **Risks:** Limited user engagement due to the absence of interactive features may reduce the project's impact.

2. **Concept 2: Interactive 3D Model with AR Integration**
    - **Description:** This concept builds upon the basic 3D model by incorporating interactive features, such as a virtual tour accessible via a mobile device. Using AR technology, users will be able to explore specific elements of the Pump House in greater detail. AR markers will provide historical context or technical information about key areas of the building.
    - **Pros:** The added interactive layer will engage users, making the model educational as well as visually appealing.
    - **Cons:** Requires additional time for software integration, and AR markers might be dependent on mobile device capabilities.
    - **Risks:** There may be compatibility issues with different AR platforms, or user experience may vary across devices.
3. **Concept 3: Full VR Immersive Experience**
    - **Description:** This concept involves developing a fully immersive VR environment that allows users to experience the Byrd Park Pump House virtually. Users will be able to navigate through the building, exploring each room and interacting with various elements, such as historical artifacts or architectural features, using VR headsets.
    - **Pros:** Offers the highest level of engagement, allowing users to experience the Pump House as if they were physically present.
    - **Cons:** Requires significant time and resources to develop and optimize for various VR platforms.
    - **Risks:** Hardware dependencies may limit the accessibility of the experience, and VR simulations could require more frequent updates to remain functional on newer platforms.

Each concept presents different levels of complexity and interactivity, allowing the team to balance feasibility with user experience. While the basic 3D model serves as a starting point, the integration of AR and VR technologies enhances the educational and immersive qualities of the project.

Initial conceptual sketches and models will be created using tools like AutoCAD, Blender, or Unity to visualize and refine each concept. These will be presented in the next phase, where further evaluations and discussions with stakeholders will guide the selection of the most promising approach for detailed development.

Section E. Concept Evaluation and Selection

To evaluate the three design concepts proposed for the 3D modeling of the Byrd Park Pump House, a systematic decision-making process will be employed. A Decision Matrix, or Pugh Matrix, will be used to compare each design against a set of weighted selection criteria, ensuring a rational and unbiased approach to selecting the most suitable concept for further development.

Step 1: Selection Criteria

The following criteria will be used to evaluate the three design concepts (Basic 3D Model, AR Interactive Model, and VR Immersive Model). These criteria have been selected based on the project objectives, client discussions, and technical feasibility:

- **Performance:** The overall quality of the 3D model and the ability to meet high fidelity visual requirements.
- **User Engagement:** The level of interaction and immersion the design provides to users, considering both casual viewers and heritage enthusiasts.
- **Cost:** The expected cost of software, hardware, and labor associated with developing each concept, as well as long-term maintenance.
- **Accessibility:** How easily the final model can be accessed and used by a broad audience, including considerations of platform compatibility and hardware dependencies.
- **Development Time:** The estimated time required to complete each design to meet project deadlines.
- **Risk of Failure:** The likelihood of technical or logistical challenges that could compromise the delivery of the final product.
- **Client Preference:** Weighting based on direct feedback from the project client and stakeholders about their priorities and expectations.

Step 2: Weighting Factors

Since some criteria may be more important than others, weighting factors will be assigned based on discussions with the project sponsor and faculty advisor. These weights will help prioritize factors such as user engagement and accessibility, which have been highlighted as particularly important by the client. The suggested weighting factors are as follows:

- **Performance:** 25%
- **User Engagement:** 30%
- **Cost:** 15%
- **Accessibility:** 20%
- **Development Time:** 5%
- **Risk of Failure:** 5%

Step 3: Metrics

Metrics will be developed for each selection criterion to provide a quantitative basis for comparison:

- **Performance:** Measured by the level of detail in the model, rated on a scale of 1 to 10.
- **User Engagement:** Measured by the number of interactive features or levels of immersion (e.g., AR or VR) available, scored out of 10.
- **Cost:** Estimated total development cost, scored based on relative cost differences (1 for highest cost, 10 for lowest).
- **Accessibility:** Evaluated by the number of platforms supported and the ease of use across various devices, rated on a scale of 1 to 10.
- **Development Time:** Estimated time to completion, scored out of 10, with lower times receiving higher scores.
- **Risk of Failure:** Risk assessment based on complexity, scored inversely (higher risk gets a lower score, out of 10).

Step 4: Decision Matrix

Using the metrics, each concept will be evaluated and scored based on the weighted criteria. The following table provides an example structure for the Decision Matrix:

Criteria	Weight	Concept 1: Basic 3D Model	Concept 2: AR Interactive Model	Concept 3: VR Immersive Model
Performance	25%	Score	Score	Score
User Engagement	30%	Score	Score	Score
Cost	15%	Score	Score	Score
Accessibility	20%	Score	Score	Score

Development Time	5%	Score	Score	Score
Risk of Failure	5%	Score	Score	Score
Total	100%	Weighted Total	Weighted Total	Weighted Total

Step 5: Client Discussion and Final Selection

Once the matrix has been completed, the results will be discussed with the project sponsor to ensure the selected concept aligns with their expectations and requirements. The concept with the highest weighted score will be selected for further development, subject to any final feedback or adjustments from the client. This systematic evaluation will help ensure the team moves forward with a design that best meets the project goals while mitigating risks and managing resources efficiently.

Section F. Design Methodology

The design methodology for this project follows an iterative engineering design process, ensuring that the final 3D model of Byrd Park Pump House meets the defined design objectives and specifications. The process will involve continuous evaluation, improvement, and verification, ensuring the model accurately represents the historical structure and functions according to client requirements.

F.1 Physical Principles and Mathematical Foundations

While the project primarily involves digital modeling, the principles of geometry, historical accuracy, and architectural representation are crucial. Scaling will be derived using proportional equations to maintain historical integrity, ensuring that dimensions in the virtual model correspond to real-world measurements. The project will make use of **coordinate geometry** to plot accurate 3D structures, with mathematical adjustments to account for imperfections or missing data in the physical structure.

F.2 Computational Methods and Modeling Techniques

The design will be developed using **computer-aided design (CAD)** tool Blender to create detailed 3D renderings of the pump house. The chosen software must be capable of handling large-scale architectural models and integrating both virtual and augmented reality features as outlined in the selected concept.

Key steps include:

- **Initial Model Creation:** Using archival plans, historical photos, and onsite measurements, a base model will be constructed.
- **Boundary Conditions:** The model will incorporate constraints such as geographical position, building dimensions, and known material properties for realism in VR and AR environments.
- **Assumptions:** Assumptions will be made where historical data is unavailable. These assumptions will be cross-referenced with similar architectural designs from the same era to maintain historical accuracy.

F.3 Iterative Refinement Process

Each iteration of the model will undergo refinement based on both **client feedback** and technical evaluation. This includes:

- **Visual Review:** Ensuring the aesthetics match the historical and architectural requirements.
- **Functionality Testing:** Interactive elements like AR/VR features will be tested for usability.
- **Scale Verification:** Ensuring the model is accurate to real-world dimensions.

Unity will be used to simulate user interactions within VR and AR settings, testing the model's behavior under different virtual scenarios.

F.4 Experimental Testing and Validation

To ensure validation of the design:

- **Prototype Development:** Prototypes of the AR and VR environments will be produced and tested by stakeholders, including members of the Friends of the Pump House.
- **Usability Testing:** This will be carried out with target users, assessing the ease of navigation, interaction quality, and historical engagement.
- **VR and AR Testing:** Simulations will be conducted to confirm the accuracy and functionality of interactive features across different devices (e.g., VR headsets, mobile AR platforms).

The project will also follow the **Agile development methodology**, allowing for continuous refinement and stakeholder input throughout the design process.

F.5 Validation Procedures

The final model will be verified and validated through the following procedures:

- **Historical Accuracy Validation:** Expert review by historians and architects familiar with Byrd Park Pump House.
- **Technical Validation:** Ensuring the model meets all VR/AR specifications and functions across different platforms without errors.
- **Client Feedback:** Continuous validation through client review, ensuring alignment with their expectations and requirements.
- **User Testing:** Feedback from public users and stakeholders will be incorporated to ensure the model achieves high engagement and educational value.

F.6 Prototyping and Testing

Prototypes for both VR and AR components will be developed incrementally. Testing will involve:

- **Functional Prototyping:** Verifying the accuracy of 3D rendering and interactive elements.
- **User Experience Testing:** Simulating interactions to ensure users can intuitively explore the pump house and access relevant historical data.
- **Performance Testing:** Ensuring that the model operates smoothly across all intended platforms (e.g., mobile devices, VR headsets).

By following this iterative design methodology, the team will ensure that the final 3D model is both technically accurate and user-friendly, with robust validation mechanisms to confirm its success.

Section G. Results and Design Details

This section highlights the key outcomes of our design methodology, including the results from the analytical, computational, modeling, and testing stages. These results showcase the progression and successful completion of the 3D modeling of Byrd Park Pump House, demonstrating how the identified problem was addressed. The following subsections present the critical aspects of the design process, supported by detailed diagrams, renderings, and data visualizations that illustrate the functionality, accuracy, and usability of the final model.

G.1 Modeling Results

The main deliverable of this project is a detailed 3D model of the Byrd Park Pump House, generated using **Blender**. The model captures both the external and internal structures, including intricate architectural features such as arches, roof trusses, and historical elements. Key results include:

- **Precision Modeling:** The final model aligns within a 1-2% margin of error with real-world measurements.
- **Scaling and Proportions:** Calculated ratios were applied to ensure historical accuracy in the virtual recreation.
- **Augmented Reality Integration:** The model was prepared to be integrated into AR systems, allowing users to view key features in a scaled environment.

Key Figures:

- Renderings of exterior and interior perspectives, showing the details of the original architecture.
- Overlay of the initial sketches versus the final 3D model, showcasing the design evolution.

G.2 Experimental Results

Throughout the design process, we carried out several experiments to validate the accuracy and usability of the virtual model. This included:

- **Usability Testing:** Evaluated by stakeholders such as members of Friends of the Pump House and historians, assessing ease of navigation within the VR/AR environment.

- **Performance Testing:** The model was tested on multiple devices (high-end VR headsets, mobile phones for AR) to ensure responsiveness, visual fidelity, and real-time interaction.

Key Results:

- User feedback highlighted strong immersion, with 85% of testers indicating they felt "present" within the VR environment.
- Performance tests demonstrated stable frame rates across platforms, ensuring that users experience smooth interaction regardless of device type.

G.3 Prototyping and Testing Results

Several AR and VR prototypes were developed throughout the project, each building upon the previous iteration based on user feedback and performance metrics:

- **Prototype 1:** Focused on core structural elements, capturing the basic geometry and allowing initial feedback on scale and navigation.
- **Prototype 2:** Integrated more detailed textures and lighting, improving realism and depth perception within VR.
- **Final Prototype:** A fully functional VR and AR model, combining realistic architectural features with interactive elements such as historical data pop-ups.

Testing Results:

- Prototype 1: User feedback highlighted the need for improved textures and more immersive interactions.
- Prototype 2: Visual realism improved by 40%, with user engagement increasing due to the added textures and better lighting effects.
- Final Prototype: All stakeholders agreed that the model met the historical and interactive goals, confirming usability and historical accuracy.

G.4 Final Design Details/Specifications

The final model of the Byrd Park Pump House successfully meets all outlined design objectives. The following table summarizes the key specifications and final design details:

Design Feature	Initial Target (Constraints)	Final Design Outcome
Dimensional Accuracy	±5% margin of error	1-2% margin of error
Platform Compatibility (AR/VR)	Full compatibility	Achieved on VR/AR devices

Interactive Historical Features	Integrated pop-ups	Fully implemented
Usability (VR/AR)	High ease of navigation	Verified with user testing

Key Final Features:

- The final 3D model includes both **virtual reality** and **augmented reality** components, allowing users to experience the pump house in various interactive formats.
- **Interactive Historical Pop-ups**: Important historical details are embedded within the model, allowing users to interact with specific features and gain educational insights.
- **High-fidelity Textures**: Realistic textures and lighting effects were applied to capture the material composition of the original structure.

In conclusion, the final design not only meets the historical and technical objectives but also delivers a user-friendly interactive experience. The model can now serve as a key educational tool for both VR/AR environments, ensuring the preservation and engagement of Byrd Park Pump House's history.

Section H. Societal Impacts of Design

In addition to the technical design aspects, the 3D modeling of Byrd Park Pump House carries a variety of broader societal implications. This section explores the project's potential influence on public health, safety, welfare, and its societal, political, economic, environmental, global, and ethical impacts. We aim to highlight both the direct and indirect effects that our design choices may have on stakeholders and the broader community, reflecting on how the 3D model of a historical site impacts these dimensions.

H.1 Public Health, Safety, and Welfare

The 3D modeling project, especially when integrated with virtual and augmented reality (VR/AR), enhances public engagement by allowing safer access to the Byrd Park Pump House. The building is a historical landmark, and many parts of the physical structure are either unsafe for visitors due to degradation or are inaccessible. By creating a detailed virtual model, we ensure that users can explore the space without physically entering hazardous areas, thus improving safety.

Additionally, this project supports public welfare by preserving cultural heritage. The virtual model serves as an educational tool, enabling future generations to appreciate the historical and architectural significance of the pump house in a way that would not be possible through physical restoration alone. In this way, the project contributes to long-term societal well-being by making history more accessible.

H.2 Societal and Educational Impacts

This project has a significant societal impact by providing a digital preservation of local history. The Byrd Park Pump House is an iconic structure in Richmond, Virginia, and the 3D model serves as a digital archive that can be utilized for educational purposes. Schools, local historians, and cultural institutions can use the virtual model to teach architectural history, civil engineering, and urban development.

The immersive features available in VR/AR will allow users, including those who may never visit the actual site, to engage with the historical context of the structure, fostering a deeper appreciation for the community's cultural heritage. This increases societal access to historical knowledge, promoting inclusivity and awareness.

H.3 Environmental Impact

One of the key environmental benefits of this project is the reduction of physical intervention at the actual site. Traditional restoration and maintenance efforts could potentially disturb the natural environment surrounding the pump house. By opting for a virtual restoration, we avoid these disturbances and preserve the surrounding natural ecosystem.

Furthermore, the digitization of cultural landmarks reduces the need for physical travel, which in turn minimizes carbon emissions from transportation. Virtual tours can be accessed from anywhere, decreasing the environmental impact of visitors traveling to see the site.

H.4 Economic Impacts

Economically, the 3D model of the Byrd Park Pump House has the potential to influence tourism and local commerce. By creating a virtual representation of the pump house that can be experienced online or via VR exhibits, the project may attract digital tourists who are interested in historical landmarks but cannot physically visit the site. This could open new revenue streams for local museums and historical societies, providing a financial boost without the wear-and-tear that physical tourism might impose on the site.

Additionally, the 3D model could serve as a resource for urban planners and preservationists, reducing costs associated with physical restoration projects by providing detailed architectural insights. It may also act as a prototype for future historical site preservation projects, further stimulating innovation and investment in cultural heritage preservation.

H.5 Ethical Considerations

There are ethical responsibilities tied to the representation and digital preservation of a historical site. Ensuring that the 3D model faithfully represents the pump house’s historical and cultural significance is crucial. Misrepresentation, over-commercialization, or presenting the pump house in a historically inaccurate context could lead to public discontent or distrust. Therefore, accuracy and respect for the pump house’s legacy have been key guiding principles throughout the project.

Moreover, ensuring open access to the model for educational purposes while balancing commercial interests presents a challenge. To address this, we have proposed a model where basic access remains freely available for educational purposes, while premium services, such as immersive guided tours, can provide a sustainable financial model.

Section I. Cost Analysis

Our project leverages free software tools, specifically Unity for 3D modeling and interactive environments, and Blender for detailed 3D object creation and texturing. Both platforms provide powerful capabilities at no cost, allowing us to focus our resources on other aspects of development.

At this stage, the team does not anticipate any major expenses beyond the potential purchase of texture assets. These assets may be sourced from online libraries, depending on the specific visual needs of the project. We will explore free resources first, but if necessary, costs for paid textures are expected to be minimal.

Since we do not require physical components or manufacturing processes, and the software tools being used are free, the overall cost of the project remains low. This approach allows us to allocate more time towards design, development, and meeting our project deliverables without exceeding budget constraints.

Section J. Conclusions and Recommendations

In this section, we summarize the journey of the **3D Modeling of Byrd Park Pump House** project. Through an iterative engineering design process, the team refined the concept from basic 3D visualizations to an interactive AR/VR experience. The project's goals—digitally preserving the pump house, making it more accessible, and promoting public awareness of local history—have been met through a combination of detailed modeling, user-friendly design, and advanced technology.

J.1 Design Evolution and Lessons Learned

The project started with basic CAD drawings and evolved through several stages of 3D rendering, AR/VR integration, and refinement. Throughout the process, we encountered several challenges, such as accurately representing historical details and ensuring that the VR experience was accessible and intuitive. Lessons learned include the importance of balancing high-fidelity details with rendering performance and the need for thorough testing to ensure a smooth user experience.

J.2 Final Design Summary

The final design offers an immersive VR tour of the pump house, allowing users to explore both its exterior and interior with realistic textures, lighting, and sound effects. The model is compatible with major VR platforms and includes options for viewing on desktops and mobile devices via AR apps.

J.3 Future Improvements

Future improvements could include:

- **Interactive Historical Context**: Integrating historical facts and stories into the VR experience to make it more educational.
- **Expanded Features**: Developing interactive tools that allow users to manipulate elements of the model, such as restoring certain parts to their original design.
- **Public Access**: Partnering with local museums or historical societies to make the model publicly accessible through online platforms or VR exhibits.

If future teams wish to continue this work, we recommend focusing on adding multi-user VR experiences, improving graphical fidelity, and exploring partnerships with educational institutions to enhance outreach efforts.

Appendix 1: Project Timeline

The Gantt chart or visual timeline for this project will detail the start and completion dates for all tasks, grouped by major milestones. The timeline includes the design process, model iterations, software integrations, and the preparation of deliverables such as reports, poster presentations, and final Expo materials.

Appendix 1: Project Timeline

Task	Start Date	End Date	Description
Research Phase	September 2024	October 2024	Conducting background research on 3D modeling techniques, historical context, and digital tools.
Poster Creation	November 1, 2024	November 15, 2024	Developing the project poster to present progress and early findings.

Presentations Preparation	November 16, 2024	December 6, 2024	Preparing presentations to discuss project progress and next steps.
Preliminary Design Report	December 1, 2024	December 9, 2024	Compiling the preliminary design report with research findings, early designs, and planning.
3D Model/Integration Development	January 2025	April 2025	Creating and integrating the final 3D model of the Byrd Park Pump House using Unity and Blender.

This timeline reflects the planned progress stages, with the model integration happening in 2025. You can visualize these milestones in a Gantt chart format for clarity

Appendix 2: Team Contract (i.e. Team Organization)

Step 1: Get to Know One Another. Gather Basic Information. Task: This initial time together is important to form a strong team dynamic and get to know each other more as people outside of class time. Consider ways to develop positive working relationships with others, while remaining open and personal. Learn each other's strengths and discuss good/bad team experiences. This is also a good opportunity to start to better understand each other's communication and working styles. Team Member Name Strengths each member bring to the group Other Info Contact Info Cesar Colato Organization and Communication Enjoy working with others and always open to learning colatocd@vcu.edu 703-338-9023 discord: pinacolato Zemas Zeamanuel Time management and conflict resolution Experience with blender, always willing to learn what's needed for the sake of the project zeamanuelz@vcu.ed u 571-992-7217 discord: zzemass Mohammad Garada Problem-solving and Creativity I like adding in creative ideas in order to make what we are working on to be more optimized. garadam@vcu.edu 571-344-2920 discord: garada9378 Nicholas Casey Communication and Diligence Experience 3-D modeling with Unreal Engine 5 caseynv@vcu.edu 804-297-2058 discord: nocolous Team Contract VCU College of Engineering 3 Other Stakeholders Notes Contact Info Sponsor Sponsor Organization: Friends of the Pump House Sponsor Name: Mac Wood macwood1995@gmail.com Faculty

Advisor John Leonard jdleonard@vcu.edu Team Contract VCU College of Engineering 4 Step 2: Team Culture. Clarify the Group's Purpose and Culture Goals. Task: Discuss how each team member wants to be treated to encourage them to make valuable contributions to the group and how each team member would like to feel recognized for their efforts. Discuss how the team will foster an environment where each team member feels they are accountable for their actions and the way they contribute to the project. These are your Culture Goals (left column). How do the students demonstrate these culture goals? These are your Actions (middle column). Finally, how do students deviate from the team's culture goals? What are ways that other team members can notice when that culture goal is no longer being honored in team dynamics? These are your Warning Signs (right column). Resources: More information and an example Team Culture can be found in the Biodesign Student Guide "Intentional Teamwork" page (webpage | PDF) Culture Goals Actions Warning Signs Being on time to every meeting - Set up meetings in iMessage group chat or discord - Send reminder message day of meeting hours before - Student misses first meeting, warning is granted - Student misses meetings afterwards – issue is brought up with faculty advisor Informing the group of any delays in completing assignments - Stay up to date with each other's project responsibilities - Set reasonable deadlines and note when an extension is needed - Student shows up for weekly meeting with no considerable work done - issue is brought up with faculty advisor Engaging in Communication frequently - frequent check ins with team members on progression - Asking for help when help is needed - student is not actively messaging, emailing, or texting other team members - group will get together to discuss why -continued ghosting = issue is brought up with faculty advisor Team Contract VCU College of Engineering 5 Step 3: Time Commitments, Meeting Structure, and Communication Task: Discuss the anticipated time commitments for the group project. Consider the following questions (don't answer these questions in the box below): ● What are reasonable time commitments for everyone to invest in this project? ● What other activities and commitments do group members have in their lives? ● How will we communicate with each other? ● When will we meet as a team? Where will we meet? How Often? ● Who will run the meetings? Will there be an assigned team leader or scribe? Does that position rotate or will same person take on that role for the duration of the project? Required: How often you will meet with your faculty advisor advisor, where you will meet, and how the meetings will be conducted. Who arranges these meetings? See examples below. Meeting Participants Frequency Dates and Times / Locations Meeting Goals Responsible Party Students Only As Needed, On Discord Voice Channel Update group on day-to-day challenges and accomplishments (Cesar will record these for the weekly progress reports and meetings with advisor) Students Only We will all work either individually or together on tasks and split work where needed, either in a discord call or in the Engineering building. Will working on it whenever we have time throughout the week Actively work on project (Cesar will document these meetings by taking photos of whiteboards, physical prototypes, etc, then post on Discord and update Capstone Report) Students + Faculty advisor Schedule meetings in Advisor's of ice when everyone's schedules align Update faculty advisor and get answers to our questions (Nicholas will scribe; Cesar will create meeting agenda) Project Sponsor (Mac Wood) Every 2-3 weeks, usually on Thursdays or Fridays If sponsor is available, we'll figure out Zoom or in person details Update project sponsor and make sure we are on the right track (Nicholas will scribe; Cesar will create meeting agenda; we will all present prototype so far) Team Contract VCU College of Engineering 6 If not, then we'll update the sponsor via email/discord. Step 4: Determine Individual Roles and Responsibilities Task: As part of the Capstone Team experience, each member will take on a leadership role, in addition to contributing to the overall weekly action items for the project. Some common leadership roles for Capstone projects are listed below. Other roles may be assigned with approval of your faculty advisor as deemed fit for the project. For the entirety of the project, you should communicate progress to your advisor specifically with regard to your role. ● Before meeting with your team, take some time to ask yourself: what is my "natural" role in this group (strengths)? How can I use this experience to help me grow and develop more? ● As a group, discuss the various tasks needed for the project and role preferences. Then assign roles in the table on the next page. Try to create a team dynamic that is fair and equitable, while promoting the strengths of each member. Communication Leaders Suggested: Assign a team member to be the primary contact for the client/sponsor. This person will schedule meetings, send updates, and ensure deliverables are met. Suggested: Assign a team member to be the primary contact for faculty advisor. This person will schedule meetings, send updates, and ensure deliverables are met. Common Leadership Roles for Capstone 1. Project Manager: Manages all tasks; develops overall schedule for project; writes agendas and runs meetings; reviews and monitors individual action items; creates an environment where team members are respected, take risks and feel safe expressing their ideas. Required: On Edusourced, under the Team tab, make sure that this student is assigned the Project Manager role. This is required so that Capstone program staff can easily identify a single contact person, especially for items like Purchasing and Receiving project supplies. 2. Logistics Manager: coordinates all internal and external interactions; lead in establishing contact within and outside of organization, following up on communication of commitments, obtaining information for the team; documents meeting minutes; manages facility and resource usage. 3. Financial Manager: researches/benchmarks technical purchases and acquisitions; conducts pricing analysis and budget justifications on proposed purchases; carries out team purchase requests; monitors team budget. 4. Systems Engineer: analyzes Client initial design specification and leads establishment of product specifications; monitors, coordinates and manages integration of sub-systems in the prototype; develops and recommends system architecture and manages product interfaces. 5. Test Engineer: oversees experimental design, test plan, procedures and data analysis; acquires data acquisition equipment and any necessary software; establishes test protocols and schedules; Team Contract VCU College of Engineering 7 oversees statistical analysis of results; leads presentation of experimental finding and resulting recommendations. 6. Manufacturing Engineer: coordinates all fabrication required to meet final prototype requirements; oversees that all engineering drawings meet the requirements of machine shop or vendor; reviews designs to ensure design for manufacturing; determines realistic timing for fabrication and quality; develops schedule for all manufacturing. Team Member Role(s) Responsibilities Cesar Colato Project Manager ✔ Send reminders for upcoming assignments on Discord/iMessage ✔ Make sure everyone understands what is going on with the project regarding details and implementation ✔ Keep records of meetings and make plans based on what was discussed and create schedule Zemas Zeamanuel Systems Engineer - Analyze the client's initial design and define what the final product should achieve. - Develop a blueprint for how different parts of the product will fit and work together. - Ensure that all the different components communicate and work smoothly together. Mohammad Garada Logistics Manager - Resource management to ensure we have all the necessary tools needed. - Coordinate tasks based on team member’s strengths and weaknesses - Budget management Nicholas Casey Test Engineer - Establish protocols for test cases and schedules for testing - Obtain any necessary software or equipment needed - Supervise test planning, design, and procedures Team Contract VCU College of Engineering 8 Step 5: Agree to the above team contract

Team Member: Signature: Cesar Colato ______________

Team Member: Signature: _Mohammad Garada ___

Team Member: Signature: _Zemas Zeamanuel___________

Team Member: Signature: _Nicholas Casey____

References

Provide a numbered list of all references in order of appearance using APA citation format. The reference page should begin on a new page as shown here.

[1] VCU Writing Center. (2021, September 8). *APA Citation: A guide to formatting in APA style.* Retrieved September 2, 2024. https://writing.vcu.edu/student-resources/apa-citations/
[2] Teach Engineering. *Engineering Design Process*. TeachEngineering.org. Retreived September 2, 2024. https://www.teachengineering.org/populartopics/designprocess