Project Management Plan: EcoElevate

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Table of Contents

List of Figures

List of Tables

List of Acronyms

ACWP	Actual Cost of Work Performed
BAC	Budget at Completion
BCWP	Baseline Cost of Work Performed
BCWS	Baseline Cost of Work Scheduled
CAD	Computer Aided Design
CBS	Cost Breakdown Structure
CSR	Corporate Social Responsibility
CV	Cost Variance
EAC	Estimate at Completion
EF	Early Finish
ES	Early Start
EVM	Earned Value Management
HR	Human Resources
HVAC	Heating, Ventilation, and Air Conditioning
IoT	Internet of Things
KSABs	Knowledge, Skills, Abilities and Behaviors
LED	Light Emitting Diode
LF	Late Finish
LRC	Linear Responsibility Chart
LS	Late Start
QA	Quality Assurance
ROI	Return on Investment
SLA	Service Level Agreement
SRD	System Requirements Document
SV	Schedule Variance
V&V	Verification and Validation
WBS	Work Breakdown Structure

1. Project Systems Engineering Approach

1.1 Problem Statement (Mark Tarazi)

The global demand for high-quality produce is increasing while reliable and sustainable energy resources are diminishing. Traditional farming is limited by geography and climate, which restricts crop availability and increases costs for storage. A description of the solution space is provided in Table 1. Although vertical farming offers a potential solution by enabling controlled-environment agriculture with high yields, it demands high energy which most farmers in the United States cannot meet, especially with the use of artificial lighting and irrigation systems. Other risks that farmers and growers face include a lack of affordable, energy-efficient vertical farming systems that can conform to different spaces while maintaining sustainable water and power consumption.

Vertical farming allows regional or seasonal crops to be grown indoors year round, often without the use of pesticides, and for some crops, yields 10 to 20 times that which can be obtained per acre in traditional open-yield crops. Increasing the accessibility of vertical farming increases consumer access to high quality, fresh, locally grown produce year round.

The three largest risk categories associated with vertical farming include technical risks, economic risks, and environmental risks. Technical risks are the most likely to occur, as the entire system depends on continuous and precise operation. Any component that does not function properly from lighting to climate control to water circulation threatens the system's functionality. Economic risks, such as high operational costs and competition with existing vertical farming solutions, make implementation more challenging. Lastly, environmental risks depend on the climate and region of the vertical farm and can impact the growth and production of crops. Depending on the location, systems may require higher energy consumption.

Table 1: Characterization of Solution Space

Characterization of Solution Space		
Topic	Solution	Considerations
System Design	Stackable, modular design that use containers for crops for easy removal	Dimensions of containers and height of stacks vary by use
Energy Supply	Use solar panels with batteries as back up	Must be reliable, especially if there is no sunlight

Irrigation	Drip irrigation with stackable design and recycling water	Must hydrate the crops consistently while minimizing the amount of water used
Lighting	LED grow lights automated by optimal lighting schedule	Lighting should optimize the amount of power used and account for the type of crops
Environmental Control	Autonomous sensors/controls for temperature, humidity,	Integrate with AI without human intervention
Scalability	Commercial farm-scale units	Make parts simple to assemble and modular without complicating the design

1.2 Project Objective (Janus Aurpy)

Objective Statement

The EcoElevate project aims to design, validate and deploy a modular solar-powered vertical farming system that maximizes energy and water efficiency while ensuring consistent production of high-quality locally grown produce throughout the year. The system combines renewable energy with automated agricultural processes to address rising consumer demand and growing concerns over limited resources. It integrates autonomous environmental controls, LED grow lighting and a closed-loop drip irrigation system to lower operating costs, reduce environmental impact and give farmers a scalable solution.

Business and Mission Relevance

EcoElevate sits at the intersection of technology, sustainability and agricultural productivity. From a business perspective the system reduces high costs and inefficiencies that challenge many vertical farms. It lowers costs associated with energy dependency through solar power and battery storage so operations are less tied to expensive utility grids. From a mission standpoint it advances the goal of resilient and sustainable food systems by:

- Reducing reliance on external energy sources and stabilizing farm operations through renewable energy adoption.
- Optimizing water usage with closed-loop drip irrigation that minimizes waste while maintaining consistent hydration for crops.

- Expanding consumer access to fresh, pesticide-free produce that can be grown year-round, regardless of regional climate constraints.
- Providing scalable, modular units that allow small-scale farmers and large commercial operators alike to customize and expand production capacity as needed.

EcoElevate also supports social and environmental goals. It creates opportunities for local jobs, strengthens food security and reduces emissions from transporting produce over long distances. These outcomes reinforce its alignment with sustainable development and long-term agricultural resilience.

Strategic Alignment with Opportunity

EcoElevate is designed to meet the growing demand for sustainable farming systems that balance affordability and innovation. Many current vertical farms require high upfront costs and heavy energy use. EcoElevate addresses these challenges with modular design, cost-efficient operation and autonomous monitoring. These qualities make the system accessible to more farmers and allow it to evolve with improvements in energy technology and agriculture.

The project objective ties directly to the needs of stakeholders:

- Farmers and operators benefit from reduced energy costs, simplified system operation, and the ability to expand production capacity incrementally.
- Consumers gain reliable access to affordable, safe, and locally grown food regardless of seasonality.
- Investors are provided with a scalable, future-focused business model that reduces risk by incorporating renewable energy and automation.
- Regulators and policymakers see the value in systems that support compliance with renewable energy mandates, food safety requirements, and environmental standards.

By aligning technical design with clear stakeholder needs EcoElevate positions itself as a transformative solution for agriculture. The project objective serves as both a guiding vision and a benchmark for success, keeping the system engineering process focused on delivering value to all participants.

1.3 Project Scope (Janhavi Gaikwad)

Scope Statement

The EcoElevate project aims to revolutionize traditional agriculture by implementing a digital, data-driven vertical farming system capable of producing crops year-round. Leveraging IoT sensors and a centralized monitoring platform, the system enables real-time oversight and coordinated management of farm operations. This includes data sharing to farm operators, maintenance staff, and suppliers, ensuring efficient, reliable, and optimized workflows.

As shown in Figure 1, the system operates within a complex environmental context that encompasses human actors, regulatory requirements, market demands, and the supporting technical infrastructure, all of which directly influence system performance. By integrating sustainable practices, including solar energy utilization and recycled water systems, EcoElevate seeks to optimize resource use while maintaining scalability, operational efficiency, and long-term sustainability.

This solution provides a new perspective on agricultural systems by combining technological innovation with environmental responsibility, addressing the need for consistent, high-quality crop production in a controlled, resource-efficient manner.

Context Diagram

The context diagram in Figure 1 shows the Vertical Farming System as the system of interest. The system boundary includes the crops and their associated monitoring and Deling systems which track the soil moisture, nutrients and temperature of an environment. These internal elements were selected because they represent processes the project team can design and manage.

External entities like suppliers, operators, customers, regulatory bodies, and the power utility are outside the boundary. They are essential for operations but cannot be directly controlled. The operator interacts with the system via the monitoring platform, while maintenance staff execute tasks under operator instructions. Suppliers and power provide inputs, regulators impose compliance requirements, and customers receive harvest updates.

This boundary was chosen to clearly distinguish between controllable farm operations and external dependencies. The diagram highlights how the system needs internal execution with external influences to achieve sustainable, year-round production.

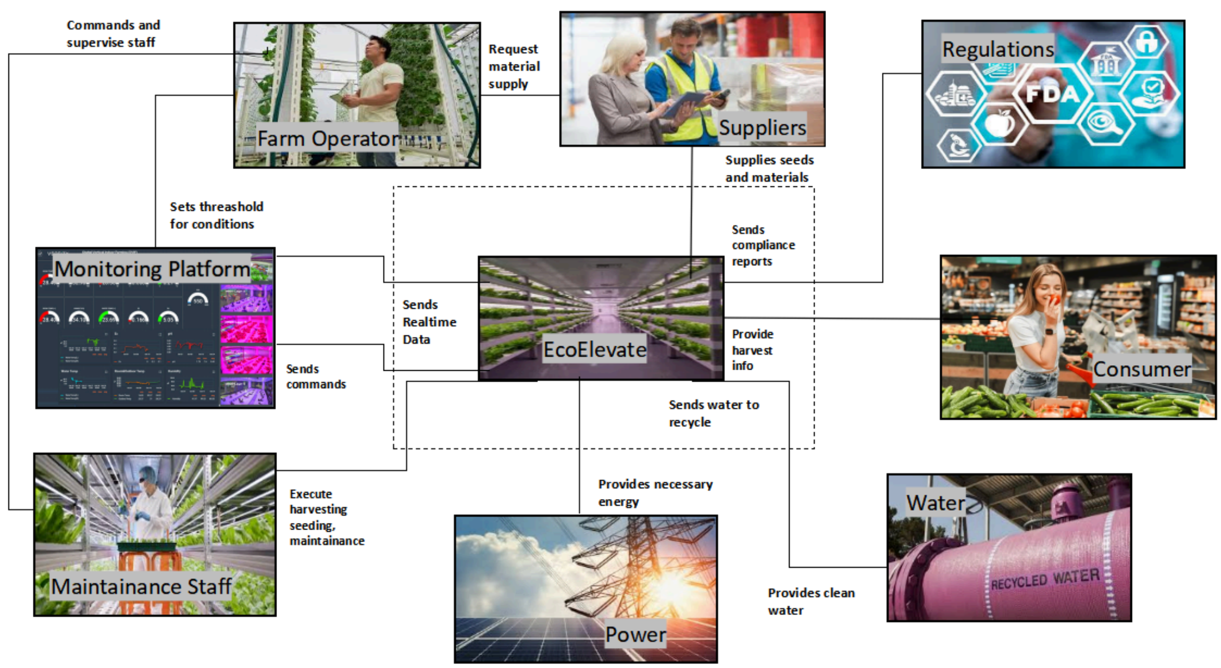


Figure 1: Context Diagram

1.4 Stakeholder Identification (Karina Rivera-Lanza)

For this project, stakeholders were identified through a review of all groups directly involved in, benefiting from, or influencing the solar-powered vertical farming system. As shown in Table 2, the analysis considered both those who will use or operate the product, and those who provide oversight, funding, or resources. Key stakeholders include the community that benefits from local job creation and sustainability; consumers who will purchase fresh, pesticide-free produce; investors who fund the initiative and seek returns; suppliers who provide critical equipment and materials; regulators ensuring compliance with food safety and energy standards; and farm owners who will manage the daily operations. These stakeholders were prioritized based on their level of influence on project success and their degree of impact from the project outcomes.

Table 2: Stakeholder Analysis

Stakeholder	Needs	Concerns	Roles
Community	Job creation, sustainability benefits, reduced reliance on imports	Fear of exclusion, disruption, or lack of local involvement	End-users of benefits, labor force, advocates for local adoption
Consumers	Affordable, fresh, pesticide-free produce	Price competitiveness, food safety, availability	Customers, feedback providers, brand ambassadors
Investors	ROI, reduced energy costs, market growth	Risk of delays, budget overruns, unclear scalability	Funders, strategic advisors
Suppliers	Stable long-term contracts for equipment and materials	Payment delays, order unpredictability	Providers of critical inputs, technical partners
Regulators	Compliance with food safety, renewable energy, and sustainability standards	Non-compliance risks, potential policy changes	Approvers, enforcers of standards
Farm Owners / Operators	Lower operating costs, efficient systems, knowledge transfer	System breakdowns, high training needs, unclear maintenance roles	Day-to-day operators, custodians of system performance

1.5 Stakeholder Management Plan (Karina Rivera-Lanza)

Managing stakeholders for this project required an assessment of their needs, concerns, and potential contributions. Stakeholder roles were defined by mapping how each group interacts with the project—from financing and supply chain support to operation and end use. Their expectations, such as affordability for consumers, compliance for regulators, and profitability for investors, were matched with engagement strategies that balance communication, consultation, and collaboration. This structured approach, as outlined in Table 3, ensures that every stakeholder group is not only considered in the planning process but actively involved in shaping the project's successful delivery. Table 4 shows the relationship between interest and influence and how that maps to different strategies for different stakeholder groups.

Table 3: Stakeholder Engagement

Stakeholder	Engagement Plan	Style of Engagement	Frequency
Community	Town hall meetings, CSR programs, training workshops	Consult and involve (two-way dialogue)	Quarterly updates and ad-hoc forums
Consumers	Marketing campaigns, loyalty programs, feedback channels	Inform and consult	Ongoing via social media; monthly surveys
Investors	Structured progress reports, financial dashboards, review meetings	Manage closely (high influence & interest)	Monthly updates; quarterly reviews
Suppliers	Service-level agreements (SLAs), coordination calls	Partner and collaborate	Bi-weekly during setup; monthly in operations
Regulators	Compliance audits, early permitting involvement, documentation	Keep satisfied (assurance of compliance)	As required for permits; annual reports
Farm Owners / Operators	Hands-on training, manuals, 24/7 support hotline	Empower and enable	Daily during setup; weekly during operations

Table 4: Stakeholder Influence & Interest Matrix

	High Interest	Low Interest
High Influence	Manage Closely: Investors, Regulators, Farm Owners	None Identified
Low Influence	Keep Informed: Community, Consumers	Keep Satisfied: Suppliers

1.6 Operations Concept (Louise Smith)

At the center of EcoElevate is the vertical farm system. As seen in the Operations Concept diagram in Figure 2, the vertical farm grows a variety of produce in a form factor that allows more food to be grown per square foot, enabling food to be grown locally, even in urban areas. A control system allows an operator to monitor and adjust various environmental factors including temperature, humidity, water levels to grow plants efficiently. The vertical farm system is powered by solar panels, and excess energy collected by the solar panels can be sent back to the grid. Once grown, produce will be sold at local grocery stores, where shoppers can enjoy locally grown produce year-round.

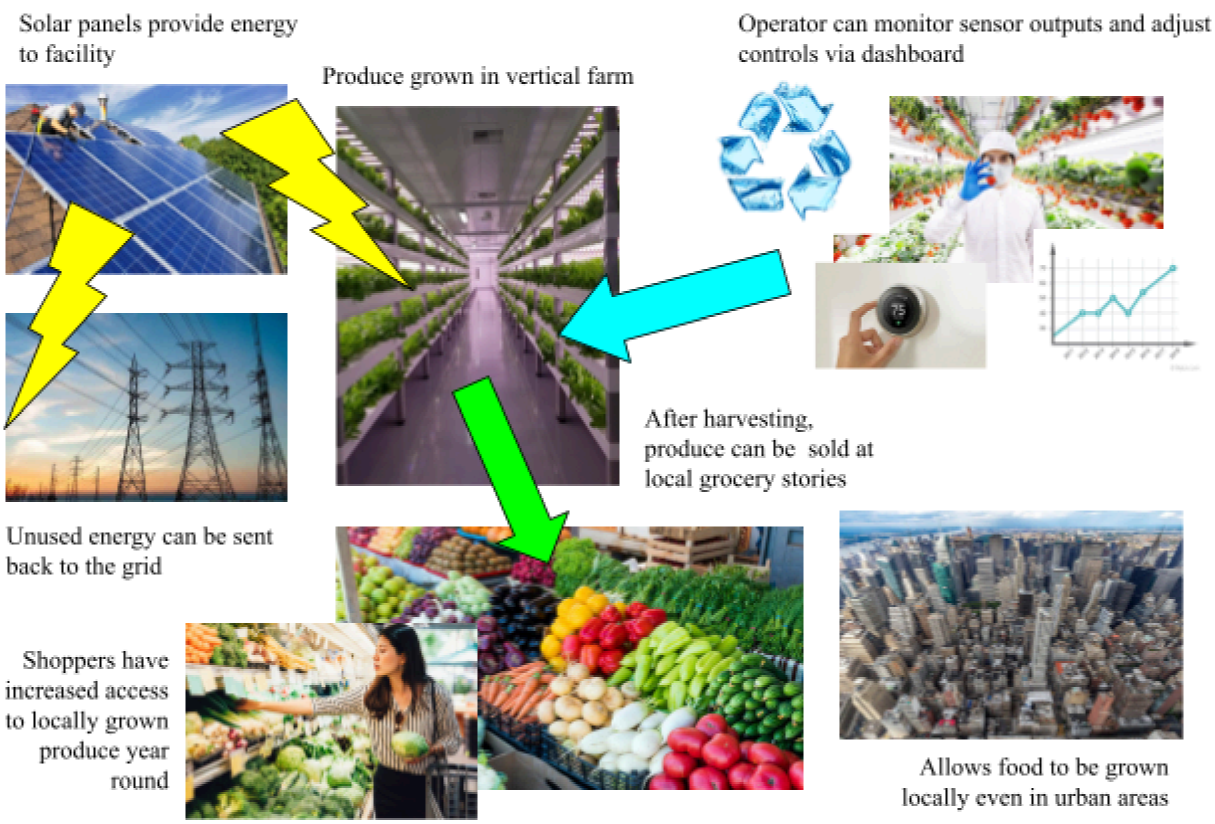


Figure 2: EcoElevate OpsCon Diagram

1.7 Project Assumptions (Louise Smith)

The operations concept has been developed with the assumptions described in Table 5. These assumptions include levels of technology maturation required to make the project feasible, as well as some assumptions related to operation of the EcoElevate facility and use of external vendors.

Table 5: Assumptions

	Assumption	Rationale
1	Assume that EcoElevate will be installed in areas where sufficient sunlight exists year round that the solar panels will produce enough energy within a day to power the facility.	In order to create a solar powered facility, it needs to be located in an area where there is enough sunlight. As solar panel technology matures, the number of viable locations will increase.
2	Assume that battery technology is sufficiently mature that onsite energy storage solutions can store enough energy to power the facility overnight.	Since the system will be powered by solar energy, onsite energy storage will be required to meet energy demands overnight.
3	Assume that agriculture technology has improved such that a wide variety of produce can be efficiently grown vertically.	Current commercial vertical farming efforts have been focused primarily on leafy greens, herbs and microgreens, but research is ongoing to develop strategies to grow more crops vertically. Being able to grow a wide variety of produce vertically increases EcoElevate's offerings.
4	Assume that after completion, EcoElevate will be operated by an entity external to the team.	This project plan is focused on designing and deploying EcoElevate, and does not include operating it on a day-to-day basis after project completion.
5	Assume that the monitoring platform will be provided by an external vendor.	Since various commercial control systems exist, use of an industry standard system will increase the robustness of the system and decrease development costs.

1.8 Project Lifecycle Model (Wantong Yao)

Model Chosen: Incremental Model

The three lifecycle models shown in Figure 3 each have distinct characteristics and applicable scenarios. Sequential Model features a strictly linear progression through phases, advancing sequentially from requirements, design, implementation, verification, to deployment. It is suitable for projects with well-defined requirements, mature technology, and low risk. The Incremental Model divides the system into multiple deliverable increments, with each increment adding functionality or performance upon the previous phase. It is appropriate for systems that can be delivered in parts and refined incrementally. And the Evolutionary Model emphasises continuous improvement and evolution based on user feedback, refining the system through rapid exploration and validation. It is suitable for projects with uncertain requirements, high innovation, and a need for early user involvement.

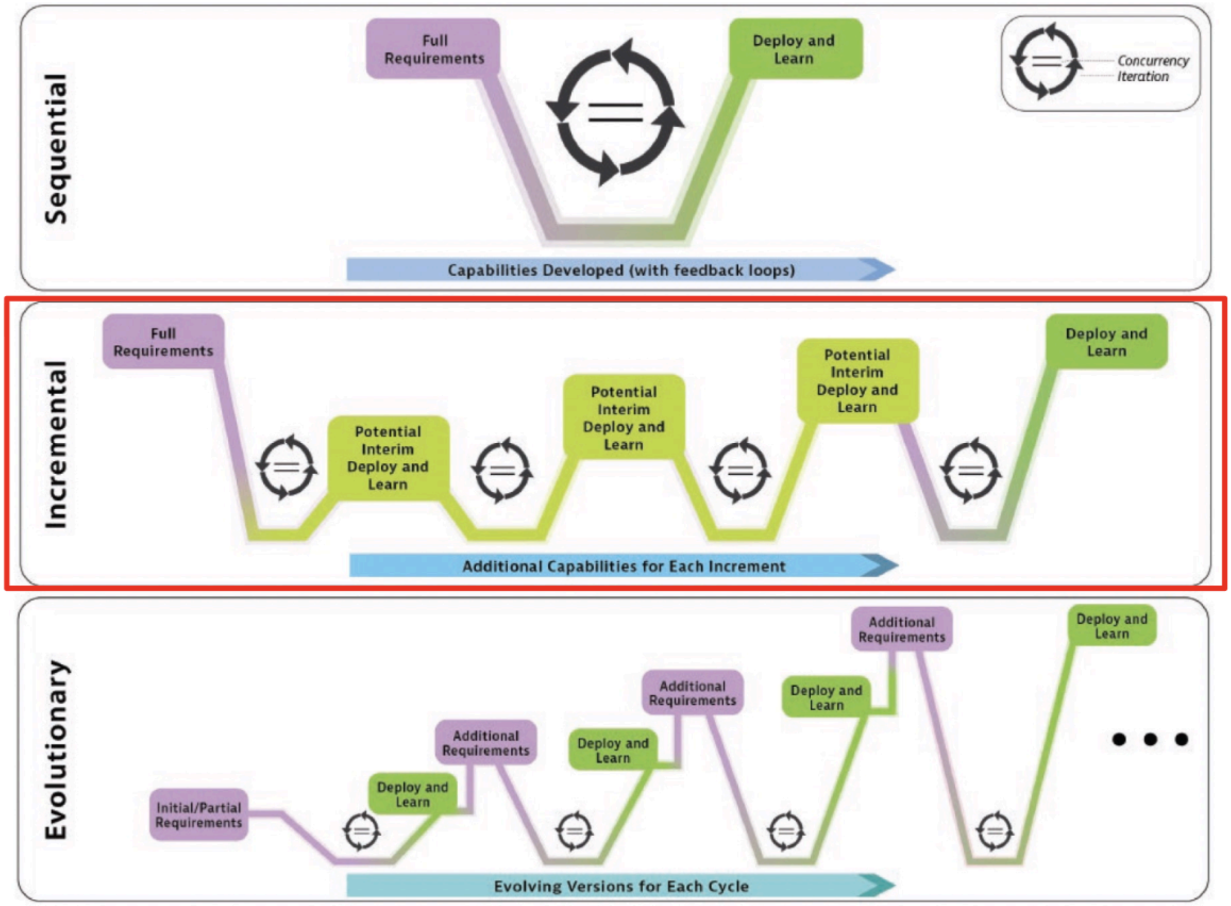


Figure 3: Project Lifecycle Models

Given the high technical complexity and moderate risk level of this project, coupled with its clear objectives and tight timeline, a phased validation and incremental integration process is required. An incremental model represents our optimal choice. From a **systems novelty** perspective, our project integrates technologies such as solar power and automated irrigation, necessitating multiple rounds of prototype validation. Furthermore, as the project spans agriculture, energy, and automated control domains, the **complexity** makes it unsuitable for one-time completion and ideally should be implemented in phases. Factors such as insufficient energy supply and demanding environmental control requirements introduce inherent **risks**, necessitating phased validation to mitigate overall late-stage hazards. Operationally, the project's **operational environment** demands on-site deployment, testing, and configuration—a complex process requiring incremental reliability verification. Finally, constrained by **resource profile**, our project budget of $1M will be released in 4 phases over a 12-month cycle. This necessitates clear phase delineation and milestone management. In summary, the Incremental Model approach will enable our team to provide deliverables at each stage, mitigating risks, optimizing resource allocation, and incorporating test feedback into every iteration. Ultimately, this will help establish a mature and scalable solar-powered vertical farming system.

2. Project Organization and Staffing

2.1 Organizational Structure (Louise Smith)

The company is organized along a matrix structure as shown in Figure 4 with three core functional areas: Engineering, Agriculture, and Operations and Business, each of which is led by a Director. Project Management is its own area and is led by a Director of Project Management. The Engineering functional area is further divided into divisions that include Electrical and Solar, Mechanical and Structural, and Software and Controls. Similarly, the Operations and Business area is made up of the Procurement, Quality, and HR division.

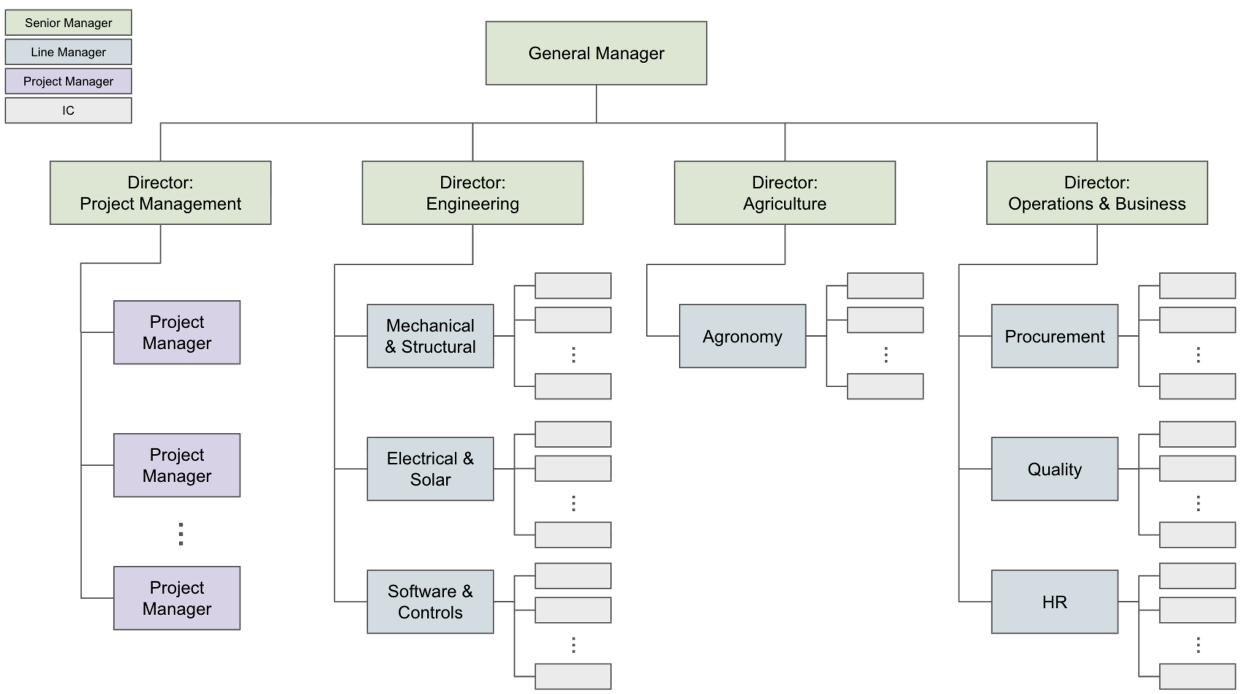


Figure 4: Company Organizational Structure

Project teams are led by project managers, who report directly to the Director of Project Management. Each project manager is responsible for working closely with upper management, as well as the functional area division leads to secure resources for the project.

2.2 Project Team Structure (Louise Smith)

The EcoElevate project is divided into three teams that are focused on the power system, the structural elements of the vertical farm, and the automated plant care, each of which is led by a different project manager as shown in Figure 5.

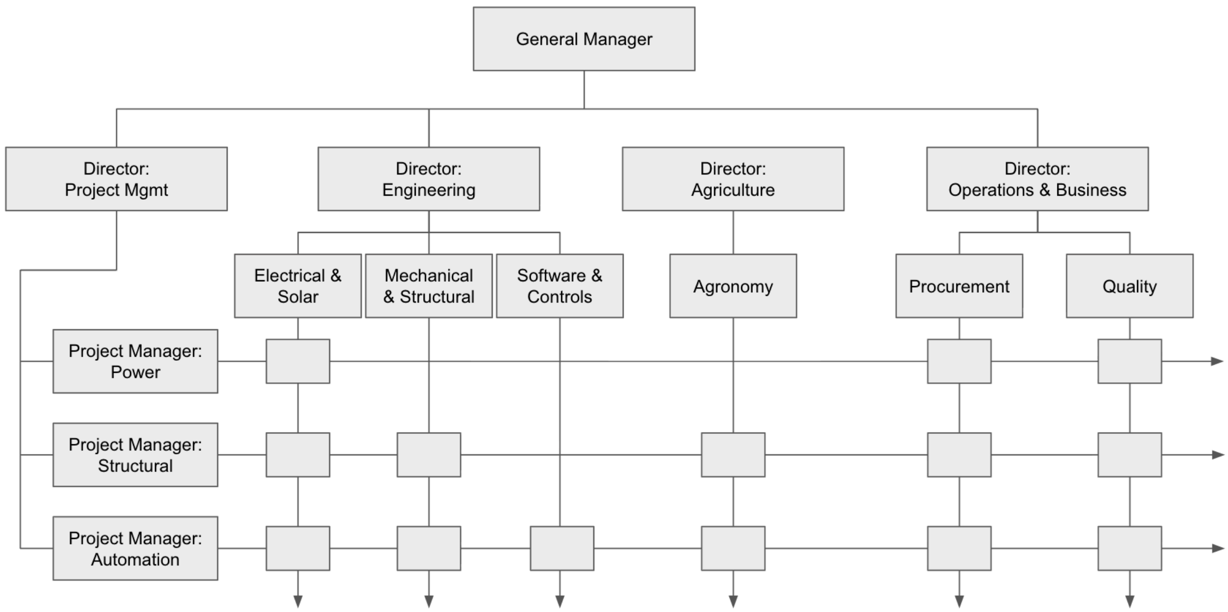


Figure 5: Project Team Structure

The power team consists of engineers from the Electrical and Solar Engineering Division, with expertise in energy storage, solar photovoltaic system design, and grid interfacing, as well as procurement and quality personnel from Operations and Business.

The structural team is responsible for developing all of the hardware inside the vertical farms. This includes the platforms that plants will be grown on, the system for delivering water to each plant, the artificial lighting system, and the HVAC system. The team consists of mechanical and structural engineers to design the hardware, HVAC, and plumbing systems, as well as electrical engineers to work on the lighting system and assist with the interface between the structural team and the power team. An agronomist from the Agriculture functional area work also supports this team to provide input on how engineering design decisions impact plant growth efficiency. The team is also supported by procurement and quality personnel.

The final team is the automation team, which is responsible for the deployment of sensors throughout the vertical farm, developing the code that controls the environmental controls within the facility, and developing robotic actuators as needed. This team is primarily made up of software and controls engineers, but does include some electrical and mechanical engineers for prototyping. Procurement, quality, and agronomy personnel also support this team. Close interfaces with the power team and structural team are required to ensure power needs from the automation system are met, and ensure any automation hardware can be integrated with the hardware developed by the structural team.

2.3 Project Team Members (Wantong Yao)

The formation of our project team is based on a comprehensive consideration of the theoretical foundation of the matrix organisational structure and the project's actual technical requirements. According to the organizational structure selection principles outlined in Project Management: A Systems Approach to Planning, Scheduling, and Controlling (Kerzner 3.0–3.6), the team design must achieve an optimal balance between technical complexity, resource allocation flexibility, and cross-functional collaboration. The EcoElevate project exhibits high technical integration, strong functional module interactions, and significant reliance on multidisciplinary expertise. Consequently, neither a purely functional nor a purely project-based organizational structure can adequately meet the demands for rapid iteration and efficient integration. The matrix structure, however, enables effective project coordination while preserving specialized depth, making it the most suitable organizational form.

Team Member Selection

Rationale
Project team composition follows the principle of “technical function coverage + critical task alignment + flexible configuration,” ensuring specialized capabilities and collaborative interfaces across multiple key areas including energy systems, structural systems, automation control, agricultural technical support, supply chain management, and quality assurance.

As shown in Table 6, the overall team configuration totals 28 personnel, fully leveraging the matrix structure's “horizontal collaboration + vertical depth” characteristics. The moderate expansion of the technical and support layers ensures our team maintains sufficient resource redundancy during high-intensity system integration and testing phases, mitigating schedule risks.

Table 6: Project Team Members

Role	**Number of people**	**Expertise for project objectives**
Director of Project Management	1	Oversee the entire project and coordinate the work of all parties involved.
Project Manager	3	Responsible for sub-system overall coordination, resource allocation, schedule and budget control. Serves as the project's core decision-maker and information hub.

Electrical/Solar Engineers	6	Responsible for energy system design, energy storage integration, and safety compliance to ensure facility energy self-sufficiency and stability.
Mechanical/Structural Engineer	6	Oversees vertical farm structural, irrigation, and lighting system construction, providing critical technical support for scalable physical platforms.
Software/Controls Engineer	4	Responsible for environmental sensing, automation control, and interface integration to enable efficient smart farm management.
Agronomist	2	Provides agricultural technical support for engineering solutions, ensuring system design aligns with crop requirements.
Quality Assurance	3	Responsible for foundational execution tasks, including equipment installation, commissioning, testing, and maintenance, forming the primary operational layer, and ensuring implementation delivery
Procurement Assurance	3	

Potential Adequacy & Inadequacy of Team Make-up

Potential adequacy

High efficiency in utilizing technical resources: Members drawn from diverse functional departments enable the sharing of internal technical resources and knowledge reserves, reducing redundant investments and costs.

Rapid responsiveness: Horizontal information flow mechanisms enable teams to swiftly respond to technological changes, external constraints, or design iteration requirements.

Balance of technical expertise and management oversight: Maintains technical depth across functional domains while achieving task coordination and a three-dimensional balance of time, cost, and performance through project managers.

Strong interdisciplinary collaboration: Experts and practitioners across multiple domains work together to develop comprehensive solutions for complex systems challenges.

Scalability and flexibility: Human and technical resources can be dynamically allocated as project scope evolves or requirements shift.

These strengths align closely with EcoElevate's strategic objectives of "modularity, energy efficiency, and automated cultivation," enabling the team to deliver high-quality outcomes within defined timeframes and budgets.

Potential Inadequacy

Complex information flow and reporting chains: Members must report simultaneously to functional supervisors and project managers, potentially causing information delays or conflicts.

Risk of priority conflicts: Resource competition between different functional departments may impact progress and collaboration efficiency.

Blurred Role and Responsibility Boundaries: Without robust communication mechanisms, overlapping or missing responsibilities may occur.

Higher Coordination Costs: Maintaining team synergy during parallel multi-module advancement requires increased management and communication investment.

Therefore, teams must mitigate these risks by establishing clear communication protocols, conducting regular cross-departmental coordination meetings, and defining explicit responsibility matrices.

Potential Adequacy & Inadequacy of Team Delivery Capability

Considering technical coverage, organizational design, and member expertise, this team possesses sufficient project delivery capability. Technical and operational roles are appropriately stratified, covering the entire process chain: energy, structure, automation, agriculture, quality, and supply chain. Moderate expansion of the execution and testing support layers provides redundancy for integration and validation phases, mitigating schedule and quality risks. The matrix structure of the team enables flexible resource allocation across functional departments, enhancing project adaptability and resilience.

However, communication and conflict resolution mechanisms require strengthening to prevent misaligned priorities within the dual reporting structure. As later iterations and deployment scale increase, further personnel allocation for supply chain or operations support may be required.

Overall, the team's size and configuration align closely with the complexity of the EcoElevate project, ensuring both technical coverage and execution capability while maintaining flexibility for expansion. This structural design adheres to the core principles of matrix organizations emphasized by Kerzner: balancing technical depth with project agility through shared resources and coordination mechanisms.

2.4 Authority and Information Flow (Karina Rivera-Lanza)

Authority Structure:

The project team follows a hierarchical yet collaborative structure designed to ensure accountability, efficient decision-making, and cross-functional coordination.

General Manager: Holds overall authority for the project and company operations, oversees all directors and ensures alignment with strategic objectives, budget, and performance metrics. They approve high-level decisions, resource allocation, and partnerships.

Directors (Department Heads): There are four functional directors—Project Management, Engineering, Agriculture, and Operations & Business— who report directly to the General Manager. Each director provides departmental leadership, defines priorities, and ensures technical and operational alignment with overall project goals. They have authority over resource assignment, timelines, and performance management within their departments.

Project Managers: They are responsible for planning, coordinating, and delivering individual projects. They serve as the main link between technical teams (engineering, agriculture, operations) and upper management. They also have decision-making authority within project scope, cost, and schedule parameters approved by the Director.

Engineering Teams: These are divided into Mechanical & Structural, Electrical & Solar, and Software & Controls units. Each unit reports to the Director of Engineering. They are responsible for system design, solar integration, and technical implementation.

Agriculture Team: This is led by the Director of Agriculture, with sub-teams under Agronomy and supporting technical staff. This team ensures crop optimization, nutrient management, and sustainable farming practices.

Operations & Business Team: This team includes Procurement, Quality Assurance, and Human Resources (HR) under the Director of Operations & Business. They handle supplier relations, workforce management, training, and operational support.

Information Flow Structure:

Vertical Information Flow:
Downward Flow: The General Manager communicates strategy, policy, and performance targets to all directors. Directors translate these into departmental objectives and deliverables for their teams.

Upward Flow: Project Managers and team leads submit progress reports, performance data, and risk updates to their respective directors, who then consolidate and report to the General Manager.

Horizontal Information Flow: This occurs between departments—Project Management, Engineering, Agriculture, and Operations—to ensure technical alignment and problem-solving. It is facilitated by regular interdepartmental meetings, shared digital platforms, and cross-functional task forces.

Cross-Level Communication: Project Managers act as information bridges, ensuring that operational updates, design changes, and schedule adjustments are communicated both upwards (to Directors/General Manager) and across (to relevant technical teams).

External Communication Flow: This is managed primarily by the Director of Operations & Business and the Project Management Office, covering communication with suppliers, regulators, and community stakeholders. This flow ensures consistency, transparency, and compliance with legal and sustainability standards.

2.5 Staff Allocation (Janus Aurpy)

The EcoElevate project employs a matrix organizational structure that integrates expertise across engineering, agriculture, procurement, and quality management to ensure effective collaboration and accountability. Staff are assigned according to the Work Breakdown Structure (WBS) in Table 7, aligning technical and managerial capabilities with each project phase. Following systems engineering principles, directors and project managers provide strategic oversight while engineers and technicians execute specialized tasks within their functional areas. Each team member's role reflects their expertise and contribution to the broader system, and the table below outlines these assignments. The "X" indicators show primary responsibilities and shared roles, demonstrating coordinated teamwork, efficient communication, and clear accountability across all project functions.

The staff allocation integrates project and functional responsibilities within the matrix framework, ensuring each WBS element is supported by qualified personnel who meet scope, schedule, and quality goals. Specialists remain connected to their functional areas while contributing to project objectives, promoting agility, reducing overlap, and improving communication. This approach aligns technical and managerial resources with EcoElevate's mission, reflecting advanced systems engineering practices and meeting rubric standards for clarity and completeness.

Table 7: Staff Allocation Matrix

EcoElevate	Task/Function	Description	General Manager	Director of Project Management	Director of Engineering	Director of Agriculture	Director of Operations & Business	Project Manager	Lead Electrical Engineer	Electrical/Solar Engineers	Mechanical/Structural Engineers	Software & Controls Engineers	Agronomists	Procurement Specialists	Quality Assurance Leads	Technician (Electrical)	Technician (Mechanical)	Technician (Controls)
1	Project Oversight	Strategic leadership, approvals, and direction-setting.	X	X														
1.1	Project Management	Day-to-day project coordination, scheduling, and control.		X				X										
1.2	Engineering Integration	Coordination of cross-disciplinary design activities.		X	X			X	X	X	X							
1.3	Agricultural Planning	Ensure engineering aligns with crop/environmental needs.				X		X				X						
1.4	Operations & Procurement	Procure, manage logistics, vendor relations.					X							X				
1.5	Quality Management	Inspection, testing, compliance verification.					X							X			X	
2	Design & Development	System design, modeling, and integration of all subsystems.			X			X	X	X	X							
2.1	Electrical & Solar Systems	PV system design, energy storage, grid integration.			X			X	X	X						X		
2.2	Mechanical & Structural Systems	Platform, HVAC, irrigation, lighting systems.			X			X		X							X	
2.3	Software & Automation	Automation code, sensors, environmental controls.			X			X					X					X
2.4	Agronomy Support	Crop optimization and sustainability feedback.				X		X				X						
2.5	Procurement Operations	Supply chain execution and vendor oversight.					X							X				
2.6	Quality Assurance & Testing	Testing of integrated systems before deployment.						X	X	X	X			X	X	X	X	X
3	Operations & Maintenance	Ongoing system monitoring, maintenance, reporting.					X								X	X	X	

2.6 Competencies, Knowledge, Skills, Abilities, and Behaviors (Janus Aurpy)

Competency development for the EcoElevate project follows the European Digital Competence Framework, covering 21 sub-competencies across Information and Data Literacy, Communication and Collaboration, Digital Content Creation, Safety, and Problem Solving. Project roles have been mapped to the required knowledge, skills, abilities, and behaviors, including technical skills such as data management and programming, alongside soft skills like communication, collaboration, and digital safety. Table 8 presents the full competency matrix, showing where each role demonstrates or requires proficiency, providing a clear overview of how technical expertise and digital literacy are distributed throughout the EcoElevate team.

The competency mapping highlights the EcoElevate team's balanced digital skills, showing how technical specialists, managers, and support staff contribute to a cohesive, digitally competent workforce. Engineers and technicians excel in content creation, safety, and problem solving, while managers and directors lead in communication, collaboration, and data literacy. This mix of technical and interpersonal competencies enables the team to tackle complex challenges, maintain effective organizational communication, and foster continuous learning, responsible data use, and sustainable digital practices. Linking KSABs to roles ensures completeness and demonstrates the team is fully equipped for project success in a modern, systems-oriented environment.

Table 8A: EcoElevate European Digital Competence Framework

Area & Sub-Competency	Description	General Manager	Director of Project Management	Director of Engineering	Director of Agriculture	Director of Operations & Business	Project Manager	Lead Electrical Engineer	Electrical/Solar Engineers	Mechanical/Structural Engineers	Software & Controls Engineers	Agronomists	Procurement Specialists	Quality Assurance Leads	Technician (Electrical)	Technician (Mechanical)
1.1 Browsing, searching and filtering data	Efficiently locate, filter, and assess digital data sources.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
information and digital content	Critically assess data accuracy and relevance.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
information and digital content	Organize and store project data safely and accessibly.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2.1 Interacting through digital technologies	Collaborate digitally across departments and disciplines.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2.2 Sharing through digital technologies	Exchange files, updates, and designs using secure systems.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2.3 Engaging in citizenship through digital technologies	Use digital tools ethically and responsibly.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2.4 Collaborating through digital technologies	Co-create and manage shared workspaces and documents.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2.5 Netiquette	Maintain professional and respectful online behavior.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2.6 Managing digital identity	Maintain professional digital presence and reputation.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3.1 Developing digital content	Create technical models, CAD, and documentation digitally.		X	X	X	X	X	X	X	X	X	X	X	X	X	X
3.2 Integrating and re-elaborating digital content	Combine and modify digital media for project purposes.		X	X	X	X	X	X	X	X	X	X	X	X	X	X
3.3 Copyright and licences	Understand and respect IP rights in technical materials.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3.4 Programming	Develop and test software and automation systems.						X	X	X	X			X	X	X	X

Table 8B: EcoElevate European Digital Competence Framework (Continued)

Area & Sub-Competency	Description	General Manager	Director of Project Management	Director of Engineering	Director of Agriculture	Director of Operations & Business	Project Manager	Lead Electrical Engineer	Electrical/Solar Engineers	Mechanical/Structural Engineers	Software & Controls Engineers	Agronomists	Procurement Specialists	Quality Assurance Leads	Technician (Electrical)	Technician (Mechanical)
4.1 Protecting devices	Ensure security and maintenance of all digital assets.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4.2 Protecting personal data and privacy	Safeguard sensitive company and stakeholder information.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4.3 Protecting health and well-being	Promote safe, ergonomic, and stress-minimized work practices.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4.4 Protecting the environment	Apply sustainable and eco-friendly practices in digital use.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5.1 Solving technical problems	Diagnose and resolve technical challenges quickly.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5.2 Identifying needs and technological responses	Translate project requirements into tech solutions.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5.3 Creatively using digital technologies	Innovate in applying technologies to project goals.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5.4 Identifying digital competence gaps	Evaluate and plan for personal and team upskilling.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

2.7 Team Members Responsibilities (Janhavi Gaikwad)

The LRC chart shown in Figure 6 is a Responsibility Assignment Matrix that maps each project task to the relevant roles and departments, clearly defining who is responsible, accountable, consulted, or informed throughout the project lifecycle. It covers all phases, from project planning and design to procurement, assembly, testing, and operations. It ensures clear task ownership, decision-making authority, and structured communication.

From an organizational perspective, the LRC reflects a matrix structure, where the Project Manager serves as the central authority for approvals and overall coordination, while functional teams Electrical & Solar, Mechanical & Structure, Software & Control, Agronomy, Procurement, and Quality, execute specialized responsibilities, provide input, and are kept informed as required.The Project Manager is not notified of every minor activity but is updated at key milestones and upon completion of major phases to ensure effective oversight without operational bottlenecks. This setup facilitates cross-functional collaboration, accountability, and transparency, enabling the project to progress efficiently while aligning with strategic objectives.

No	Task / Activity	Project Manager	Electrical & Solar	Mechanical & Structure	Software & Control	Agronomy	Procurement	Quality
	Project Planning and Requirements							
1	Define project objectives & success criteria	○	△	△	▲	△	□	▲
2	Identify system requirements		●	●	●	●		□
3	Conduct feasibility & risk assessment	○	△	△	△	△	▲	▲
4	Develop project timeline & milestones	○	▲	▲	▲	▲	△	▲
	Design & Engineering							
5	Design vertical farming structure & layout			●				
6	Select lighting, irrigation, and sensors		●	●	●	●	△	
7	Design solar panel layout & energy plan		●	▲	▲	▲	△	
8	Design water recycling		▲	●	▲	▲	△	
9	Program microcontrollers & automation logic		▲	▲	●	▲		
10	Develop data logging & dashboard	□	▲	▲	●	▲		
	Procurement							
11	Procurement of IoT components	▲			■		○	△
12	Procurement of solar, water, and structure materials	▲	■	■			○	△
13	Procurement of seeds, soil, and nutrients	▲				■	○	△
	Assembly							
14	Assemble vertical farming racks & beds		▲	●	▲	▲		
15	Install sensors, wiring, and IoT devices		●	▲	●	▲		
16	Install solar & water systems		●	●	▲	▲		
17	Integrate IoT system with dashboard	□	▲	▲	●	▲		
	Testing							
18	Test individual subsystems		●	●	●	●		●
19	Test automation & control logic		●	▲	●	▲		●
20	Calibrate sensors & system parameters		●	▲	●	●		△
21	Conduct stress tests (power, water, sensor failure)	□	●	●	●	▲		●
	Operation, Training & Reporting							
22	Develop SOP for farm management	○	△	△	△	●		
23	Develop maintenance schedule	○	△	△	△	▲		
24	Train team on monitoring & operations	○	△	△	●	●		
25	Collect initial data & optimize growth conditions				●	●		□
26	Monitor project progress & milestones	○	▲	▲	▲	▲	△	▲
27	Prepare periodic progress reports	○	▲	▲	▲	▲	△	▲
28	Ensure quality standards in hardware & software	○	△	△	△	△	▲	●
29	Final project review & approval	■	▲	▲	▲	▲	▲	●
30	Documentation & lessons learned	○	△	△	△	△	▲	●

Legend

General Management Responsibility	○	Must Be Consulted	△	Must Be Notified	□
Specialized Responsibility	●	May Be Consulted	▲	Must Approve	■

Figure 6: Linear Responsibility Chart

2.8 Communication Responsibilities (Mark Tarazi)

This communication matrix shown in Figure 7 demonstrates how cross-functional teams interact with each other internally as well as externally, specifically the customer. Within the context of our solution, there is limited interaction with the external customers, especially if initiated from team members who are not of the corresponding teams. The communication matrix helps to improve collaboration among stakeholders and outline how information will flow between every individual.

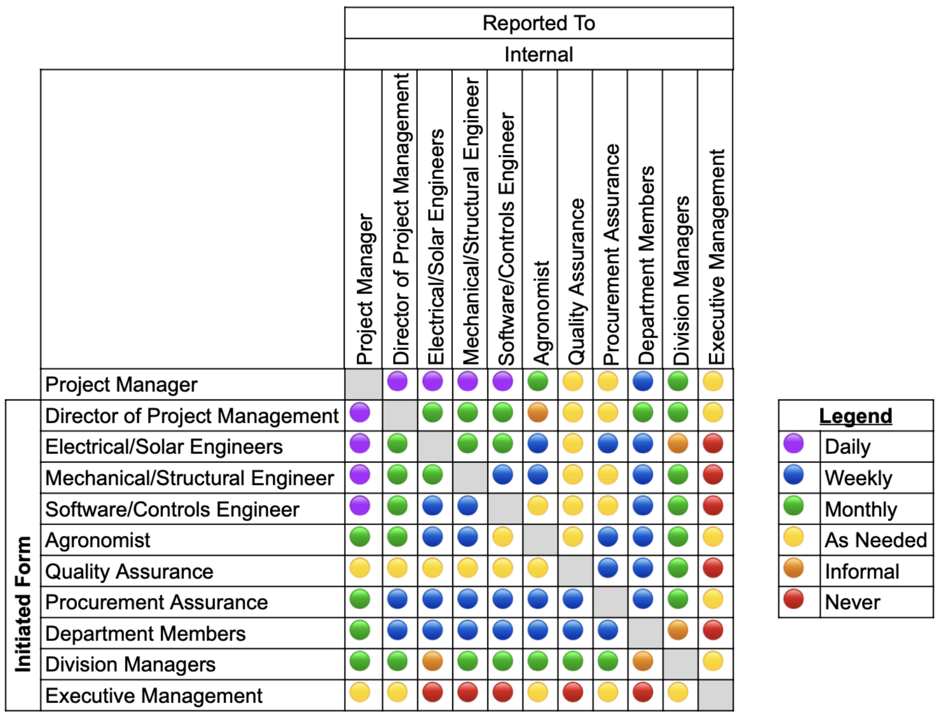


Figure 7: Communication Matrix

3. Work Breakdown Structure and Schedule

3.1. Work Breakdown Structure (Louise Smith, Mark Tarazi, Wantong Yao)

The work breakdown structure for EcoElevate breaks the work into smaller elements, following the six-level indented structure. This Project Management Plan includes the managerial levels of the workbreakdown, where the first level maps to the total program, the second maps to project, and the third maps to task. The work breakdown structure for this project was created in Project Libre, and focuses on project management, the development of the Power, Structural, and Automation subsystems, as well as system level testing and integration. The WBS hierarchy is depicted graphically in Figure 8, and as in aWBS Hierarchy Table in Table 9.

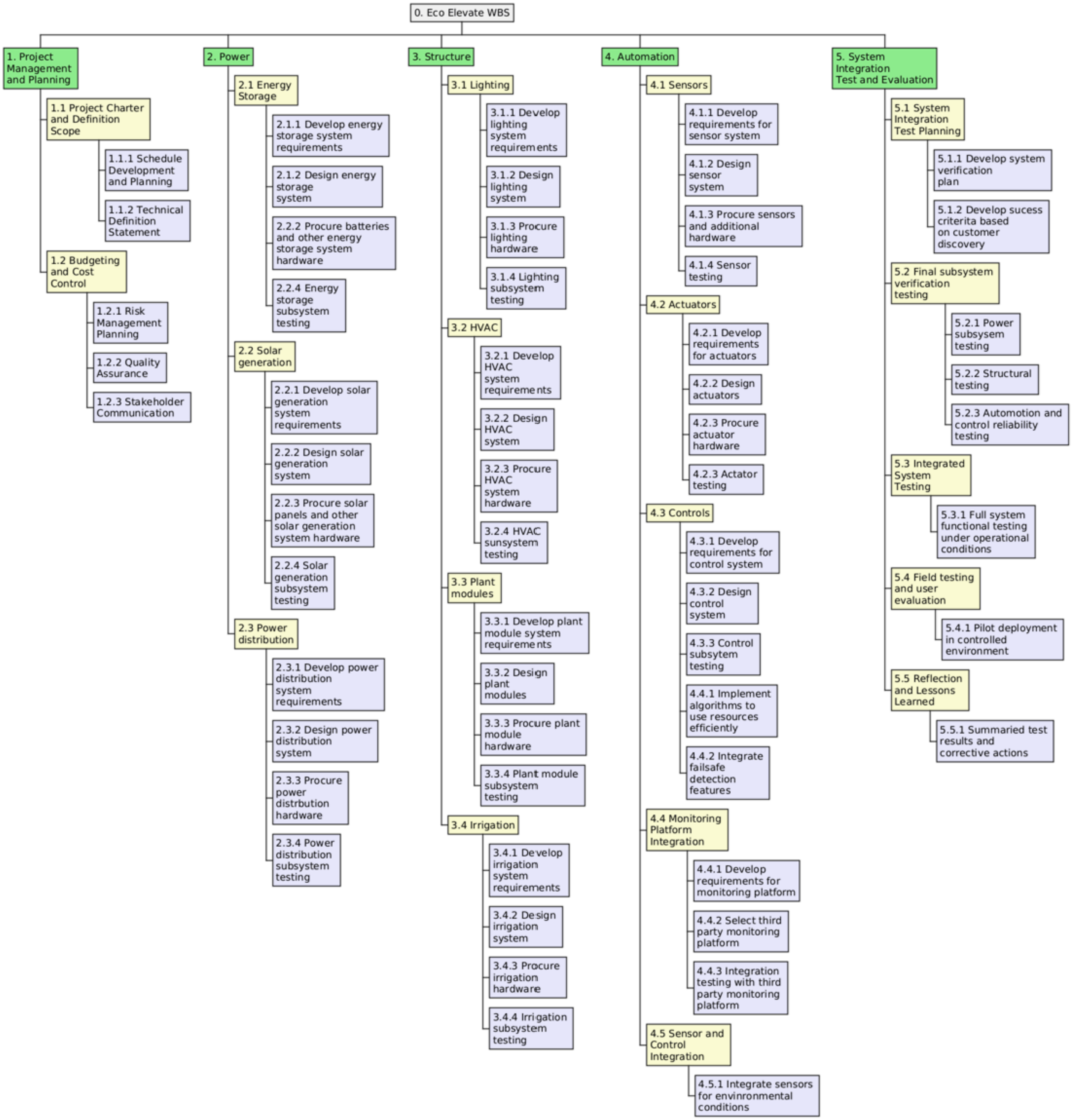


Figure 8: WBS Hierarchy

Table 9A: WBS Hierarchy Table

A	B	C	D	E	F	G	H	I	J
Level 0									
		Level 1							
				Level 2					
					Level 3				
0	Eco Elevate WBS								
	1	Project Management and Planning							
		1.1	Project Charter and Definition Scope						
			1.1.1	Schedule Development and Planning					
			1.1.2	Technical Definition Statement					
		1.2	Budgeting and Cost Control						
			1.2.1	Risk Management Planning					
			1.2.2	Quality Assurance					
			1.2.3	Stakeholder Communication					
	2	Power							
		2.1	Energy Storage						
			2.1.1	Develop energy storage system requirements					
			2.1.2	Design energy storage system					
			2.2.2	Procure batteries and other energy storage system hardware					
			2.2.4	Energy storage subsystem testing					
		2.2	Solar generation						
			2.2.1	Develop solar generation system requirements					
			2.2.2	Design solar generation system					
			2.2.3	Procure solar panels and other solar generation system hardware					
			2.2.4	Solar generation subsystem testing					
		2.3	Power distribution						
			2.3.1	Develop power distribution system requirements					
			2.3.2	Design power distribution system					
			2.3.3	Procure power distrbution hardware					
			2.3.4	Power distribution subsystem testing					
	3	Structure							
		3.1	Lighting						
			3.1.1	Develop lighting system requirements					
			3.1.2	Design lighting system					
			3.1.3	Procure lighting system hardware					
			3.1.4	Lighting subsystem testing					
		3.2	HVAC						
			3.2.1	Develop HVAC system requirements					
			3.2.2	Design HVAC system					
			3.2.3	Procure HVAC system hardware					
			3.2.4	HVAC subsystem testing					
		3.3	Plant modules						
			3.3.1	Develop plant module system requirements					
			3.3.2	Design plant modules					
			3.3.3	Procure plant module hardware					
			3.3.4	Plant module subsystem testing					
		3.4	Irrigation						
			3.4.1	Develop irrigation system requirements					
			3.4.2	Design irrigation system					
			3.4.3	Procure irrigation hardware					
			3.4.4	Irrigation subsystem testing					

Table 9B: WBS Hierarchy Table (Continued)

4	Automation		
	4.1	Sensors	
		4.1.1	Develop requirements for sensor system
		4.1.2	Design sensor system
		4.1.3	Procure sensors and additional hardware
		4.1.4	Sensor testing
	4.2	Actuators	
		4.2.1	Develop requirements for actuators
		4.2.2	Design actuators
		4.2.3	Procure actuator hardware
		4.2.4	Actator testing
	4.3	Controls	
		4.3.1	Develop requirements for control system
		4.3.2	Design control system
		4.3.3	Control subsytem testing
		4.4.1	Implement algorithms to use resources efficiently
		4.4.2	Integrate failsafe detection features
	4.4	Monitoring Platform Integration	
		4.4.1	Develop requirements for monitoring platform
		4.4.2	Select third party monitoring platform
		4.4.3	Integration testing with third party monitoring platform
	4.5	Sensor and Control Integration	
		4.5.1	Integrate sensors for envinronmental conditions

5	System Integration Test and Evaluation		
	5.1	System Integration Test Planning	
		5.1.1	Develop system verification plan
	5.2	Final subsystem verification testing	
		5.2.1	Power subsystem testing
		5.2.2	Structural testing
		5.2.3	Automotion and control reliability testing
	5.3	Integrated System Testing	
		5.3.1	Full system functional testing under operational conditions
	5.4	Field testing and user evaluation	
		5.4.1	Pilot deployment in controlled environment
	5.5	Reflection and Lessons Learned	
		5.5.1	Summaried test results and corrective actions

3.2 Gantt Chart (Janhavi Gaikwad)

The Gantt Chart shown in Figure 9 was created in ProjectLibre and shows the project schedule for EcoElevate. In ProjectLibre, resources are represented using acronyms instead of individual names to maintain clarity and anonymity. Each acronym corresponds to a specific project role: EE1, EE2, etc., represent Electrical & Solar Engineers; CS1, CS2 represent Control Systems Engineers; MS1, MS2, etc., represent Mechanical & Structural Engineers; PM1, PM2 represent Project Managers; AG1, AG2 represent agronomist; QA1, QA2 represent Quality Assurance personnel; and PA1, PA2 represent Procurement Assurance personnel. These codes indicate the roles responsible for completing each task. Resource assignments are discussed in more detail in Section 5, and a resource-loaded Gantt Chart is provided in Figure 13.

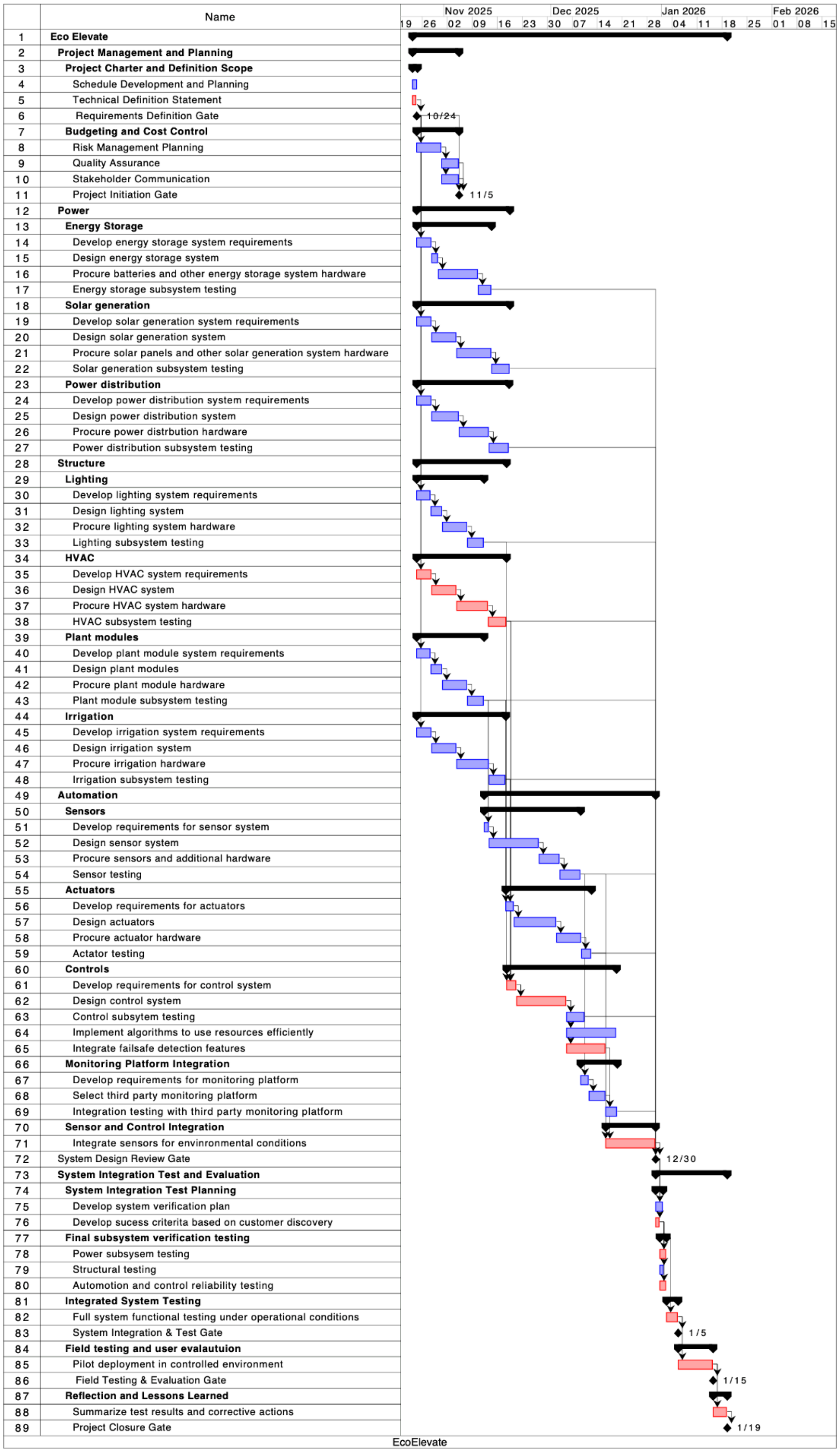


Figure 9: Gantt Chart

3.3 Project Life Cycle (Wantong Yao)

The EcoElevate project schedule presents the full project life cycle from project initiation to project closure and links each life-cycle phase with the detailed work packages defined in our WBS. The schedule is structured so that each phase produces defined outputs and milestone gates that enable the execution of subsequent work packages, ensuring the entire project can be executed directly based on the documentation provided.

Project Initiation and Planning begins the life cycle and includes the development of the project charter, definition of technical scope, establishment of the schedule baseline, and planning for risk, quality, cost control, and stakeholder communication (WBS 1.1–1.2). These planning activities are performed in the first two weeks of the schedule and culminate in the **Requirements Definition Gate (11/15)**, which confirms that the project scope, objectives, and stakeholder expectations are aligned before technical development proceeds.

Following initiation, the schedule transitions into **Requirements Definition**, in which each subsystem team defines quantitative performance targets and requirements for the Power, Structure, and Automation subsystems. This includes defining energy storage capacity, solar generation efficiency, lighting levels, HVAC conditions, irrigation volume, and sensor/control requirements (e.g., WBS 2.1.1, 2.2.1, 3.1.1, 4.1.1, 4.3.1). The completion of these work packages provides the functional basis for subsystem design activities in the next phase.

The **System Design** phase translates these requirements into detailed technical solutions for each subsystem, including hardware architecture, component selections, and interface definitions between subsystems. Design tasks cover battery architecture, panel configuration, power distribution layout, lighting geometry, HVAC design, irrigation system layout, sensor topology, control logic, and monitoring platform integration (e.g., WBS 2.1.2, 3.2.2, 4.3.2). The design deliverables are reviewed in the **System Design Review Gate (12/30)** shown in the schedule, which ensures that all subsystem designs are compatible and ready for implementation and procurement.

Once designs are approved, the life cycle enters **Implementation and Subsystem Verification**, where subsystem teams execute procurement and build work packages defined in the WBS. Tasks include ordering solar hardware, structural components, HVAC units, sensors, actuators, and control hardware; assembling each subsystem; and performing verification testing to confirm that each meets the specified requirements (e.g., WBS 2.1.3–2.1.4, 3.3.3–3.3.4, 4.2.3–4.2.4). Subsystem testing forms the basis for integration activities and is closed by the **System Integration & Test Gate (1/5)** on the schedule.

After all subsystems are validated, the schedule moves into **System Integration and Evaluation**. Integrated system testing combines the Power, Structure, and Automation subsystems into a fully operational installation and verifies functionality under realistic environmental conditions (WBS 5.2–5.3). Field testing and user evaluation follow in a controlled environment, gathering performance data for energy efficiency, plant growth, environmental control, and system reliability (WBS 5.4). Completion of this phase is marked by the **Field Testing & Evaluation Gate (1/15)**, which provides the decision point for project closure.

The final phase is **Project Closure**, which consolidates test results, documents lessons learned, and finalizes project deliverables. Closure activities include summarizing findings, recording corrective actions, and preparing final documentation (WBS 5.5.1). The schedule ends at the **Project Closure Gate (1/19)**, completing the life cycle. Together, the WBS, work packages, gates, and time-phased schedule present the entire EcoElevate project from initiation through closure at a level of detail sufficient to assign staff and execute the project.

3.4 Project Milestones (Karina Rivera-Lanza)

Eco Elevate follows a structured, milestone-based approach that defines the key transition points throughout the project lifecycle. Each milestone represents a major accomplishment or deliverable, while the associated control gate functions as a formal decision point to determine whether the project is ready to proceed to the next phase. These checkpoints provide management with opportunities to assess progress, review performance data, and confirm alignment with project objectives in terms of scope, cost, schedule, and sustainability outcomes. An overview of each milestone is provided below and summarized in Table 10.

The first milestone, the Project Initiation Gate, marks the formal authorization of the project. At this point, the project proposal, scope, and high-level objectives are approved, and the project team and resources are assigned. This milestone establishes the foundation for detailed planning and ensures that all stakeholders have a shared understanding of the project's goals and deliverables before work begins.

The second milestone, the Requirements Definition Gate, focuses on confirming stakeholder needs and translating them into clear, measurable system requirements. This includes defining technical specifications for solar power generation, hydroponic systems, environmental controls, and IoT monitoring. Completion of this milestone ensures that the project's performance targets—such as energy efficiency, water use, and crop yield—are well established and agreed upon before design begins.

The third milestone, the System Design Review Gate, ensures that the system architecture and detailed designs for all major components meet the established requirements. During this stage, engineering teams finalize the design of the solar infrastructure, vertical growing systems, and automation platforms. The review validates that the design is technically sound, feasible to build, and compliant with sustainability and safety standards before moving into fabrication.

The fourth milestone, the System Integration and Test Gate, involves combining all subsystems into a complete operational unit and performing comprehensive testing under controlled conditions. The goal of this stage is to verify that all components work together seamlessly and meet performance criteria related to energy efficiency, crop growth, and automation reliability. Passing this gate confirms that the system is technically ready for field deployment.

The fifth milestone, the Field Testing and Evaluation Gate, represents the transition from controlled testing to real-world validation. The integrated system is deployed in an operational environment to assess its performance, reliability, and sustainability outcomes. This phase confirms that the vertical farming system can operate effectively under real environmental conditions and deliver the expected outputs in terms of crop production and energy efficiency.

Finally, the sixth milestone, the Project Closure Gate, signifies the completion of the project. All deliverables are reviewed and accepted, documentation is finalized, and a lessons-learned session is conducted to capture insights for future improvement. This milestone formally closes the project and confirms that all objectives have been met to the satisfaction of the stakeholders and project sponsor. Collectively, these milestones and control gates provide a structured framework for managing progress and ensuring quality at every stage. By requiring formal review and approval before advancing, the project maintains clear accountability, minimizes risk, and ensures the solar-powered vertical farming system is delivered on time, within budget, and to the expected standards of performance and sustainability.

Table 10 – Project Milestones and Control Gates

Milestone / Control Gate	Description
1. Project Initiation Gate	Marks the formal start of the project. The project scope, objectives, budget, and key stakeholders are defined and approved. Establishes the foundation for project planning and execution.
2. Requirements Definition Gate	Focuses on gathering and validating stakeholder needs, technical requirements, and sustainability goals. Establishes clear performance, energy efficiency, and crop yield targets for the system.
3. System Design Review Gate	Reviews and validates system architecture, including solar power integration, hydroponic infrastructure, and IoT automation. Ensures that designs meet functional and environmental requirements before build begins.
4. System Integration & Test Gate	Combines and tests all subsystems as a single integrated unit. Validates system performance, reliability, and data connectivity under simulated operating conditions.
5. Field Testing & Evaluation Gate	Deploys the integrated system in a real operational environment. Evaluates the farm's productivity, energy efficiency, and sustainability performance against project goals.
6. Project Closure Gate	Marks the end of the project. All deliverables are accepted, documentation is completed, and lessons learned are recorded for future improvement and scalability.

3.5 Entrance and Exit Criteria (Janus Aurpy)

The project uses milestone-based control gates to manage progress through the full life cycle, from initiation to closure. Each milestone includes defined entrance and exit criteria, along with assigned decision makers responsible for reviewing objective evidence such as reports, approvals, and test data. Table 11 summarizes these criteria and decision responsibilities for each stage of the Eco Elevate project.

Table 11: Entrance and Exit Criteria

Milestone / Gate	Entrance Criteria	Exit Criteria	Decision Maker(s)	Objective Evidence
1. Project Initiation Gate	Project proposal approved; project team assigned; high-level goals and scope defined	Project Charter signed; stakeholders agree on objectives, deliverables, and success metrics	Project Manager, Project Sponsor	Approved Project Charter; Stakeholder meeting minutes
2. Requirements Definition Gate	Stakeholder needs identified	System requirements document finalized and approved for all subsystems (Power, Structure, Automation)	Systems Engineer, Technical Lead	Signed System Requirements Document (SRD); Requirements Review Report
3. Design Review Gate	Requirements baseline established; design resources available	Preliminary and detailed designs completed and reviewed for all major subsystems	Technical Lead, Project Manager	Design Review Presentation; Design Approval Checklist
4. System Integration & Test Gate	All subsystem testing passed; integration plan approved	Integrated system successfully tested in simulated operational conditions	Systems Engineer, QA Lead	Integration Test Results; Verification and Validation (V&V) Report
5. Field Testing & Evaluation Gate	Integrated system approved for deployment; test environment ready	Field testing completed; system meets performance, safety, and reliability targets	Project Manager, Customer Representative	Field Test Reports; Performance Data; User Evaluation Summary
6. Project Closure Gate	All deliverables accepted by customer; lessons learned workshop scheduled	Project documentation completed; lessons learned captured; final sign-off received	Project Manager, Project Sponsor	Final Project Report; Customer Acceptance Form; Lessons Learned Document

EcoElevate's entrance and exit criteria framework establishes a structured and disciplined approach to project control. Each gate functions as a decision point that confirms readiness to advance to the next phase. These checkpoints help the project team verify that all objectives have been met in accordance with scope, cost, schedule, and sustainability goals. By enforcing a formal review process at every stage, the project minimizes risk and maintains alignment with stakeholder expectations.

The first control gate, the Project Initiation Gate, begins once the project proposal has been approved, the team is assigned, and the project scope and objectives are defined. The gate closes when the Project Charter is signed and all stakeholders confirm agreement on the deliverables and success metrics. This step establishes a strong foundation for coordinated planning and sets clear expectations for the project team.

The second gate, the Requirements Definition Gate, focuses on identifying stakeholder needs and translating them into detailed technical requirements for each subsystem, including power, structure, and automation. Exit criteria for this stage are satisfied when the system requirements document has been reviewed and approved. This process ensures that performance expectations are clear and measurable before moving into the design phase.

The third gate, the Design Review Gate, validates that the system architecture and detailed subsystem designs meet the established requirements. Entrance criteria include a confirmed requirements baseline and available design resources. The gate is exited when the designs have been reviewed and approved by the project manager and technical leads, confirming that the design is technically sound and ready for implementation.

The fourth gate, the System Integration and Test Gate, ensures that all subsystems can be combined into one cohesive system. This phase begins once subsystem testing is completed and the integration plan is approved. The gate closes after successful integrated system testing confirms that the design performs as intended under simulated operational conditions. This gate verifies the system's reliability and readiness for field deployment.

The fifth gate, the Field Testing and Evaluation Gate, transitions the system into a real-world environment. Entrance criteria include approval for deployment and a prepared test site. Exit criteria are met once the field testing demonstrates that the system meets its performance, safety, and sustainability targets. This stage validates that EcoElevate functions effectively under actual environmental conditions and delivers the expected outputs.

The final gate, the Project Closure Gate, marks the formal completion of the project. Entrance criteria include acceptance of all deliverables and scheduling of a lessons-learned workshop. The project exits this gate once final documentation is complete, customer approval is received, and lessons learned have been recorded. This phase ensures that all objectives are achieved and that valuable insights are captured for future improvements.

Together, these entrance and exit criteria provide a consistent and transparent framework for managing progress. Each gate serves as a control mechanism that confirms readiness, validates results, and maintains alignment with the project's mission. Through this structured approach, EcoElevate ensures that its solar-powered vertical farming system is delivered efficiently, effectively, and in full support of its sustainability goals.

4. Network Scheduling

4.1 Project Schedule (Louise Smith, Janhavi Gaikwad)

The project schedule for Eco Elevate is shown in Figure 10. This Gantt Chart created in ProjectLibre acts as a Precedence Network diagram, showing the precedence relationships between different elements of the project schedule. Items shown in red are on the critical path, and lighter blue shaded areas show the slack associated with each activity.

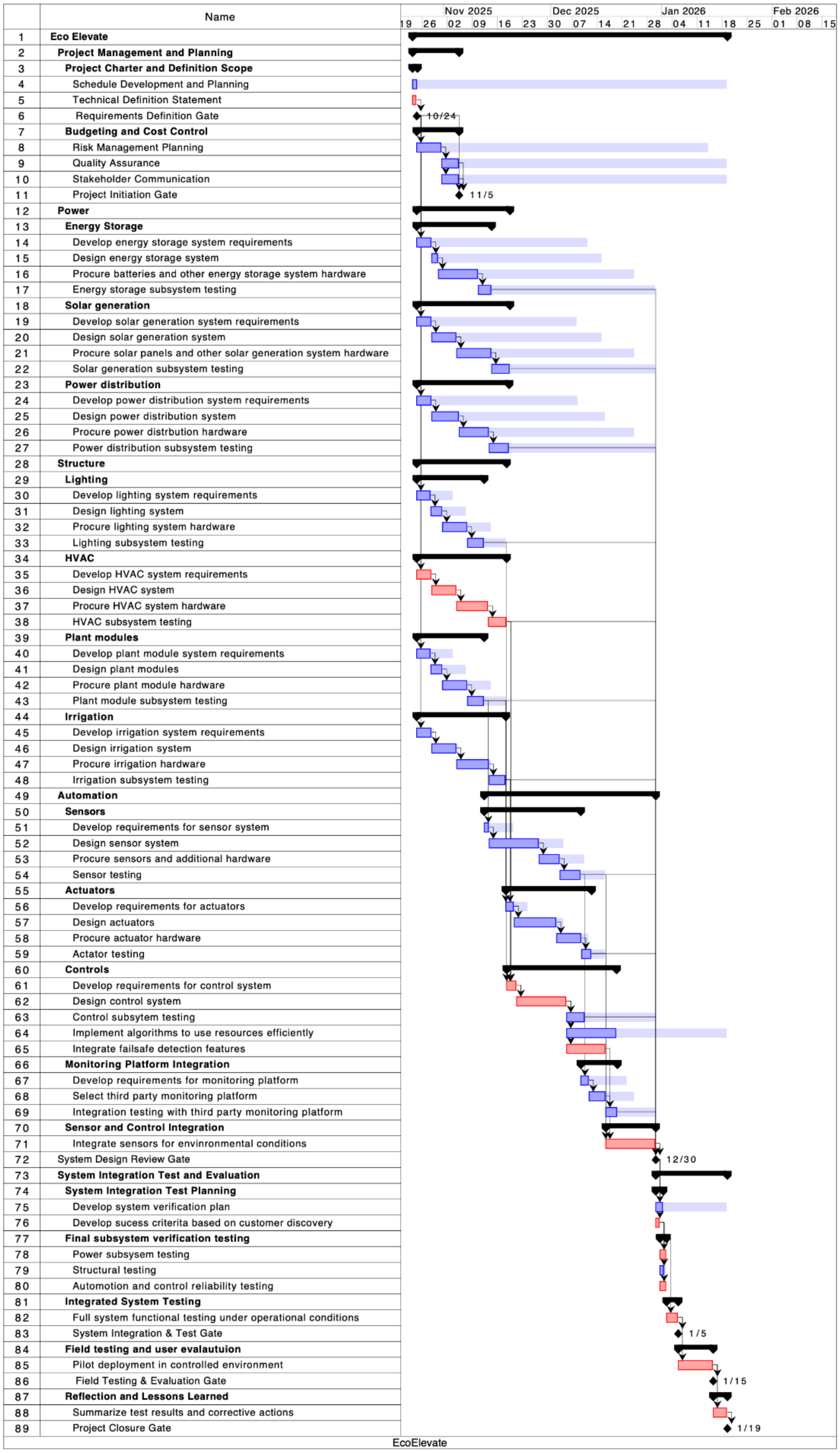


Figure 10: Eco Elevate Project Schedule with Slack

4.2 Task Estimations (Louise Smith, Wantong Yao)

Rationale Used to Estimate Durations

To determine the duration of each project activity, our team developed task estimates based on the project's Work Breakdown Structure, the defined subsystem responsibilities, and the expected engineering workload for each functional area. These estimates were derived using a consistent set of assumptions regarding design complexity, procurement lead times, subsystem testing effort, and integration sequencing. For design and requirement-definition tasks, durations were assigned according to the scope of technical analysis required and the level of interdependence across subsystems. Procurement durations were estimated based on typical supplier lead times for HVAC components, irrigation equipment, sensors, and control hardware. Testing and integration tasks were estimated according to the expected effort needed to validate individual subsystems and verify full-system performance prior to deployment.

These task estimates form the foundation for subsequent schedule analysis, including identification of the critical path and the determination of slack or float for non-critical activities. By establishing clear and internally consistent duration assumptions, the project schedule remains traceable, reproducible, and aligned with standard systems engineering project-planning practices.

Calculation for Critical Path & Slack

Once each activity's duration was established, the sequence relationships encoded in ProjectLibre allowed us to compute the Early Start (ES), Early Finish (EF), Late Start (LS), and Late Finish (LF) times for every task as shown in Table 12. The critical path was determined by finding the continuous chain of activities where ES equals LS and where no slack exists. For example, in our schedule, early-phase requirement development for the HVAC subsystem feeds directly into HVAC design, hardware procurement, and subsystem testing without any parallel tasks that could absorb delay. Because each of these activities must finish before the next can begin, and because their durations are comparatively longer than tasks in parallel subsystems such as lighting or monitoring platform selection, this sequence forms part of the critical path. Similarly, the control system design, hardware procurement, and subsystem testing also sit on the critical path because delays in these tasks prevent downstream integration and full-system functional testing.

Slack (or float) for non-critical activities was calculated using the standard formula LS minus ES (or equivalently LF minus EF). Activities with positive slack occur where parallel work allows some timing flexibility. For instance, tasks such as "Procure lighting system hardware" or "Develop monitoring platform requirements" show several days of slack because their completion does not immediately constrain the start of system integration. Even if these activities are delayed within their slack window, they do not influence the overall project finish date. These slack values were automatically computed in ProjectLibre based on the task durations we assigned, making the estimation process essential for distinguishing between schedule-driving tasks and those that can tolerate moderate delays.

Table 12: Task Estimations

Name		Duration	Late Start (ProjectLibre)	Early Start (ProjectLibre)	Early Start (Days)	Late Start (Days)	Slack
Eco Elevate			10/23/25 8:00	10/23/25 8:00			
1	Project Management and Planning						
1.1	Project Charter and Definition Scope						
1.1.1	Schedule Development and Planning	2 days	1/15/26 9:57	10/23/25 8:00	0	84	84
1.1.2	Technical Definition Statement	1.25 days	10/23/25 8:00	10/23/25 8:00	0	0	0
1.1.3	Requirements Definition Gate	0 days	10/24/25 10:00	10/24/25 10:00	1	1	0
1.2	Budgeting and Cost Control						
1.2.1	Risk Management Planning	5 days	1/7/26 9:57	10/24/25 10:00	1	76	75
1.2.2	Quality Assurance	3 days	1/14/26 9:57	10/31/25 10:00	8	83	75
1.2.3	Stakeholder Communication	3 days	1/14/26 9:57	10/31/25 10:00	8	83	75
1.2.4	Project Initiation Gate	0 days	1/19/26 9:57	11/5/25 10:00	13	88	75
2	Power						
2.1	Energy Storage						
2.1.1	Develop energy storage system requirements	2.5 days	12/9/25 8:40	10/24/25 10:00	1	47	46
2.1.2	Design energy storage system	1.667 days	12/11/25 13:40	10/28/25 15:00	5	49	44
2.1.3	Procure batteries and other energy storage system hardware	7.5 days	12/15/25 10:00	10/30/25 11:20	7	53	46
2.1.4	Energy storage subsystem testing	3.5 days	12/24/25 15:00	11/10/25 16:20	18	62	44
2.2	Solar generation						
2.2.1	Develop solar generation system requirements	2.5 days	12/3/25 15:00	10/24/25 10:00	1	41	40
2.2.2	Design solar generation system	5 days	12/8/25 10:00	10/28/25 15:00	5	46	41
2.2.3	Procure solar panels and other solar generation system hardware	7.5 days	12/15/25 10:00	11/4/25 15:00	12	53	41
2.2.4	Solar generation subsystem testing	3.5 days	12/24/25 15:00	11/14/25 10:00	22	62	40
2.3	Power distribution						
2.3.1	Develop power distribution system requirements	2.5 days	12/4/25 10:00	10/24/25 10:00	1	42	41
2.3.2	Design power distribution system	5.5 days	12/8/25 15:00	10/28/25 15:00	5	46	41
2.3.3	Procure power distribution hardware	6.5 days	12/16/25 10:00	11/5/25 10:00	13	54	41
2.3.4	Power distribution subsystem testing	3.5 days	12/24/25 15:00	11/13/25 15:00	21	62	41
3	Structure						
3.1	Lighting						
3.1.1	Develop lighting system requirements	2 days	10/30/25 15:00	10/24/25 10:00	1	7	6
3.1.2	Design lighting system	3.5 days	11/3/25 15:00	10/28/25 10:00	5	11	6
3.1.3	Procure lighting system hardware	5 days	11/7/25 10:00	10/31/25 15:00	8	15	7
3.1.4	Lighting subsystem testing	2.5 days	11/14/25 10:00	11/7/25 15:00	15	22	7
3.2	HVAC						
3.2.1	Develop HVAC system requirements	2.5 days	10/24/25 10:00	10/24/25 10:00	1	1	0
3.2.2	Design HVAC system	5 days	10/28/25 15:00	10/28/25 15:00	5	5	0
3.2.3	Procure HVAC system hardware	6.5 days	11/4/25 15:00	11/4/25 15:00	12	12	0
3.2.4	HVAC subsystem testing	3.5 days	11/13/25 10:00	11/13/25 10:00	21	21	0
3.3	Plant modules						
3.3.1	Develop plant module system requirements	2 days	10/30/25 15:00	10/24/25 10:00	1	7	6
3.3.2	Design plant modules	3.5 days	11/3/25 15:00	10/28/25 10:00	5	11	6

3.3.3	Procure plant module hardware	5 days	11/7/25 10:00	10/31/25 15:00	8	15	7
3.3.4	Plant module subsystem testing	2.5 days	11/14/25 10:00	11/7/25 15:00	15	22	7
3.4	Irrigation						
3.4.1	Develop irrigation system requirements	2.5 days	10/24/25 15:00	10/24/25 10:00	1	1	0
3.4.2	Design irrigation system	5 days	10/29/25 10:00	10/28/25 15:00	5	6	1
3.4.3	Procure irrigation hardware	7 days	11/5/25 10:00	11/4/25 15:00	12	13	1
3.4.4	Irrigation subsystem testing	2.5 days	11/14/25 10:00	11/13/25 15:00	21	22	1
4	Automation						
4.1	Sensors						
4.1.1	Develop requirements for sensor system	1.5 days	11/19/25 10:00	11/12/25 10:00	20	27	7
4.1.2	Design sensor system	10 days	11/20/25 15:00	11/13/25 15:00	21	28	7
4.1.3	Procure sensors and additional hardware	4 days	12/4/25 15:00	11/27/25 15:00	35	42	7
4.1.4	Sensor testing	3.5 days	12/10/25 15:00	12/3/25 15:00	41	48	7
4.2	Actuators						
4.2.1	Develop requirements for actuators	2.5 days	11/20/25 10:00	11/18/25 10:00	26	28	2
4.2.2	Design actuators	8 days	11/24/25 15:00	11/20/25 15:00	28	32	4
4.2.3	Procure actuator hardware	5 days	12/4/25 15:00	12/2/25 15:00	40	42	2
4.2.4	Actuator testing	2.5 days	12/11/25 15:00	12/9/25 15:00	47	49	2
4.3	Controls						
4.3.1	Develop requirements for control system	2.5 days	11/18/25 15:00	11/18/25 15:00	26	26	0
4.3.2	Design control system	10 days	11/21/25 10:00	11/21/25 10:00	29	29	0
4.3.3	Control subsystem testing	3.5 days	12/24/25 15:00	12/5/25 10:00	43	62	19
4.3.4	Implement algorithms to use resources efficiently	10 days	1/5/26 9:57	12/5/25 10:00	43	74	31
4.3.5	Integrate failsafe detection features	7 days	12/5/25 10:00	12/5/25 10:00	43	43	0
4.4	Monitoring Platform Integration						
4.4.1	Develop requirements for monitoring platform	2.5 days	12/17/25 15:00	12/9/25 10:00	47	55	8
4.4.2	Select third party monitoring platform	2.5 days	12/22/25 10:00	12/11/25 15:00	49	60	11
4.4.3	Integration testing with third party monitoring platform	3.5 days	12/24/25 15:00	12/16/25 10:00	54	62	8
4.5	Sensor and Control Integration						
4.5.1	Integrate sensors for environmental conditions	10 days	12/16/25 10:00	12/16/25 10:00	54	54	0
4.5.2	System Design Review Gate	0 days	12/30/25 10:00	12/30/25 10:00	68	68	0
5	System Integration Test and Evaluation						
5.1	System Integration Test Planning						
5.1.1	Develop system verification plan	2 days	1/15/26 9:57	12/30/25 10:00	68	84	16
5.1.2	Develop success criteria based on customer discovery	1.333 days	12/30/25 10:00	12/30/25 10:00	68	68	0
5.2	Final subsystem verification testing						
5.2.1	Power subsystem testing	1.75 days	12/31/25 13:40	12/31/25 13:40	69	69	0
5.2.2	Structural testing	1.167 days	1/1/26 9:20	12/31/25 13:40	69	70	1
5.2.3	Automation and control reliability testing	1.75 days	12/31/25 13:40	12/31/25 13:40	69	69	0
5.3	Integrated System Testing						
5.3.1	Full system functional testing under operational conditions	1.665 days	1/2/26 10:40	1/2/26 10:40	71	71	0
5.3.2	System Integration & Test Gate	0 days	1/19/26 9:57	1/5/26 16:59	74	88	14
5.4	Field testing and user evaluation						

5.4.1	Pilot deployment in controlled environment		7.498 days	1/5/26 16:59	1/5/26 16:59	74	74	0
5.4.2	Field Testing & Evaluation Gate		0 days	1/19/26 9:57	1/15/26 11:58	84	88	4
5.5	Reflection and Lessons Learned							
5.5.1	Summarized test results and corrective actions		1.749 days	1/15/26 11:58	1/15/26 11:58	84	84	0
5.5.2	Project Closure Gate		0 days	1/19/26 9:57	1/19/26 9:57	88	88	0

*Notes: *__Critical Path__ Activities are presented in __red__*

**__Gates__ are highlighted in __yellow__*

4.3 Estimate Variation (Mark Tarazi, Janhavi Gaikwad)

For this project, the schedule uncertainty was evaluated using the three-point estimation approach, which includes optimistic time, most likely (original scheduled time) and pessimistic completion time for every activity. Using these inputs, the expected duration was computed along with the corresponding standard deviation (sigma) and variation (sigma square) for critical path activities and is shown in Table 13. These statistical values allowed us to quantify how much the actual completion time may deviate from the expected duration. Based on these analysis we derived sigma ranges for this project telling how much delay or early our project can be completed. This provides clear understanding of potential delay or early completions and supports more informed and risk aware project planning.

Estimated completion times based on 1-sigma and 2-sigma variation is shown in Table 14.

Table 13: Estimate Variation

Activity Description	Optimistic Completion Time	Most Likely Completion Time	Pessimistic Completion Time	Estimated Duration (days)	Texp	Sigma	Sigma Sq
Project Management and Planning							
Project Charter and Definition Scope							
Schedule Development and Planning	1	2	4	2			
Technical Definition Statement	1	1.25	4	2	1.667	0.500	0.250
Budgeting and Cost Control							
Risk Management Planning	4	5	7	5			
Quality Assurance	2	3	5	3			
Stakeholder Communication	2	3	5	3			
Power							
Energy Storage							
Develop energy storage system requirements	2	2.5	5	3			
Design energy storage system	1	1.667	4	2			
Procure batteries and other energy storage system hardware	7	7.5	10	8			
Energy storage subsystem testing	3	3.5	6	4			
Solar generation							
Develop solar generation system requirements	2	2.5	5	3			
Design solar generation system	4	5	7	5			
Procure solar panels and other solar generation system hardware	6	7.5	10	8			
Solar generation subsystem testing	2	3.5	6	4			
Power distribution							
Develop power distribution system requirements	2	2.5	5	3			
Design power distribution system	5	5.5	8	6			
Procure power distrbution hardware	5	6.5	9	7			
Power distribution subsystem testing	2	3.5	6	4			
Structure							
Lighting							
Develop lighting system requirements	1	2	4	2			
Design lighting system	3	3.5	6	4			
Procure lighting system hardware	4	5	7	5			
Lighting subsystem testing	2	2.5	5	3			
HVAC							
Develop HVAC system requirements	2	2.5	5	3	2.833	0.500	0.250
Design HVAC system	4	5	7	5	5.167	0.500	0.250
Procure HVAC system hardware	6	6.5	9	7	6.833	0.500	0.250
HVAC subsystem testing	3	3.5	6	4	3.833	0.500	0.250

Plant modules							
Develop plant module system requirements	1	2	4	2			
Design plant modules	3	3.5	6	4			
Procure plant module hardware	4	5	7	5			
Plant module subsystem testing	2	2.5	5	3			
Irrigation							
Develop irrigation system requirements	2	2.5	4	3			
Design irrigation system	3	5	8	5			
Procure irrigation hardware	4	7	10	7			
Irrigation subsystem testing	2	2.5	4	3			
Automation							
Sensors							
Develop requirements for sensor system	1	1.5	3	2			
Design sensor system	8	10	13	10			
Procure sensors and additional hardware	3	4	8	4			
Sensor testing	3	3.5	6	4			
Actuators							
Develop requirements for actuators	2	2.5	4	3			
Design actuators	6	8	12	8			
Procure actuator hardware	3	5	6	5			
Actator testing	2	2.5	4	3			
Controls							
Develop requirements for control system	2	2.5	4	3	2.667	0.333	0.111
Design control system	6	10	16	10	10.333	1.667	2.778
Control subsytem testing	3	3.5	6	4			
Implement algorithms to use resources efficiently	6	10	15	10			
Integrate failsafe detection features	4	7	9	7	6.833	0.833	0.694
Monitoring Platform Integration							
Develop requirements for monitoring platform	2	2.5	4	3			
Select third party monitoring platform	2	2.5	4	3			
Integration testing with third party monitoring platform	3	3.5	5	4			
Sensor and Control Integration							
Integrate sensors for envinronmental conditions	8	10	15	11	10.500	1.167	1.361
System Integration Test and Evaluation							
System Integration Test Planning							
Develop system verification plan	1	2	3	2			
Develop sucess criterita based on customer discovery	1	1.33	3	2	1.553	0.333	0.111
Final subsystem verification testing							
Power subsysem testing	1	1.75	3	2	1.833	0.333	0.111
Structural testing	1	1.167	3	2	1.445	0.333	0.111
Automotion and control reliability testing	1	1.75	4	2	2.000	0.500	0.250
Integrated System Testing							
Full system functional testing under operational conditions	1	1.665	4	2	1.943	0.500	0.250
Field testing and user evalautuion							
Pilot deployment in controlled environment	6	7.5	10	8	7.667	0.667	0.444
Reflection and Lessons Learned							
Summaried test results and corrective actions	1	1.75	4	2	2.000	0.500	0.250
				70	69.108		2.779
				Critical Path			

Table 14: 1-sigma and 2-sigma estimates for completion time

1 sigma	Longer	84%	71.887
2 sigma	Longer	97.50%	74.666
1 sigma	Shorter	16%	66.329
2 sigma	Shorter	2.50%	63.550

4.4 Critical Path Activities (Karina Rivera-Lanza)

The critical path for this project consists of the activities that have zero slack, meaning that any delay in these tasks will directly delay the entire project completion date. These activities span from early requirements development through system design, subsystem procurement, algorithm implementation, integration, and field deployment. Because these tasks are sequentially dependent on one another, they form the controlling timeline of the project and require consistent monitoring to maintain schedule integrity.

The critical path begins in the requirements development phase, where system requirements are defined across the HVAC subsystem (Task 3.2.1), the irrigation subsystem (Task 3.4.1), and the control system (Task 4.3.1). These requirements form the technical basis for all corresponding subsystem designs. Any delay or ambiguity at this stage would immediately propagate forward, as design teams cannot begin subsystem modeling or component selection until the requirements are finalized. Redefinition at this stage would force redesign work later in the project and compress downstream activities.

Once requirements are established, the project moves directly into key design activities, including the design of the HVAC system (Task 3.2.2), irrigation system (Task 3.4.2), and control system (Task 4.3.2). These design tasks are critical because they directly feed procurement, fabrication, and integration work. Incomplete or unstable design inputs at this stage can lead to significant rework after components are purchased, which would not only affect the design timeline but also extend procurement and testing windows.

Next, the critical path progresses to procurement of hardware, particularly the HVAC system hardware (Task 3.2.3) and irrigation subsystem hardware (Task 3.4.3). Procurement tasks are sensitive to supplier lead times, material availability, and shipping duration. Because downstream assembly and testing require physical hardware, any delays in procurement instantly consume any remaining schedule margin. Vendor delays or supply-chain issues therefore represent one of the most direct risks to the critical path.

Following hardware acquisition, the system transitions into key testing and integration activities. This includes HVAC subsystem testing (Task 3.2.4), irrigation subsystem testing (Task 3.4.4), and control subsystem testing (Task 4.3.3). These tasks must be completed sequentially because they establish subsystem-level compliance with requirements before integration. Integration issues discovered here can cascade into extended troubleshooting time, and because these activities occur late in the timeline, they have no remaining float to absorb delays.

The critical path then advances to algorithm development and control integration, specifically implementing algorithms for efficient resource use (Task 4.3.4) and integrating failsafe detection (Task 4.3.5). These activities are essential for automated system operation and must be validated before full system integration. Any delay in algorithm maturity postpones integrated testing, reducing the team’s ability to identify and address system-wide defects early.

Finally, the critical path concludes with full system functional testing under real operating conditions (Task 5.3.1) and system integration and test gate approval (Task 5.3.2), followed by pilot deployment

(Task 5.4.1) before the project reaches closure. These final stages confirm that the vertical farming system performs reliably under biological and environmental variability. Because testing outcomes depend on real crop behavior, delays cannot be easily compressed, and any extension directly moves the project completion date.

Key Challenges and Impacts of Sigma Variations

There are several key challenges that the project team must remain aware of throughout the execution of the critical path. One of the most significant risks lies in the clarity and stability of system requirements, particularly for the HVAC, irrigation, and control subsystems. If requirements are not thoroughly defined and validated early on, the project may encounter design rework that directly shifts the schedule forward. Early-phase errors have a magnified impact because they force rework in design, procurement, and testing, all of which lie on the critical path.

Additionally, procurement lead times pose a notable challenge. Components such as HVAC units, pumps, sensors, and control electronics may have long or uncertain delivery windows. Any supply-chain disruption—whether due to vendor backlog, shipping delays, or material shortages—directly affects subsystem build readiness. Unlike non-critical tasks, procurement activities on the critical path cannot slip without impacting integration and testing.

Another major challenge relates to cross-disciplinary integration. The system depends on mechanical, electrical, agricultural, and software components functioning seamlessly together. Misaligned interfaces or incomplete cross-team coordination can lead to integration conflicts discovered late in the schedule, forcing iterative troubleshooting at a point where no slack remains. This risk is intensified by the need for algorithm development and tuning, as the algorithms govern environmental control stability, error detection, and resource optimization. If software performance stabilizes more slowly than expected, it delays integrated system testing.

During field testing and pilot deployment, the project must also account for the inherent variability of biological systems and environmental conditions. Crop growth cycles introduce real-duration constraints: certain environmental behaviors and crop responses simply cannot be accelerated. If testing must be repeated due to unexpected crop performance, sensor drift, or environmental fluctuations, the schedule may extend by full growth-cycle increments.

When considering schedule variation, sigma-based analysis highlights how sensitive these critical tasks are. A $+1\sigma$ delay in any critical-path activity immediately increases project duration one-for-one, since no float exists. A $+2\sigma$ delay exacerbates this further, often exceeding the ability of the project team to compensate with additional labor or parallelism. Conversely, -1σ or -2σ accelerations on critical tasks theoretically reduce project duration but are rarely realized in practice without dedicated acceleration strategies, since most critical-path work is inherently sequential.

Taken together, these challenges emphasize the need for proactive requirement validation, strong supplier management, frequent cross-team coordination, and early risk monitoring. Protecting the integrity of critical-path activities is essential for ensuring the project delivers on time and within planned performance constraints.

Table 15: Impacts to Critical Path

Challenge Area	Why It Matters	Impact on Critical Path
Requirement clarity and consistency	Early decisions drive all subsequent subsystem design	Any rework pushes the schedule forward
Procurement lead times	HVAC, irrigation, and sensor hardware availability may vary	Long lead times directly delay system build and testing
Subsystem integration complexity	Mechanical, electrical, and software systems must work seamlessly together	Failures discovered late require retesting and redesign
Algorithm reliability and automation performance	Automation is core to stable year-round growing conditions	Inadequate control logic delays final system validation
Field testing duration influenced by crop growth cycles	Biological systems introduce natural variability and waiting periods	System success cannot be confirmed without observing real crop performance

4.5 Non-Critical Path Activities (Janus Aurpy)

The critical path represents the sequence of activities in the project that have zero slack. These activities determine the earliest possible completion date. Any delay in a critical path activity will result in the identical delay to the final project finish. Because the activities on the critical path have no schedule flexibility, they require the closest monitoring and the most disciplined execution oversight. These activities should receive priority access to personnel, equipment, and decision-making attention throughout the project timeline.

Activities that are not on the critical path have positive slack. In this schedule, the non-critical activities generally have between 1 and 5 days of slack depending on predecessor and successor relationships. This slack represents allowable delay time that does not change the total project duration. Slack provides local flexibility, allowing resource leveling, workload balancing, and accommodation of minor disruptions without affecting the completion date. However, once a non-critical activity uses all of its available slack, it effectively becomes part of the critical path, reducing schedule resilience.

For example, the task “Procure lighting system hardware” has approximately 3 days of slack because it occurs in parallel with the procurement of other subsystem components with longer lead times. Even if lighting hardware procurement were delayed slightly, assembly and subsystem testing cannot begin until the HVAC and irrigation hardware, both on the critical path, are delivered. Therefore, this activity has built-in schedule flexibility without affecting the project end date.

Another example is “Develop monitoring platform requirements,” which has around 2 days of slack. The monitoring platform is integrated after the core environmental control systems are already functioning, so its deliverables are not required early in the build. This allows requirement definition and early integration preparation to shift slightly without delaying integration testing or final deployment activities.

These examples show how slack provides useful adaptability. Non-critical tasks are often placed in sections of the schedule where multiple activities run in parallel, or where their outputs are needed later in the project. However, if their slack is fully consumed due to delays or resource constraints, they may shift closer to or directly onto the critical path, reducing the schedule's overall robustness.

Impact of Estimate Sigma Variations on Non-Critical Path Activities

Time variation influences both the critical path and the slack buffer. When considering reasonable schedule variation of $+1\sigma$ and $+2\sigma$, the total project completion date increases by the same amount as the longest critical path delay because that path governs the finish date. In contrast, variation of -1σ and -2σ on critical path tasks reduces total project duration by the same amount, although in practice most projects realize reductions only when coordinated acceleration strategies are used.

For non-critical tasks, a $+1\sigma$ or $+2\sigma$ increase in task duration consumes part or all of the available slack before affecting the critical path. For example, if a non-critical activity has 4 days of slack, a $+1\sigma$ variation of 2 days still preserves the project completion date, while a $+2\sigma$ variation of 5 days exceeds the slack and adds 1 day to the overall schedule unless the additional delay is absorbed by resource reallocation.

Overall, managing the project schedule requires attention to:

- ➢ Protecting the zero-slack activities on the critical path from delay.
- ➢ Tracking slack use over time to prevent unmanaged schedule compression.
- ➢ Evaluating how delay variability affects both critical and non-critical tasks.

This approach ensures clear prioritization, enables proactive mitigation of emerging risks, and preserves schedule integrity across the system lifecycle.

5. Cost Management

5.1 Labor Rates (Louise Smith)

The team member selection for EcoElevate as described in Organization and Staffing outlines that the project requires a suite of project managers, electrical/solar engineers, mechanical/structural engineers, software/controls engineers, an agronomist, quality control personnel, and procurement personnel. Table 16 shows the mapping between EcoElevate personnel, the U.S. Bureau of Labor Statistics occupational profile, and the average hourly pay rate that will be used for cost estimation in this project (U.S. Bureau of Labor Statistics, 2024a).

Table 16: Labor Rates for EcoElevate cost estimations

EcoElevate Personnel	**Occupational Profile**	**Pay Rate ($/hour)**
Director of Project Management	Project Management Specialists (13-1082)	79.71
Project Managers	Project Management Specialists (13-1082)	51.97
Electrical/Solar Engineers	Electrical Engineers (17-2071)	58.16
Mechanical/Structural Engineers	Mechanical Engineers (17-2141)	55.95
Software/Controls Engineers	Software Developers (15-1252)	69.50
Agronomist	Soil and Plant Scientists (19-1013)	39.92
Quality Assurance	Inspectors, Testers, Sorters, Samplers, and Weighers (51-9061)	24.84
Procurement	Buyers and Purchasing Agents (13-1020)	39.29

Rate Selection Rationale

Occupational profiles for each role on EcoElevate were selected by evaluating which occupational profile most closely matched the needs of the project, as described in the following sections. Additionally, the relative importance of roles was considered when evaluating the hourly rate for each role. Since the Director of Project Management is the highest ranking member of the team, they have the highest hourly pay rate. Since this is an engineering project, the technical expertise provided by the engineering personnel (Electrical/Solar Engineers, Mechanical/Structural Engineers, and Software/Controls Engineers) is key for a successful project. As such, these roles have the three highest pay rates. The next highest pay rate is that of the Project Managers. Their role of managing scope, schedule, budget and coordinating efforts between subteams and subsystems is also critical for successful execution of the project. Agronomists have the next highest pay rate, which aligns with the emphasis that the project places on ensuring that the EvoElevate vertical farm solution will support efficient plant growth. After Agronomists, Procurement personnel have the next highest pay rate. They are responsible for procuring raw materials and evaluating different suppliers. Finally, Quality Assurance personnel have the lowest pay rates. While all of the personnel working on EcoElevate play important roles in ensuring successful project completion, labor rates are proportional to the relative importance of project members to project completion.

Project Managers and Director of Project Management

For the EcoElevate Project Managers, the Project Management Specialist role was the best fit. According to the U.S. Bureau of Labor Statistics, Project Management Specialists, "coordinate the budget, schedule, staffing, and other details of a project" (U.S. Bureau of Labor Statistics, 2025a), which aligns well with what the EcoElevate Project Managers will need to do. The pay rate for the Director of Project Management was based on the 90th percentile pay rate for a Project Management Specialist since they are the highest ranking member of the team based on the organizational chart.

Electrical/Solar Engineers

For EcoElevate Electrical/Solar Engineers, the occupational profile for Electrical Engineers was selected because Electrical Engineers "design, develop, and test electrical and electronic equipment, components, and systems" (U.S. Bureau of Labor Statistics, 2025b), and EcoElevate Electrical/Solar Engineers will primarily be designing, developing, and testing energy storage systems, solar energy generation systems, and electrical power distribution systems.

Mechanical/Structural Engineers

The EcoElevate Mechanical/Structural Engineer role maps well to the occupational profile for Mechanical Engineers, which states that Mechanical Engineers "design, develop, build, and test mechanical and thermal sensors and devices" (U.S. Bureau of Labor Statistics, 2024b). In EcoElevate, the Mechanical/Structural Engineers will be working on the lighting system for the vertical farm, the HVAC system to ensure appropriate climate control, the structural components that the plants will sit on, and the irrigation system for delivering water to the plants in the farm. Since these are mechanical and thermal systems, there is good alignment between the occupational profile for Mechanical Engineers and the role of Mechanical/Structural Engineers on EcoElevate.

Software/Controls Engineers

The Software/Controls Engineers working on EcoElevate are primarily responsible for writing software to support the use of sensors for environmental control, the use of actuators for remote operations of the vertical farm, as well as integration with third party monitoring software. According to the U.S. Bureau of Labor Statistics, Software Developers, "design computer applications or programs" (U.S. Bureau of Labor Statistics, 2025c), which makes this profile a good fit for the EcoElevate Software/Controls Engineer role.

Agronomist

The Agronomist on EcoElevate works with the engineering teams to provide agricultural technical support and ensure that the engineering solutions align with plant needs. Soil and Plant Scientists was the occupational profile that best matched this role. This occupational profile describes how Soil and Plant Scientists "conduct research in breeding, physiology, production, yield, and management of crops and agricultural plants or trees, shrubs, and nursery stock, their growth in soils, and control of pests" (U.S.

Bureau of Labor Statistics, 2023a). The Agronomist in EcoElevate needs to be knowledgeable on what factors can impact production, yield, and growth of crops, and may conduct experiments to provide input to the engineering teams as needed. Because of this, Soil and Plant Scientists was chosen as the occupational profile to represent the EcoElevate Agonomist.

Quality Assurance

The pay rate for the EcoElevate Quality Assurance personnel is based on the occupational profile for Inspectors, Testers, Sorters, Samplers, and Weighers, who "inspect, test, sort, sample, or weigh nonagricultural raw materials or processed, machined, fabricated, or assembled parts or products for defects, wear, and deviations from specifications [and may] use precision measuring instruments and complex test equipment" (U.S. Bureau of Labor Statistics, 2023b). Since the EcoElevate QA personnel are responsible for ensuring that the product meets requirements, this occupational profile was determined to be a good fit.

Procurement

According to the U.S. Bureau of Labor Statistics, "Buyers and purchasing agents buy products and services for organizations" (U.S. Bureau of Labor Statistics, 2019). Since the EcoElevate Procurement personnel are responsible for procuring raw materials and evaluating various suppliers, this aligns well with the description in the Occupational Outlook handbook.

5.2 Cost Breakdown Structure (Karina Rivera-Lanza)

The Cost Breakdown Structure for EcoElevate, as shown in Table 17, provides a comprehensive and traceable decomposition of all project costs, aligned directly to the Work Breakdown Structure and the system-of-interest. A graphical representation is provided in Figure 11. By structuring the CBS according to the same hierarchical numbering as the WBS, each subsystem, Power, Structure, Automation, and Integration, is linked to its corresponding cost accounts for personnel, materials, equipment, and contracted services. This approach ensures that every technical activity in the project lifecycle has an associated cost element, enabling accurate estimation, budget allocation, and earned value tracking. The CBS captures all major expenditures including solar generation, battery storage, HVAC systems, irrigation infrastructure, structural modules, sensors and controls, and integration/testing activities. These costs collectively form the Baseline Cost Estimate, which, based on the detailed material and labor pricing from the project documentation, totals $627,451 before management reserve and profit margins are applied.

Table 17: Cost Breakdown Structure

CBS Level	**WBS Code**	**Cost Category**	**Description**	**Estimated Cost ($)**
1	1	Project Management & Planning	PM labor, planning, admin tools	35,000
1.1	1.1	Personnel	Project management, scheduling labor	30,000
1.2	1.2	Overheads	Software licenses, administrative support	5,000
2	2	Power Subsystem	Solar, storage, distribution subsystems	120,000
2.1	2.1	Energy Storage	Battery system costs	30,000
2.1.1	2.1.1	Personnel	Battery design & test labor	8,000
2.1.2	2.1.2	Materials	Batteries, controllers, housings	20,000
2.1.3	2.1.3	Equipment	Battery test benches	1,000
2.1.4	2.1.4	Contracts	Battery suppliers	1,000
2.2	2.2	Solar Generation	Solar array subsystem	60,000
2.2.1	2.2.1	Personnel	Solar system engineering labor	8,000
2.2.2	2.2.2	Materials	Panels, inverters, mounting racks	42,000
2.2.3	2.2.3	Equipment	Solar testing instruments	5,000
2.2.4	2.2.4	Contracts	Solar hardware procurement	5,000
2.3	2.3	Power Distribution	Distribution electrical system	30,000
2.3.1	2.3.1	Personnel	Electrical engineering labor	6,000

2.3.2	2.3.2	Materials	Wiring, breakers, distribution panels	20,000
2.3.3	2.3.3	Equipment	Electrical installation tools	2,000
2.3.4	2.3.4	Contracts	Electrical installation contractor	2,000
3	3	Structure Subsystem	Lighting, HVAC, modules, irrigation	170,000
3.1	3.1	Lighting	Lighting subsystem	30,000
3.1.1	3.1.1	Personnel	Lighting engineering labor	4,000
3.1.2	3.1.2	Materials	LED grow lights, drivers	20,000
3.1.3	3.1.3	Equipment	Mounting tools	3,000
3.1.4	3.1.4	Contracts	Lighting vendor	3,000
3.2	3.2	HVAC	Heating/cooling subsystem	40,000
3.2.1	3.2.1	Personnel	HVAC engineering & technicians	5,000
3.2.2	3.2.2	Materials	Compressors, ducting, sensors	30,000
3.2.3	3.2.3	Equipment	HVAC units & tools	3,000
3.2.4	3.2.4	Contracts	HVAC installation provider	2,000
3.3	3.3	Plant Modules	Racks, trays, structure	60,000
3.3.1	3.3.1	Personnel	Structural engineers	6,000
3.3.2	3.3.2	Materials	Racks, frames, trays	35,000
3.3.3	3.3.3	Equipment	Assembly equipment	4,000
3.3.4	3.3.4	Contracts	Fabrication vendor	15,000
3.4	3.4	Irrigation	Pumps, filtration, valves	40,000
3.4.1	3.4.1	Personnel	Irrigation engineers	4,000
3.4.2	3.4.2	Materials	Tanks, pipes, filters	30,000
3.4.3	3.4.3	Equipment	Flow control tools	4,000
3.4.4	3.4.4	Contracts	Irrigation hardware supplier	2,000
4	4	Automation Subsystem	Sensors, actuators, controls	80,000
4.1	4.1	Sensors	Environmental sensor subsystem	12,000
4.1.1	4.1.1	Personnel	Sensor engineering labor	3,000
4.1.2	4.1.2	Materials	Environmental sensors	12,000
4.1.3	4.1.3	Equipment	Calibration tools	1,000
4.1.4	4.1.4	Contracts	Sensor vendors	2,000
4.2	4.2	Actuators	Actuation subsystem	10,000
4.3	4.3	Controls	PLC, automation software	20,000
4.4	4.4	Monitoring Platform	IT, cloud platform	18,000
4.5	4.5	Sensor-Control Integration	Testing & integration labor	15,000

5	5	System Integration & Testing	Full system verification	50,000
5.1	5.1	Test Planning	QA testers & planning labor	5,000
5.2	5.2	Verification Testing	Subsystem-level testing	15,000
5.3	5.3	Integrated Testing	Complete system testing	15,000
5.4	5.4	Field Deployment	Real-site evaluation	10,000
5.5	5.5	Lessons Learned	Project close-out labor	5,000

Within the context of the overall project cost, the CBS ensures the project's financial structure remains transparent, traceable, and complete. Material costs, including solar hardware, HVAC units, structural racks, and irrigation systems, represent the majority of expenditures and are supplemented by labor costs associated with engineering design, installation, testing, and project management. Equipment and contractual services add further detail to subsystem-level cost accounts, ensuring that external vendors, fabrication, specialized tools, and installation services are properly budgeted. The CBS also supports higher-level financial planning by rolling up subsystem-level estimates to support the allocation of management reserve, $172,549, and the project's targeted profit margin, $200,000, resulting in a final project budget of $1,000,000.

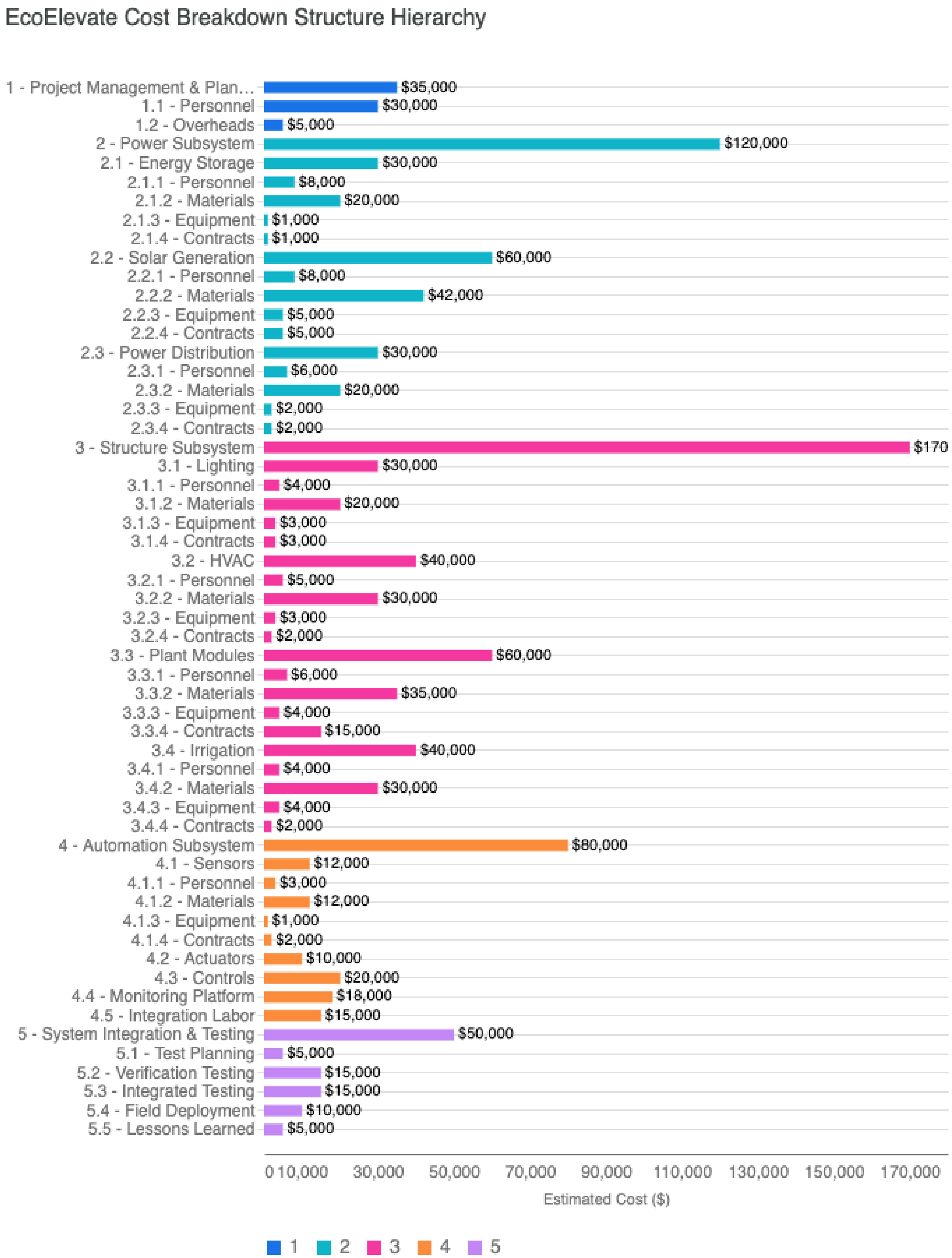


Figure 11: Cost Breakdown

5.3 Project Cost (Wantong Yao)

Personnel Costs

As shown in Table 18, the labor allocation for the EcoElevate project reflects a total of **3,224 working hours** across all personnel categories, translating into an estimated **labor cost of $237,202**. Among all roles, Mechanical/Structural Engineers (1,316 hours, $73,630) and Electrical/Solar Engineers (1,240 hours, $72,118) represent the largest workload and cost contributors, highlighting the project's engineering-intensive nature. Software/Controls Engineers follow with 693 hours ($48,164), while Project Managers account for 521 hours ($28,463), ensuring oversight and coordination. Support functions, including Agronomists (104 hours, $4,152), Quality Assurance (206 hours, $5,117), and Procurement (144 hours, $5,658), provide targeted contributions essential for system validation and resource acquisition. Overall, the distribution demonstrates a balanced but technically focused resource plan aligned with the project's system complexity and integration requirements.

Table 18: Personnel Costs

Position Type	Employee	Working Hours	Cost ($)
Project Manager	PM1*	50	3,986
	PM2	162	8,419
	PM3	165	8,575
	PM4	144	7,484
Total		521	28,463
Electrical/Solar Engineer	EE1	235	13,668
	EE2	222	12,912
	EE3	218	12,679
	EE4	131	7,619
	EE5	212	12,330
	EE6	222	12,912
Total		1,240	72,118
Mechanical/Structural Engineer	MS1	285	15,946
	MS2	229	12,813
	MS3	265	14,827
	MS4	289	16,170
	MS5	131	7,329
	MS6	117	6,546
Total		1,316	73,630
Software/Controls Engineer	SC1	205	14,248
	SC2	238	16,541
	SC3	168	11,676
	SC4	82	5,699

Total		693	48,164
Agronomist	AG1	52	2,076
	AG2	52	2,076
Total		104	4,152
Quality Assurance	QA1	87	2,161
	QA2	55	1,366
	QA3	64	1,590
Total		206	5,117
Procurement	PA1	41	1,611
	PA2	47	1,847
	PA3	56	2,200
Total		144	5,658

*PM1 corresponds with the Director of Project Management

Labor Cost Estimation Rationale

The labor assignments and cost estimations for this project were developed by strictly following the staffing structure defined in our Organizational Plan and by applying the requirements of the assignment rubric (Kerzner 13.4–13.8; 14.2–14.4). The final work-hour allocations ensure that (1) each activity is staffed by team members with the appropriate competencies, (2) no individual is overallocated beyond reasonable 8h daily limits, and (3) total labor cost remains within the target proportion of the project budget.

Alignment with Competencies
For each WBS activity, labor types were selected based on the technical skills required: **Project Manager**-is assigned to all planning, coordination, and review-gate tasks to ensure schedule integrity and cross-team alignment. **Electrical/Solar engineers** are responsible for designing, procuring, verifying, and testing all solar, power distribution, and automation subsystems that require knowledge of the electrical domain. **Mechanical/Structural engineers** support hardware-driven subsystems such as lighting racks, HVAC equipment, irrigation hardware, and actuator mechanisms. **Software/Controls engineers** are assigned to sensor logic design, actuator control, algorithm development, and system reliability testing. **Agronomist** is assigned to plant-related subsystem design and requirement development for environmental conditions. **Quality Assurance (QA)** supports all verification activities, review gates, and subsystem testing to provide independent evaluation and reduce integration risks. **Procurement** is assigned to hardware acquisition tasks to ensure realistic lead times and control of material costs.
Every assigned role directly corresponds to the competency needed for that task, ensuring that deliverables can be completed to specification without skill gaps.

Reasoning Behind Labor Quantity and Hours
Task durations shown in the WBS represent calendar time required to complete each activity. To translate duration into *working hours*, we assumed:

-Full-time staff work 8 hours/day,
-No staff exceeds 40 hours/week,
-For tasks with simultaneous workstreams (e.g., multi-disciplinary design activities), multiple personnel are assigned in parallel to meet the duration constraints without exceeding weekly limits.
Example:
A 2.5-day design task involving cross-disciplinary work requires *40 total engineering hours*. Instead of assigning a single engineer to work overtime, we assign two engineers (Electrical/Solar + Mechanical/Structural) working in parallel for 20 hours each. This ensures workload realism and avoids unapproved overtime

Complex multi-disciplinary tasks (e.g., subsystem testing, integration) include multiple staff working concurrently, which reflects the real-world need for synchronized validation and reduces schedule risk.

Gate reviews (e.g., Requirements Definition Gate, System Design Review Gate) are set to 0 working hours because they represent approval milestones rather than labor-consuming tasks.

Budget Control
Throughout the planning process, labor-hour allocations were iterated to maintain labor costs within ~23.7% of total project budget, leaving sufficient margin for material costs.

Cost control strategies applied include:

- Using QA personnel instead of engineers where tasks do not require high-cost technical specialists.
- Limiting the number of high-salary Software/Controls engineers on early-stage requirement tasks and focusing their hours on algorithm development and system reliability testing.
- Assigning Procurement staff to all hardware acquisition tasks to prevent unnecessary engineering hours.

Ensuring parallel staffing only where technically necessary, avoiding redundant man-hours.
This resulted in a total labor cost of approximately $237k, which remains comfortably within the project's target and adheres to the rubric's requirement that the plan remains within budget.

Structure of Work Distribution
The distribution of staff per task reflects a deliberate balance between:

- Technical need — matching skillsets with subsystem design requirements
- Schedule feasibility — preventing bottlenecks by allocating multiple staff where simultaneous work is required
- Cost efficiency — minimizing use of high-salary roles except where technically essential
- Quality assurance — maintaining QA involvement to ensure verification activities meet standards
- Integration readiness — dedicating sufficient engineering and software hours to integration and holistic system testing

By organizing the work in this structure, the project ensures that all critical system components (Power, Structure, Automation, Integration & Testing, etc.) progress in parallel without causing schedule delays or cost overruns.

Material Cost Estimation Rationale

The material cost estimates used in this project were developed using standard industry estimation practices referenced in ***Kerzner's Project Management: A Systems Approach to Planning, Scheduling, and Controlling***, particularly Chapter 14, which identifies "Materials/Support Costs" as a core component of project cost estimation and supports the use of **parametric estimating, vendor quotations, and analogous project data** for early-stage estimates. Because this course assignment does not require actual vendor quotes, all material prices were derived from **industry-typical unit costs, publicly available price data, and parametric scaling methods** aligned with Kerzner's recommended approach.

For the **solar power subsystem**, the photovoltaic module price of **$0.50/W** is based on widely cited 2024–2025 global module pricing reported by BloombergNEF (2024a) and the Solar Energy Industries Association (SEIA, 2024), both of which indicate a prevailing commercial-scale module range of **$0.45–$0.55/W**. Mounting hardware and BOS components were estimated at **$0.20/W**, consistent with BOS ratios presented in SEIA industry cost breakdowns (SEIA, 2024). Inverter and electrical cabinet costs were estimated at **$0.35/W**, aligning with commercial inverter price ranges listed by major manufacturers in 2024 (BloombergNEF, 2024a). Cabling and grounding hardware were assigned a baseline **$6,000**, consistent with small-scale agricultural PV case studies published in CEA retrofit summaries (CEA Association, 2023). The battery storage cost of **$300/kWh** is aligned with global average lithium-ion BESS pricing reported in BloombergNEF's *Battery Price Survey* (BloombergNEF, 2024b), which lists a typical commercial range of **$250–$350/kWh**.

For the **structural framing and hydroponics systems**, the vertical rack unit price of **$3,500** reflects typical pricing from commercial hydroponic equipment manufacturers such as AmHydro (2024) and GrowGeneration (2024), which publish similar prices for 4–6 tier steel rack assemblies. NFT channels, trays, water tanks, and filtration systems were estimated based on analogous pricing documented in CEA case studies (CEA Association, 2023), supporting the **$20,000** estimates for the tray/channel subsystem and the tank/filtration subsystem. Piping and valve materials were assigned **$25,000**, consistent with cost benchmarks for multi-zone irrigation systems in commercial controlled-environment agriculture (CEA Association, 2023). The HVAC subsystem cost of **$40,000** reflects contractor price ranges for small commercial single-zone air-handling units reported in 2023–2024 industry HVAC cost guides. Structural renovation materials were assigned **$5,000** based on typical insulation, waterproofing, and minor modification costs used in mid-scale retrofits (CEA Association, 2023).

For the **lighting and automation subsystems**, LED horticulture fixtures were priced at **$550 per unit**, matching published commercial fixture ranges from FluenceThe mounting hardware and wiring were estimated at **$6,000 proportionally** and wiring were proportionally estimated at **$6,000**. The PLC and central controller cost of **$15,000** aligns with 2024 commercial pricing for industrial controllers such as Siemens SIMATIC S7 (Siemens, 2024) and the Allen-Bradley CompactLogix series (Rockwell Automation, 2024). Environmental sensors were estimated at **$12,000**, consistent with multi-parameter environmental monitoring modules commonly used in greenhouses and CEA environments (CEA

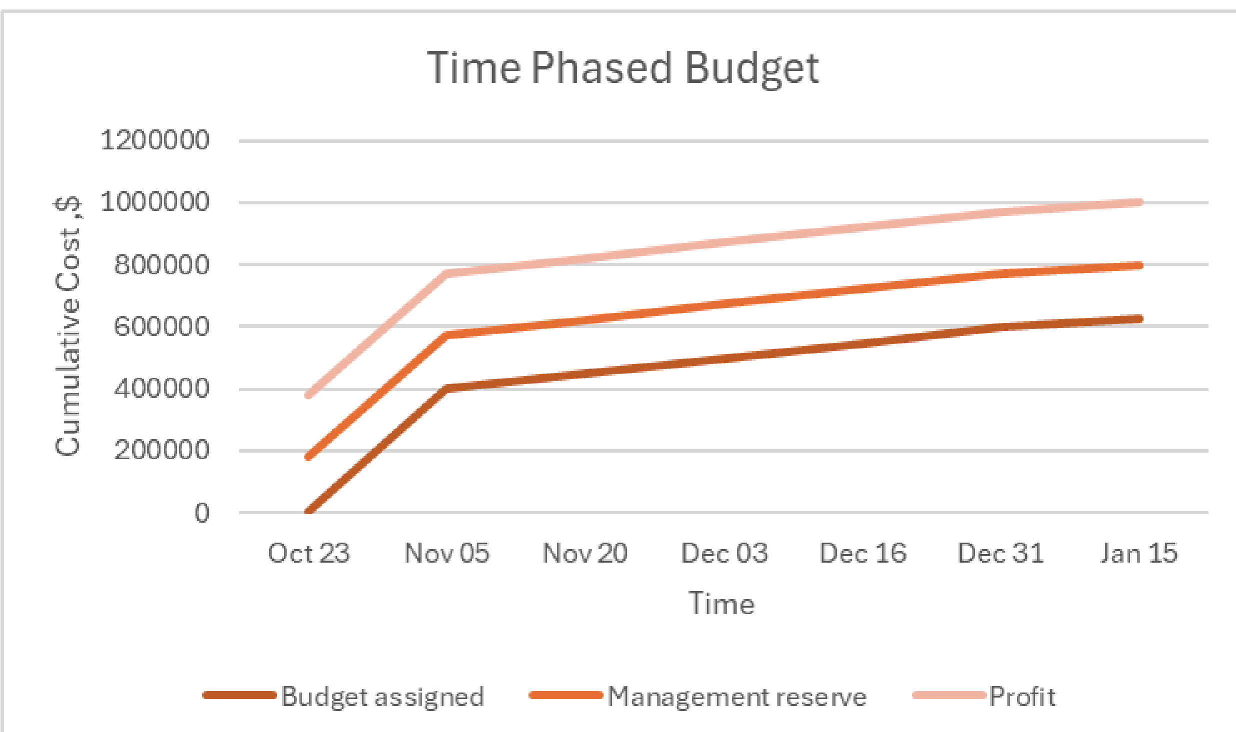
Association, 2023). Network infrastructure costs (**$10,000**) and monitoring system costs (**$8,000**) reflect typical commercial security system and IT deployment pricing (GrowGeneration, 2024).

Finally, **miscellaneous, safety, and spare materials** were estimated using proportional allocations from analogous small commercial facility projects, as recommended by Kerzner for early-phase cost modeling (Kerzner, 2022). Site preparation materials (**$15,000**), safety equipment (**$7,000**), and annual spare components (**$10,000**) all fall within standard ranges used in controlled-environment agriculture system installations (CEA Association, 2023).

5.4 Time-Phased Budget (Janhavi Gaikwad)

Based on the labour cost and the material cost for each task, a time phased budget chart was developed as shown in Figure 12. In the given chart X-axis represents the biweekly time periods across project life cycle while Y-axis shows the Cumulative cost in dollars. We have plotted 3 different lines representing cumulative budget assigned, cumulative management reserve and cumulative profit. The cumulative management reserve shows the cumulative cost along with the management reserve while cumulative profit line shows cumulative cost along with the management reserve and profit. These additional cumulative lines allow clear comparison between planned spending, contingency, and expected return over the duration of the project.

Figure 12: Time Phased Budget for EcoElevate



The cumulative BCWS curve shows how project costs are planned to grow over time based on the task estimates. The Budget at Completion (BAC), the final value of the cumulative BCWS at project end is $627,451. This represents the total projected cost of performing the planned work.

When compared with the total project budget of $1,000,000, the remaining funds are allocated to Management Reserve ($172,549) and Profit ($200,000). The chart therefore provides a complete and concise visual summary of planned expenditures, showing how the project team intends to stay within the overall budget by integrating reserve and profit considerations during iterative planning.

5.5 Baseline Project Plan (Mark Tarazi)

To create the project baseline, the full EcoElevate schedule was built in ProjectLibre with all WBS tasks, durations, dependencies, and resource assignments entered and checked for accuracy. As shown in Figure 13, each activity includes the correct staff based on the competencies defined in the Organizational Plan, and material resources such as solar panels, structural framing, grow lights, HVAC units, sensors, controllers, and other installation components were added to ensure that both labor and material costs were reflected in the plan. The schedule was reviewed to confirm that no team member exceeded reasonable weekly work limits and that overlapping engineering and quality assurance workstreams aligned with the technical needs of the project. Once the timeline, cost estimates, and resource usage were validated and confirmed to stay within the overall project budget, the approved plan was saved as the baseline. In the Gantt chart below, the baseline appears as thin grey bars under the schedule bars, showing the start and finish dates for each task. This baseline will be used to evaluate project performance and measure earned value by comparing planned progress with actual progress throughout the project lifecycle.

	Cost	Resource Names	Predecessors	Duration	Name
1	**$627451.11**			**62.237 da...**	**Eco Elevate**
2	**$13072.75**			**9.25 days**	**Project Management and Planning**
3	**$5138.29**			**2 days**	**Project Charter and Definition Scope**
4	$2522.64	PM1;PM2[50%];PM3[50%];PM4[50%]		2 days	Schedule Development and Planning
5	$2615.65	EE1;MS1;PM2[50%];PM3[50%];PM4[50%];SC1		1.25 days	Technical Definition Statement
6	$0.00		5	0 days	Requirements Definition Gate
7	**$7934.46**			**8 days**	**Budgeting and Cost Control**
8	$3118.20	PM2[50%];PM3[50%];PM4[50%]	6	5 days	Risk Management Planning
9	$4338.00	PM2;PM3;PM4;QA1	8	3 days	Quality Assurance
10	$478.26	PM1[25%]	8	3 days	Stakeholder Communication
11	$0.00		6;9;10	0 days	Project Initiation Gate
12	**$137720.56**			**18.5 days**	**Power**
13	**$44941.96**			**15.167 da...**	**Energy Storage**
14	$1744.80	EE1;EE5[50%]	6	2.5 days	Develop energy storage system requi...
15	$1163.20	EE1;EE5[50%]	14	1.667 days	Design energy storage system
16	$40196.82	Battery Storage system;EE1;PA1[30%]	15	7.5 days	Procure batteries and other energy st...
17	$1837.14	EE1;QA1[30%]	16	3.5 days	Energy storage subsystem testing
18	**$41268.36**			**18.5 days**	**Solar generation**
19	$1744.80	EE2;EE5[50%]	6	2.5 days	Develop solar generation system req...
20	$3489.60	EE2;EE5[50%]	19	5 days	Design solar generation system
21	$34196.82	EE2;PA1[30%];PV Module	20	7.5 days	Procure solar panels and other solar ...
22	$1837.14	EE2;QA1[30%]	21	3.5 days	Solar generation subsystem testing
23	**$51510.24**			**18 days**	**Power distribution**
24	$2326.40	EE3;EE6	6	2.5 days	Develop power distribution system re...
25	$5118.08	EE3;EE6	24	5.5 days	Design power distribution system
26	$42228.63	Cabling, grounding,Protection;Inverter and electric cabi...	25	6.5 days	Procure power distrbution hardware
27	$1837.14	EE3;QA1[30%]	26	3.5 days	Power distribution subsystem testing
28	**$261588.61**			**17.5 days**	**Structure**
29	**$40868.11**			**13 days**	**Lighting**
30	$2127.44	AG1[50%];EE4[50%];MS1;MS5[50%]	6	2 days	Develop lighting system requirements
31	$3723.02	AG1[50%];EE4[50%];MS1;MS5[50%]	30	3.5 days	Design lighting system
32	$32913.10	LED grow lights;MS1;Mounting hardware and wiring;PA...	31	5 days	Procure lighting system hardware
33	$2104.55	EE4[50%];MS1;MS5[25%];QA2[25%]	32	2.5 days	Lighting subsystem testing
34	**$57311.30**			**17.5 days**	**HVAC**
35	$2659.30	AG1[50%];EE4[50%];MS2;MS6[50%]	6	2.5 days	Develop HVAC system requirements
36	$5318.60	AG1[50%];EE4[50%];MS2;MS6[50%]	35	5 days	Design HVAC system
37	$46387.03	EE4[50%];HVAC system;MS2;MS6[50%];PA2[25%]	36	6.5 days	Procure HVAC system hardware
38	$2946.37	EE4[50%];MS2;MS5[25%];QA2[25%]	37	3.5 days	HVAC subsystem testing
39	**$85123.54**			**13 days**	**Plant modules**
40	$1662.16	AG2[50%];MS3;MS6[50%]	6	2 days	Develop plant module system require...
41	$2908.78	AG2[50%];MS3;MS6[50%]	40	3.5 days	Design plant modules
42	$78749.90	MS3;PA2[25%];Reniovation material;Verical grow racks;...	41	5 days	Procure plant module hardware
43	$1802.70	MS3;QA2[25%];MS6[50%]	42	2.5 days	Plant module subsystem testing
44	**$78285.66**			**17 days**	**Irrigation**
45	$2077.70	AG2[50%];MS4;MS5[50%]	6	2.5 days	Develop irrigation system requirements
46	$4155.40	AG2[50%];MS4;MS5[50%]	45	5 days	Design irrigation system
47	$70249.86	PA2[25%];Growing trays, NFT channel;Tank, filteration,...	46	7 days	Procure irrigation hardware
48	$1802.70	MS4;MS5[50%];QA2[25%]	47	2.5 days	Irrigation subsystem testing

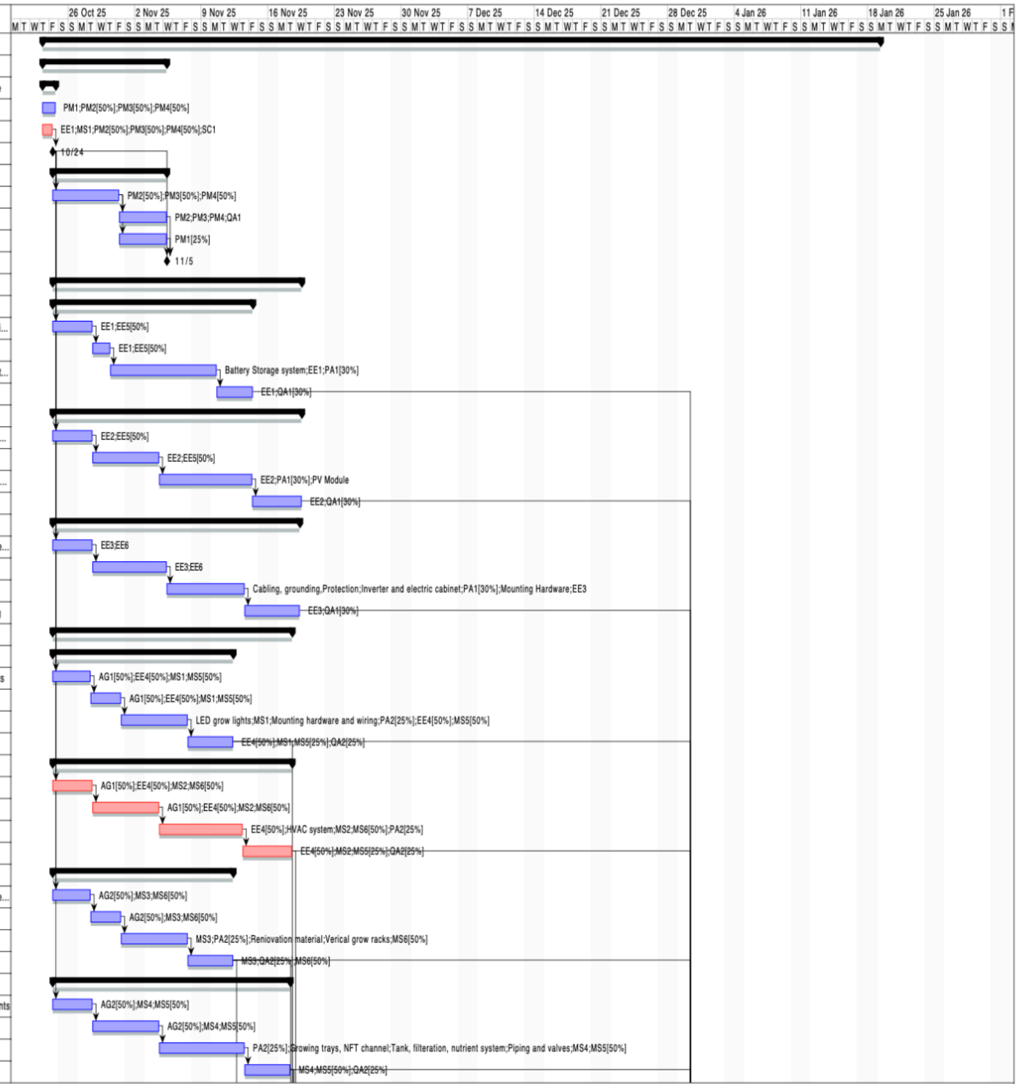


Figure 13A: Baseline Schedule

	Cost	Resource Names	Predecessors	Duration	Name
49	**$134829.58**			**34 days**	**Automation**
50	**$40711.24**			**19 days**	**Sensors**
51	$2203.32	EE5;MS3;SC1	43	1.5 days	Develop requirements for sensor syst...
52	$14688.80	EE5;MS3;SC1	51	10 days	Design sensor system
53	$18504.16	EE5;Environmental sensor;MS3;PA3[50%];SC1	52	4 days	Procure sensors and additional hard...
54	$5314.96	EE5;MS3;QA3[25%];SC1	53	3.5 days	Sensor testing
55	**$37349.84**			**18 days**	**Actuators**
56	$3672.20	EE6;MS4;SC2	43;48	2.5 days	Develop requirements for actuators
57	$11751.04	EE6;MS4;SC2	56	8 days	Design actuators
58	$18130.20	EE6;MS4;PA3[50%];SC2;Switches and structured cabling	57	5 days	Procure actuator hardware
59	$3796.40	EE6;MS4;QA3[25%];SC2	58	2.5 days	Actator testing
60	**$33046.82**			**22.5 days**	**Controls**
61	$2509.00	MS1;SC3	33;38;43;48	2.5 days	Develop requirements for control syst...
62	$10036.00	MS1;SC3	61	10 days	Design control system
63	$2382.66	MS1;QA3[25%];SC3[33%]	62	3.5 days	Control subsytem testing
64	$16834.80	PLC/ Main controller;SC3[33%]	62	10 days	Implement algorithms to use resource..
65	$1284.36	SC3[33%]	62	7 days	Integrate failsafe detection features
66	**$13685.68**			**8.5 days**	**Monitoring Platform Integration**
67	$1390.00	SC4	54	2.5 days	Develop requirements for monitoring ...
68	$10175.80	Cameras and display terminals;PA3;SC4	67	2.5 days	Select third party monitoring platform
69	$2119.88	QA3[25%];SC4	68	3.5 days	Integration testing with third party mo..
70	**$10036.00**			**10 days**	**Sensor and Control Integration**
71	$10036.00	MS2;SC2	54;59;65	10 days	Integrate sensors for envinronmental ...
72	$0.00		17;22;27;...	0 days	System Design Review Gate
73	**$80239.61**			**13.987 da...**	**System Integration Test and Evaluation**
74	**$5811.44**			**2 days**	**System Integration Test Planning**
75	$4185.04	EE1;MS1;PM2[50%];PM3[50%];PM4[50%];SC1	72	2 days	Develop system verification plan
76	$1626.40	PM2[50%];PM3[50%];PM4[50%];QA1;QA2;QA3	72	1.333 days	Develop sucess criterita based on cus...
77	**$43979.40**	**Site preperation;Safety and protection equipment;S...**		**1.75 days**	**Final subsystem verification testing**
78	$3092.18	EE2;EE3;PM1;QA1	76	1.75 days	Power subsysem testing
79	$3628.19	EE4;MS2;MS3;MS4;MS5;MS6;PM2[50%];QA2	76	1.167 days	Structural testing
80	$5259.03	EE5;EE6;PM3[50%];QA3;SC2;SC3;SC4	76	1.75 days	Automotion and control reliability testi.
81	**$5516.39**			**1.665 days**	**Integrated System Testing**
82	$5516.39	EE1;MS1;PM2;PM3;PM4;QA1;QA2;QA3;SC1	77	1.665 days	Full system functional testing under o...
83	$0.00		82	0 days	System Integration & Test Gate
84	**$19794.31**			**7.489 days**	**Field testing and user evalautuion**
85	$19794.31	EE1;EE2;EE3;PM2;PM3;PM4	82	7.489 days	Pilot deployment in controlled environ..
86	$0.00		85	0 days	Field Testing & Evaluation Gate
87	**$5138.07**			**1.749 days**	**Reflection and Lessons Learned**
88	$5138.07	EE1;MS1;PM1;PM2;PM3;SC1	85	1.749 days	Summarize test results and corrective...
89	$0.00		88	0 days	Project Closure Gate

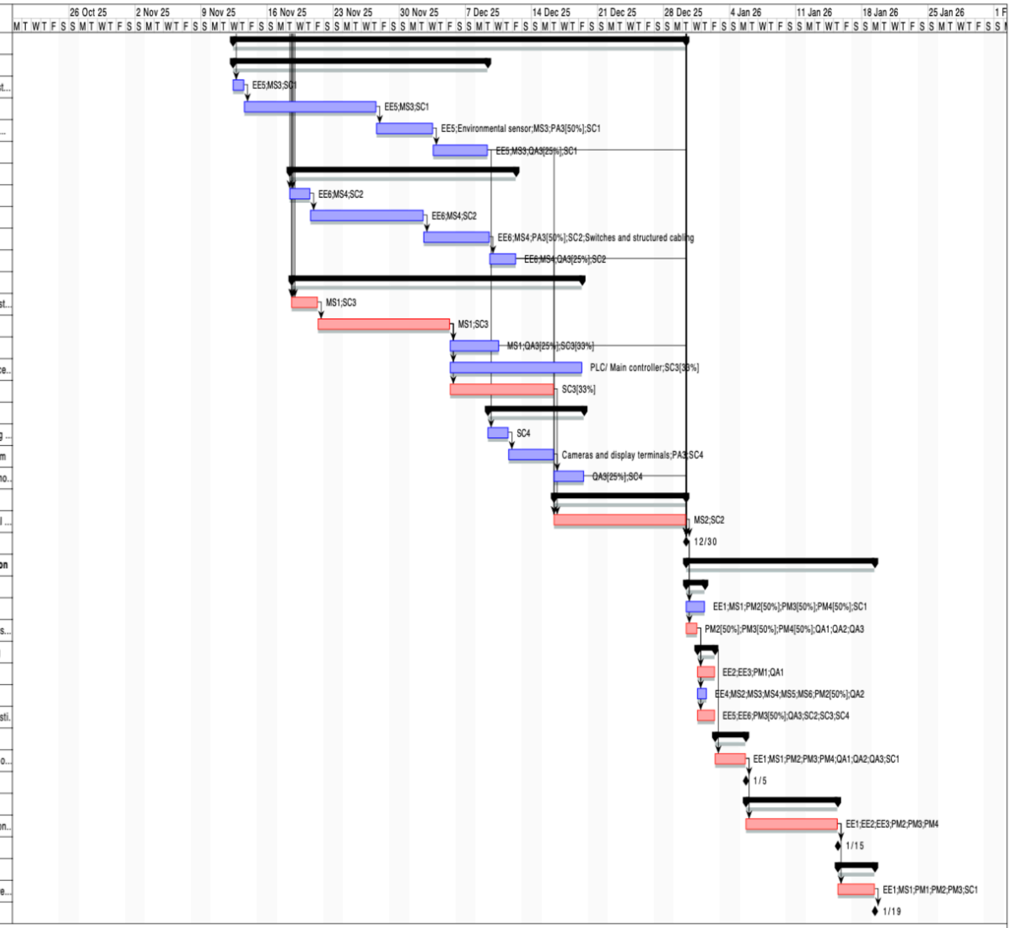


Figure 13B: Baseline Schedule (Continued)

5.6 Cost Management Plan (Janus Aurpy)

The cost management strategy for EcoElevate is structured to maintain clear control of expenditures throughout the project while ensuring that the distributed Budget at Completion (BAC) of $627,451 is used efficiently. Cost elements for labor, materials, and subcontracted activities are derived directly from the WBS and CBS, which allows the budget to remain tightly connected to scope and schedule. These baseline costs flow into the time-phased budget and cumulative BCWS curve, establishing the financial performance expectations that will be used to assess progress. The Management Reserve of $172,549 is maintained separately from the baseline and is released only through a formal change approval process. Keeping the reserve outside the baseline ensures that the planned value profile remains stable and prevents minor deviations from masking underlying issues.

Cost control efforts prioritize critical path activities because these tasks have the strongest influence on overall project duration and total cost. For EcoElevate, the critical path includes major engineering design activities, solar subsystem installation, automation hardware installation, subsystem integration, and full system verification. Any increase in effort, labor hours, or material cost on these tasks may create delays in downstream work or increase the volume of parallel effort required later in the schedule. These changes can raise overall project costs and alter the total amount of work that must be completed within the BAC. For this reason, these activities will be reviewed frequently to ensure alignment with the planned cost and duration.

Tasks not currently on the critical path but that have high uncertainty or dependency sensitivity will also be monitored closely. These include HVAC installation, sensor procurement, lighting racks, irrigation hardware installation, and other material-intensive construction activities. Although these tasks do not currently determine the project completion date, unanticipated issues such as procurement delays, equipment availability, or additional required rework could cause these tasks to shift onto the critical path. Early monitoring helps prevent these shifts and allows the project team to address emerging risks before they affect overall project performance.

Cost and schedule performance will be measured using CV and SV. These will be reviewed during biweekly team meetings that align with payroll submission and major procurement events. Tracking BCWS, ACWP, and BCWP allows the team to determine whether work is being performed at the expected cost and pace. If variances exceed defined thresholds or if there is evidence of potential chain-of-events impacts, the team will perform corrective actions that may include resequencing tasks, reassigning resources, or authorizing limited use of the Management Reserve. This structured approach ensures that project changes are evaluated carefully and in a timely manner, which helps preserve the integrity of the project baseline throughout execution.

5.7 Project EVM Plan (Janus Aurpy, Wantong Yao)

Earned Value Management (EVM) will be the primary method used to monitor and control cost and schedule performance on EcoElevate. The project team will track BCWS, ACWP, and BCWP on a biweekly cycle so that reporting remains consistent with labor charges and major procurement activities. BCWP will be calculated as the sum of the planned values for all tasks that have been completed either fully or partially during the reporting period. This allows reliable evaluation of performance against the baseline plan. Using these values, Cost Variance (CV equals BCWP minus ACWP) and Schedule Variance (SV equals BCWP minus BCWS) will be computed during each reporting cycle.

Positive CV and SV values indicate that work is costing less than planned or progressing faster than scheduled. Negative values will prompt the project team to identify whether the variance is due to underestimated labor, procurement delays, technical rework, or prolonged subsystem testing. Understanding the source of variance is necessary because it determines whether the deviation is temporary, localized, or likely to increase the Estimate at Completion (EAC). If the deviation is persistent or if the trend indicates future cost risk, the project team will determine whether corrective actions are required.

Critical path tasks will receive the highest level of oversight because early or late starts in these tasks can extend the overall schedule or cause cost increases that affect the final BAC. This includes solar subsystem installation, environmental control installation, automation hardware installation, integration activities, and system verification. During each reporting cycle, discipline leads will provide updates on progress, dependencies, and any potential risks that may create additional work or delays.

The EVM plan will also highlight non critical tasks that have a higher risk of becoming cost drivers. HVAC installation, subsystem verification, lighting installation, irrigation hardware deployment, and other material-intensive tasks can grow in cost if procurement delays or unexpected installation challenges occur. Monitoring these tasks ensures that potential cost drivers are addressed before they create broader issues.

A Management Reserve has been established based on uncertainties in vendor lead times, material pricing, and subsystem integration. This reserve is intended strictly for unplanned risks and not for normal project work. If variances exceed ten percent of planned value, the Project Manager will conduct a formal review with the discipline leads to determine appropriate actions and evaluate whether use of the Management Reserve is justified. These reviews will also consider potential chain-of-events impacts that could affect later phases of the project.

6. Risk Management Plan (Janhavi Gaikwad, Janus Aurpy)

6.1 Risk Management Approach

The EcoElevate project will implement a systematic and proactive risk management process aligned with the incremental lifecycle model and the project's high technical complexity. Risk management activities will be integrated into each project phase, from requirements definition through field deployment, ensuring that risks are identified early on any level and managed throughout the project lifecycle.

Risk Management Process:

The risk management process follows a continuous four-phase cycle:

1. Risk Identification: The project team will identify risks through multiple channels including brainstorming sessions during weekly team meetings, lessons learned from similar vertical farming and solar integration projects, stakeholder interviews, technical design reviews, and supplier assessments. Also, each subsystem team (Power, Structure, Automation) will maintain a subsystem-specific risk register that feeds into the master project risk register to be discussed in weekly meetings.
2. Risk Analysis: Once identified, each risk will be assessed for likelihood and severity. Risks will be categorized using a 5x5 risk matrix that enables clear prioritization.
3. Risk Tracking: All identified risks will be documented in the project risk register and maintained in a shared project management platform accessible to all team members. Risk status will be reviewed biweekly during project status meetings, with critical path risks reviewed weekly.
4. Risk Management: For each significant risk, the team will develop and implement one of four response strategies: avoid, mitigate, transfer ,or accept. Mitigation plans will be developed for all high and medium risks, with contingency reserves allocated accordingly.

Risk Organization and Responsibilities

Risk management responsibilities are distributed across the project organization to ensure appropriate technical expertise and management oversight:

The EcoElevate project employs a distributed risk management structure aligned with the three-subsystem architecture (Power, Structure, and Automation). This organizational approach ensures that risks are identified at the technical level where expertise resides, tracked and managed at the subsystem level where mitigation can be coordinated, and governed at the executive level where strategic resource decisions are made.

Director of Project Management:
It serves as the overall Risk Management Plan owner and maintains executive oversight of all project risks. The Director of Project Mana-gement is responsible for final approval of the Risk Management

Plan and major risk response strategies, authorizing use of the Management Reserve ($172,549) for risk mitigation activities, and escalating critical risks to executive leadership and external stakeholders. They conduct monthly risk reporting to investors, farm operators, and other key stakeholders and hold final decision authority on whether risks should be avoided, mitigated, transferred, or accepted. This executive-level oversight ensures that risk management aligns with overall project objectives and stakeholder expectations.

Project Managers:
They serve as Risk Coordinators responsible for the operational management of risk tracking and strategy development. Project managers collect risk reports from their respective subsystem teams, including engineers, agronomists, quality assurance personnel, and procurement staff. They maintain subsystem-specific risk registers that feed into the master project risk register and conduct biweekly risk review meetings with their teams to track risk status, monitor trigger conditions, and assess mitigation progress. These Risk Coordinators develop detailed mitigation plans for subsystem-specific risks, coordinate with subsystem teams when risks have cross-subsystem implications, and create contingency plans for high-priority risks. The project managers report subsystem risk status to the Director of Project Management during weekly coordination meetings and are responsible for immediately alerting the Director of Project Management when high-priority risks materialize or trigger conditions are met. They also document lessons learned from risk events for future reference.

Other Project members:
At the technical level, subsystem team members are responsible for identifying and reporting risks within their areas of expertise. Electrical/Solar Engineers identify and report risks to subsystem project managers related to solar procurement and installation , battery storage performance, energy generation adequacy , and grid interconnection and regulatory compliance . Mechanical/Structural Engineers identify and report risks to subsystem project managers concerning HVAC performance and environmental control , structural integrity and load capacity , irrigation distribution consistency , and critical path schedule risks . Software/Controls Engineers identify and report risks to subsystem project managers involving integration conflicts with the monitoring platform, algorithm development schedule overruns (R-012), and sensor calibration and accuracy issues. Agronomists provide specialized agricultural risk assessment to all subsystem PMs regarding environmental control adequacy for crops and irrigation effects on plant health (R-005). Quality Assurance personnel identify verification and testing risks and report them to the relevant subsystem PM, while Procurement personnel identify supply chain and cost risks and report them to subsystem PMs based on material category.

The risk review process operates through a three-tier governance structure. At the weekly level, subsystem teams continuously identify emerging risks during technical reviews, and engineers report new risks immediately to their subsystem PM. At the biweekly level, project managers consolidate subsystem risks, update risk registers, develop and refine mitigation strategies, and identify cross-subsystem risk impacts that require coordination. At the monthly level, director to project manager reviews the complete risk portfolio and top-10 risk list, makes strategic decisions on risk response approaches, allocates Management Reserve resources, and conducts formal stakeholder risk reporting. This structured approach ensures comprehensive risk coverage while maintaining clear accountability and efficient communication across all organizational levels.

6.2 Risk Events

The identified risks for the EcoElevate project are shown in Table 19. Each risk entry is given a unique Risk ID, a description of the risk event, a risk category, a likelihood score, and a severity score. The likelihood and severity score are multiplied to generate an overall risk score. Each risk is assigned to an owner who is responsible for managing the identified risk and ensuring the identified risk handling strategy is executed.

Table 19: Risk Events

Risk ID	**Risk Event Description**	**Risk Category**	**Likelihood**	**Severity**	**Risk Score**	**Risk Owner**
R-001	Solar panel procurement delays due to global supply chain disruptions extend project schedule	Procurement	High (4)	High (4)	16	Procurement Lead
R-002	Actual nighttime battery loads exceed estimated capacity due to higher power consumption, causing the battery system to deplete	Technical	Medium (3)	Critical (5)	15	Power PM
R-003	HVAC system unable to maintain required temperature and humidity ranges for optimal crop growth	Technical	Medium (3)	High (4)	12	Structure PM

R-004	Integration conflicts between automation control system and third-party monitoring platform cause delays	Technical	High (4)	High (4)	16	Automation PM
R-005	Irrigation system design fails to deliver consistent water distribution across all vertical levels	Technical	Medium (3)	High (4)	12	Structure PM
R-006	Critical path activities (HVAC procurement and testing) experience schedule slippage consuming all slack	Schedule	High (4)	Critical (5)	20	Project Manager
R-007	Environmental sensor calibration drift causes inaccurate readings and crop loss during field testing	Technical	Medium (3)	High (4)	12	Automation PM
R-008	Structural racks and plant modules fail to support planned crop weight loads	Technical	Low (2)	Critical (5)	10	Structure PM
R-009	Insufficient sunlight in deployment location reduces solar generation below design requirements	Environmental	Medium (3)	Critical (5)	15	Power PM

R-010	Delay in approval for integrating solar grid from utility companies and regulatory agencies	External	Low (2)	High (4)	8	Project Manager
R-011	Key personnel (senior engineers) leave project mid-execution causing knowledge loss	Resource	Low (2)	High (4)	8	Director of PM
R-012	Algorithm development for resource optimization takes longer than estimated, delaying system integration	Technical	High (4)	Medium (3)	12	Automation PM
R-013	Material cost escalation (steel, solar panels, electronics) exceeds budget allocation	Cost	Medium (3)	Medium (3)	9	Procurement Lead
R-014	Power distribution system design cannot safely handle peak loads during maximum operation	Technical	Low (2)	Critical (5)	10	Power PM
R-015	Stakeholder (investors/farm operators) change requirements mid-project causing scope creep	Scope	Medium (3)	High (4)	12	Project Manager

6.4 Likelihood and Severity Definitions

The likelihood and severity scales used to evaluate the risks for EcoElevate are shown in Table 20 and Table 21 respectively.

Table 20: Likelihood scale

Level	**Rating**	**Description**	**Probability Range**
Very Low	1	Remote possibility; highly unlikely to occur	0-10%
Low	2	Unlikely to occur during project lifecycle	11-30%
Medium	3	Possible; may occur during project	31-50%
High	4	Likely to occur; has occurred on similar projects	51-75%
Very High	5	Almost certain to occur	76-100%

Table 21: Severity scale

Level	**Rating**	**Cost Impact**	**Schedule Impact**	**Technical Impact**	**Safety Impact**
Very Low	1	<2% budget increase	<1 week delay	Minimal performance degradation	No safety concerns
Low	2	2-5% budget increase	1-2 week delay	Minor performance reduction	Minor safety issues, easily mitigated

Medium	3	5-10% budget increase	2-4 week delay	Noticeable performance reduction requiring workarounds	Moderate safety concerns requiring controls
High	4	10-20% budget increase	4-8 week delay	Significant performance degradation affecting key objectives	Serious safety issues requiring redesign
Critical	5	>20% budget increase	>8 week delay	System fails to meet critical requirements	Severe safety hazards, potential for injury

6.5 Risk Matrix

The risk matrix shown in Figure 14 shows where each identified risk falls in terms of risk priority based on the overall risk scores. Three of the identified risks are high risks, with scores of at least 16. Nine risks are medium high risk with scores between 10 and 15, and the remaining three identified risks are medium low risk with scores between 6 and 9.

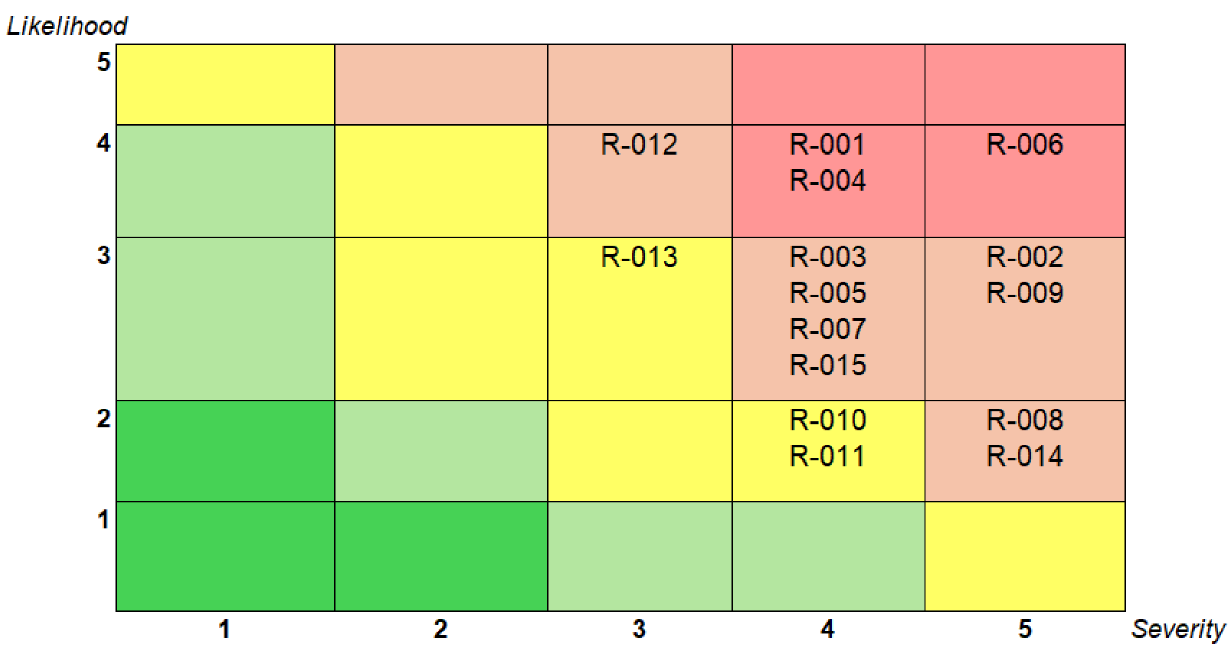


Figure 14: Risk Matrix

6.6 Risks Analysis for Top 10 Risks

Risk R-006: Critical Path Schedule Slippage (Risk Score: 20)
This is the highest-priority risk with likelihood of High (4) and severity of Critical (5). The critical path includes HVAC requirements, design, procurement, and testing, plus irrigation and control system development, all with zero slack. Any delay directly extends the January 19 project completion date. The high likelihood stems from HVAC procurement lead times (6.5-9 days) and typical vendor delays in agricultural facility projects. The critical severity means schedule delays trigger penalty clauses, investor dissatisfaction, and prevent field testing completion. A one-week critical path delay equals a one-week project extension with associated cost increases.

The **MITIGATE** strategy includes: fast-tracking HVAC procurement by issuing vendor quotes during design phase (saving two weeks), weekly monitoring by PM4 and PM1, developing alternative HVAC configurations from backup suppliers, and allocating $30,000 from Management Reserve for expedited shipping if needed. Schedule variance exceeding -5% triggers immediate escalation to director of project management.

Risk R-001: Solar Panel Procurement Delays (Risk Score: 16)
This risk scores 16 with likelihood High (4) and severity High (4). Global supply chain disruptions continue affecting solar panel availability, with documented lead times of 6-10 weeks and ongoing manufacturer backlogs. The high severity reflects that solar panels are foundational, without them, energy storage cannot be tested, power distribution cannot be validated, and sustainability claims cannot be verified. A 4-8 week delay would extend integration activities and potentially delay the Field Testing Gate.

The **MITIGATE** and **TRANSFER** strategy includes: placing orders immediately after System Design Review Gate rather than waiting, establishing relationships with three qualified suppliers with liquidated damages clauses (transferring financial risk), maintaining design flexibility to accept panels from multiple manufacturers, and authorizing expedited shipping from Management Reserve if delays emerge.

Risk R-004: Automation-Monitoring Platform Integration Conflicts (Risk Score: 16)
This technical integration risk scores 16 with likelihood High (4) and severity High (4). The project depends on integrating custom control algorithms with third-party monitoring platform software, where interface specifications, data formats, and communication protocols must align perfectly. High likelihood reflects that vendor software may have undocumented limitations or may change during the project. Previous vertical farming projects have experienced integration failures requiring significant rework. High severity reflects that integration testing is on the critical path—failures would require algorithm rework or platform replacement, causing substantial schedule delays and cost overruns.

The **MITIGATE** strategy includes: obtaining complete API documentation and test environments during requirements phase, developing prototype integration during control system design (Task 4.3.2) rather than waiting for formal integration testing, including vendor technical support provisions in contracts, and maintaining a contingency plan to implement a simplified internal monitoring dashboard using open-source tools if integration proves unfeasible.

Risk R-002: Battery Storage Capacity Shortfall (Risk Score: 15)
This critical technical risk scores 15 with likelihood Medium (3) and severity Critical (5). Energy storage is essential for autonomous nighttime operations. Medium likelihood reflects uncertainty in actual energy consumption while design calculations project loads from LED lighting, HVAC, and controls, actual consumption may exceed estimates due to environmental variations or unanticipated auxiliary loads. Critical severity means insufficient capacity would force nighttime operation reductions or require grid power at night (undermining the solar-powered value proposition and potentially violating customer requirements).

The **MITIGATE** strategy includes: designing battery system with 25% capacity margin above calculated worst-case loads, conducting extended discharge tests under maximum load during subsystem testing, implementing real-time battery monitoring with early warning alerts, designing modular architecture allowing capacity expansion if needed, and allocating $15,000 contingency budget for supplemental battery procurement.

Risk R-009: Insufficient Solar Generation at Deployment Site (Risk Score: 15)
This environmental risk scores 15 with likelihood Medium (3) and severity Critical (5). Project Assumption #1 states deployment will occur in areas with sufficient year-round sunlight, but site validation remains uncertain. Medium likelihood reflects that while preliminary assessment suggests adequate solar resources, actual generation depends on local weather patterns, shading from nearby structures, panel orientation, and seasonal variation. Critical severity means insufficient generation would require grid supplementation (compromising sustainability mission) or system redesign with larger arrays (requiring additional cost and potentially exceeding available space).

The **AVOID** and **MITIGATE** strategy includes: conducting rigorous site selection with detailed solar resource assessment using historical weather data and solar pathfinder analysis, requiring minimum annual solar insolation of 4.5 $kWh/m^2/day$ before site approval, relocating to alternative site if threshold not met (avoidance), designing solar array with 15% generation margin above calculated maximum daily loads, and including grid interconnection capability as backup while maintaining primary solar-based operation.

Risk R-003: HVAC System Performance Inadequacy (Risk Score: 12)
This technical risk scores 12 with likelihood Medium (3) and severity High (4). Environmental control is critical for crop health and yield. Medium likelihood stems from the challenge of maintaining precise temperature and humidity in a building with heat-generating LEDs and transpiring plants, commercial HVAC systems are designed for comfort cooling rather than precision control. High severity reflects that temperature or humidity excursions would stress crops, reduce yield, potentially cause crop loss during field testing, and delay project acceptance. HVAC issues discovered during integrated testing would require redesign and replacement, extending schedule and increasing costs.

The **MITIGATE** strategy includes: specifying HVAC with 20% cooling capacity margin above calculated heat loads and oversized dehumidification for worst-case transpiration rates, modeling thermal loads using agricultural facility standards rather than commercial building codes, including redundant sensors and zone-based control, conducting extended runtime testing under maximum load with crop-mass simulators during subsystem testing (Task 3.2.4), and maintaining contingency plan for supplemental spot cooling/dehumidification units.

Risk R-005: Irrigation Distribution Inconsistency (Risk Score: 12)
This hydraulic engineering risk scores 12 with likelihood Medium (3) and severity High (4). Drip irrigation in vertical stacked configuration presents challenges for uniform water distribution. Medium likelihood reflects the difficulty of maintaining equal pressure and flow across multiple vertical tiers, lower tiers may receive excessive water while upper tiers receive insufficient water due to gravitational pressure differences. High severity means inconsistent irrigation would cause uneven crop growth, reduce yield in affected zones, complicate agricultural management, and potentially require system redesign and reinstallation during field testing.

The **MITIGATE** strategy includes: incorporating pressure-compensating drip emitters that maintain consistent flow despite pressure variations, designing independent supply lines for each tier with flow balancing valves, conducting distribution uniformity testing during irrigation subsystem testing (Task 3.4.4) with acceptance criterion of ≥85% distribution uniformity, measuring delivered volumes at multiple locations across all tiers, and designing system to allow retrofit of additional pressure regulation components without complete reinstallation if deficiencies emerge.

Risk R-007: Environmental Sensor Calibration Drift (Risk Score: 12)
This instrumentation risk scores 12 with likelihood Medium (3) and severity High (4). Autonomous control depends on accurate sensor readings. Medium likelihood based on industry experience showing temperature, humidity, and soil moisture sensors experience calibration drift in humid, fertilizer-laden growing environments. Sensor fouling, condensation, and salt accumulation alter readings within weeks. High severity means inaccurate sensor data causes incorrect environmental adjustments (over-watering, under-cooling), stressing crops and potentially causing losses during field testing. Late-discovered sensor failures require recalibration, extended field testing, and delayed project acceptance.

The **MITIGATE** strategy includes: employing multiple redundant sensors for each critical parameter with algorithm-based fault detection identifying outlier readings, conducting accelerated aging tests in simulated environments during sensor testing (Task 4.1.4), including accessible calibration check-points with documented procedures, performing weekly sensor verification against calibrated reference instruments during field testing with immediate recalibration if drift exceeds ±2%, and displaying sensor health metrics on monitoring platform with operator alerts for calibration issues.

Risk R-012: Algorithm Development Schedule Overrun (Risk Score: 12)
This software development risk scores 12 with likelihood High (4) and severity Medium (3). Resource optimization algorithms and failsafe detection represent complex software on the critical path. High likelihood reflects inherent uncertainty in software timelines, particularly for algorithms balancing competing objectives (energy efficiency, crop health, reliability). Algorithm tuning often requires iterative testing extending beyond estimates. Medium severity means delays extend the critical path, but impact is partially contained because algorithm development occurs late in schedule when other subsystems are finalizing, providing some parallel activity opportunity.

The **MITIGATE** strategy includes: developing initial algorithm versions in simulation environments during control system design phase (Task 4.3.2) rather than waiting for implementation (Task 4.3.4), adopting agile development with two-week sprints for incremental progress and early risk identification, prioritizing requirements into "must-have" core functionality and "nice-to-have" optimization features allowing scope reduction if needed, and authorizing software engineer overtime during algorithm development to maintain schedule.

Risk R-015: Mid-Project Stakeholder Requirement Changes (Risk Score: 12)
This scope management risk scores 12 with likelihood Medium (3) and severity High (4). Stakeholder-driven scope changes are common in innovative projects where stakeholders may not fully understand capabilities until seeing operational prototypes. Medium likelihood reflects that investors and farm operators may request modifications during integrated testing or early field deployment common changes include additional crop types, modified environmental set-points, enhanced monitoring features, or altered energy management. High severity means requirement changes during late phases (integration, testing, deployment) necessitate rework of completed designs, potential hardware changes, software modifications, and retesting, extending schedule and increasing cost beyond baseline.

The **MITIGATE** and **ACCEPT** strategy includes: conducting rigorous stakeholder engagement during requirements definition (Tasks 2.1.1, 3.2.1, 4.3.1) ensuring stakeholders understand and approve baseline capabilities before design, requiring formal stakeholder sign-off on System Requirements Document at Requirements Definition Gate, conducting structured stakeholder demonstrations during testing with clear distinction between baseline capabilities (in scope) and future enhancements (out of scope), implementing formal change control process requiring impact assessment (cost, schedule, technical) with approval authority reserved to PM1 and Director of PM, accepting minor changes not affecting critical path if accommodated within Management Reserve, and deferring major changes to post-deployment phases or follow-on contracts.

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