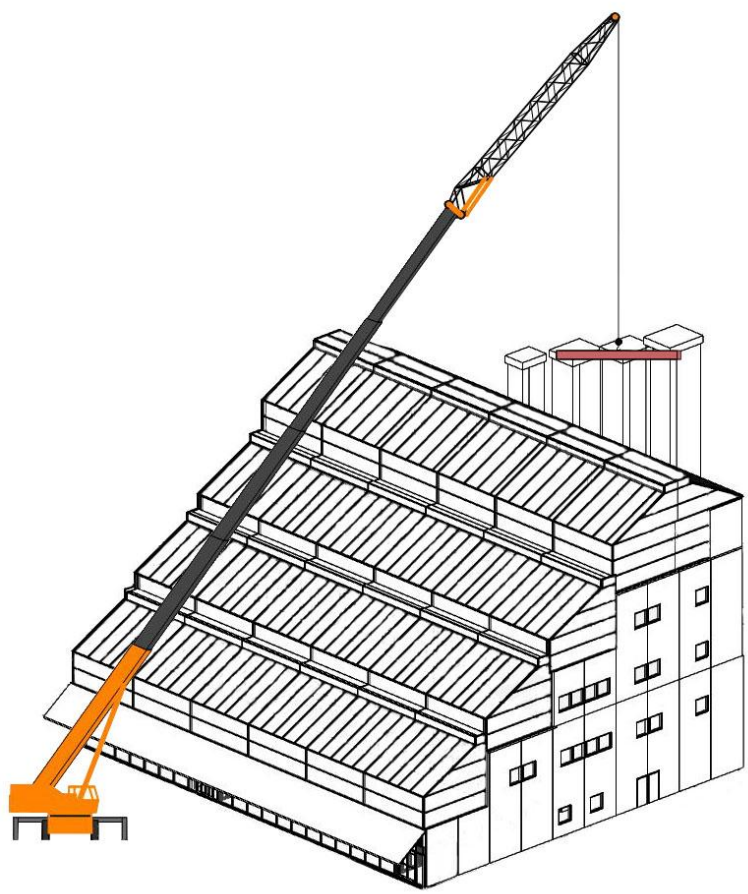
Synthesis
Engineering for Architecture

AEI STUDENT DESIGN COMPETITION

Construction Report



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Contents

Below are symbols the Synthesis Construction Engineers will be utilizing throughout the report to illustrate how 3 main concepts (cost, schedule, and safety) are affected with regards to each report section.

Safer

Schedule Improvement

Lifecycle Cost Decrease

Executive Summary

With an overall objective of creating an adaptable educational space capable of producing crops year round, team Synthesis developed three main goals to guide the design and construction process. The goals consisted of:

- Development of an adaptable building design
- Establishing a self-sustaining ecosystem
- Cultivation of a great environment and learning experience through the design and construction of a Vertical Farm

Construction Engineering Objectives

1. Building construction that assures good ***quality***
2. Constructing an ***efficient long-lasting*** building
3. Creation of a building in which the ***learning experience*** and environment thrives
4. Use of ***innovative construction methods*** that can be ***adapted*** to other geographical locations
5. ***Guiding*** the designers throughout design and construction

Schedule

It is the responsibility of the construction engineers to develop and manage both the design and construction schedule. Innovative construction and team collaboration techniques are the keys to providing the owner with a thorough and on time design. Synthesis is proposing a design-based project schedule of 9 months and a construction schedule of 7 months with the building set to open in the beginning of May 2016. This opening date allows the facility to open in a month when a low amount of artificial grow lighting is being used and the weather is appropriate to utilize the outdoor market space.

Budget

The building is designed to be a prototype for future Vertical Farms. Emphasis is placed on engineering systems that allow Growing Power to become its own self-sustaining ecosystem. With innovative systems in mind, the Synthesis team chose to perform a lifecycle analysis of the unique mechanical systems and use the payback period to offset the upfront cost. The construction engineers have established a budget of $11.7 million dollars with an annual payback of $349,877.

Façade System

The building façade is split into two factions: architectural precast panels on the north, east and west portions of the building, and a polycarbonate curtain system on the southern façade. The precast panels play a large role in the shortened construction schedule because they are manufactured offsite. They also aid in the reduction of waste on site because of the 'prefabrication' process.

Greenhouse Module

The greenhouses were an interdisciplinary collaboration between all members of the Synthesis team. The construction engineers were responsible for developing a greenhouse module construction plan that includes adaptability in the event that building dimensions are changed for a future site.

Natural HVAC

One of the defining attributes of this building is the use of natural ventilation throughout the building using Raised Access Flooring (RAS) with an Under Floor Air Distribution System (UFAD). With the mechanical constraints that come along with this innovative system, the UFAD is only used on a portion of the 2nd, 3rd and 4rd floors, meaning that those levels needed to be designed for two different slab elevations. It was the job of the construction engineers to develop a comprehensive plan of how the separate elevations could efficiently be erected during construction.

Another key characteristic of the natural HVAC system is the use of intake and exhaust towers on the north side of the building to supply outdoor air to each floor and exhaust the stale air. For the construction engineers, this required creation of a plan to erect the towers. The steel structure towers with hybrid CMU infill walls, on every level, were a key point for collaboration between the construction engineers and the structural engineers.

Foundation

The Growing Power building site consists of silty, sandy clay soils which produced a low allowable bearing capacity. The site also features a high water table, with test borings detecting free water at depths ranging from 8'-0" to 12'-0". To accommodate the high water table and low bearing capacity of the soil, the construction engineers, working closely with the structural team, implemented a soil improvement system known as Geopiers, and utilized sheet piling during the excavation process.

In summary, Synthesis is an integrated team decicated to meeting the clients needs throughout the design and construction of the Vertical Farm.

1.0 Project Introduction

Growing Power, Inc., a local Milwaukee, Wisconsin urban farming organization currently feeds more than 10,000 locals each year through school kitchens, restaurants, affordable food baskets, and at farmers markets. Growing Power is looking to increase their sphere of influence and production with the implementation of a new Vertical Farm project located on their existing site at 5500 W. Silver Spring Drive, Milwaukee, WI. Five stories of south facing greenhouse areas will allow aquaponic production of plants and fish year round. Expanded educational classrooms, conference spaces, and a demonstration kitchen will further support Growing Power's mission as a local and national resource for learning about sustainable urban food production.

Project Scope – The Growing Power Project required the Synthesis Construction Engineers to emphasize the following tasks:

- Innovative Construction Engineering
- Construction Management
- Construction Methods
- Project Budget & Schedule

These processes, in conjunction with preliminary information about Growing Power and its needs, led to the development of project wide goals and design criteria for the Vertical Farm.

2.0 Project Goals

The Synthesis Construction Engineers emphasized engineering systems and spaces that are:

Educational

Synthesis is committed to engineering an environment for Growing Power that promotes a meaningful learning experience for everyone who visits the Vertical Farm.

Ecological

The entire construction plan should consider material choices and impact on other building systems and occupants while also taking into account the external effect it has on the environment.

Adaptable

Strong emphasis has been placed on designing a prototype building that is easily adjusted to new building conditions, emerging technologies, and geographical environments.

3.0 Team Direction

These goals helped to direct the team while developing a design that would benefit all the project's stakeholders (shown in figure CE.1).

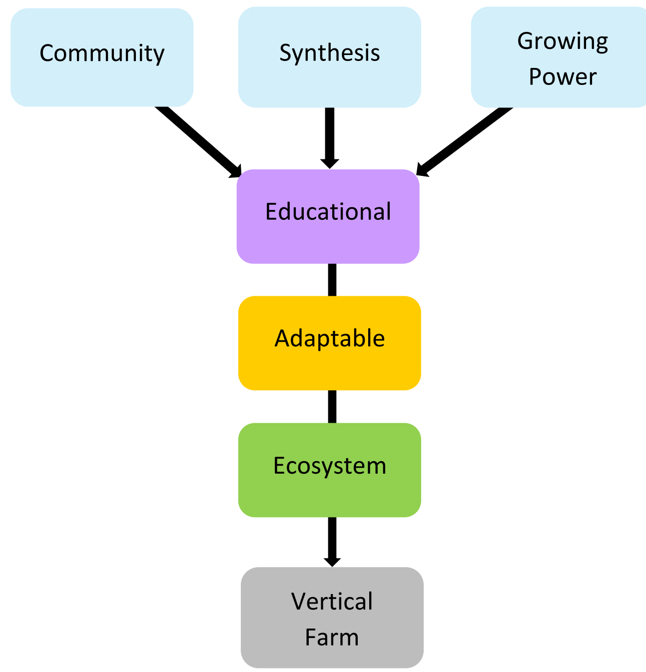

FIGURE CE.1: SYNTHESIS PHILOSOPHY ALIGNMENT

The team was developed based on the selection of individuals that collectively have the desirable skill set required for project success including the establishment of the building components and systems with maximum integration. Dedication, experience, dependability, technical competence, and exceptional communication skills brought this team together.

The energetic attitude of Synthesis provided the team with the capabilities necessary to strive for innovation and a unique approach to a successfull Vertical Farm prototype design. Synthesis interpreted prototype to mean design of a building constructed in Milwaukee that has the ability to adapt to a variety of other locations with minimal alterations. The team did not limit their potential to produce the most innovative and integrated design that is intended to set the standard for future vertical farms. The design has raised the bar on many aspects of efficiency and sustainability.

4.0 Team Organization

4.1 Delivery Method

Growing Power's Vertical Farm design was developed, and will be constructed using a Joint Venture Design-Build delivery approach as detailed in Figure CE.2 below(What is Design-Build? 2015).

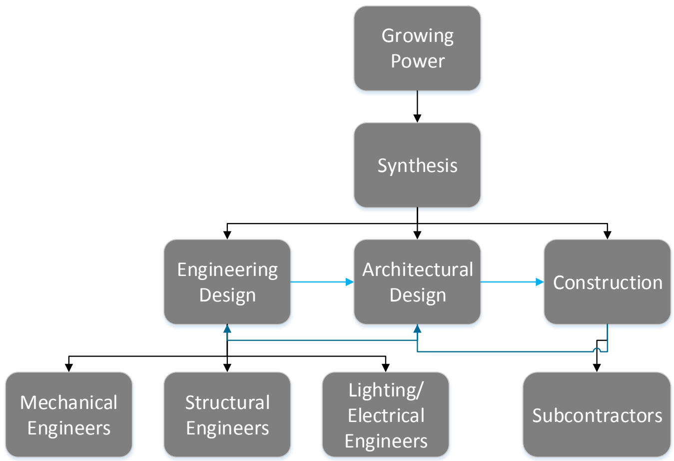

FIGURE CE.2: JOINT VENTURE DESIGN BUILD DELIVERY METHOD

This delivery method requires that the architectural and engineering based designs be developed concurrently. Another crucial function of this delivery method is that the Synthesis Joint Venture team is responsible for both the design and construction of the Growing Power project. The joint venture method allowed fast feed back to design engineers regarding the the construction practicality, design functionality, and affect on the rest of the building.

Throughout this open and collaborative design process, the budget was monitored as decisions were made. The value engineering process was continuous instead of being an afterthought. A visible and changing budget allowed for the design engineers to make educated decisions with regard to each respective design's impact on the budget. This method also allowed for open collaboration between the engineering disciplines and an architectural design that enhances and adapts to the engineering system chosen by each discipline. Collaboration promoted by this delivery method helped the Synthesis team to create a seamlessly unique and innovative building that provides Growing Power with an adaptable building that can be used for teaching while sustaining itself with regard to energy and efficiency.

4.2 Collaboration

The philosophy of the engineering design team is that time spent up front on collaboration will save both the team and the owner time during the actual construction process. This philosophy was reinforced through weekly meetings minutes shown in Appendix R and the use of the tools further explained in this section of the report.

Trello - Is an online tool used to maintain activities that are to be completed and track progress. This created an efficient process in which the entire team was able to communicate and view progress in real time. Within Trello, the team members created task specidic cards that were assigned to those members involved with the task (Figure CE.3).

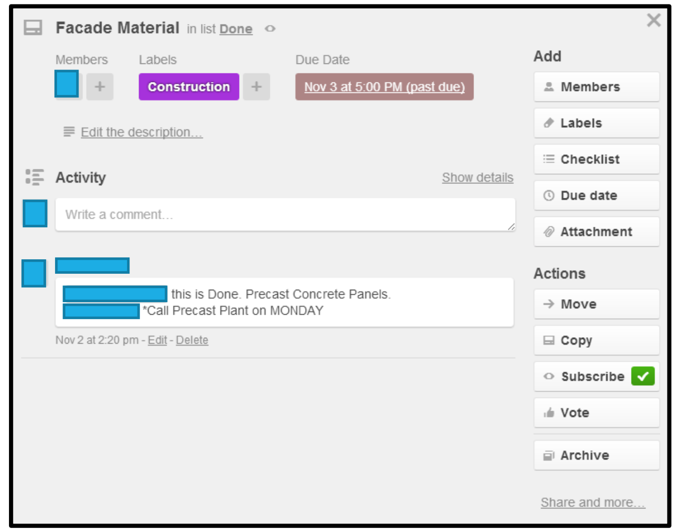

FIGURE CE.3: EXAMPLE OF A TRELLO CARD

The task was then given a deadline and a checklist to monitor progress. Team tasks were organized into the following categories (this is shown in Appendix J): To-Do: Short Term, To-Do: Long Term, Doing, Done, and Collaboration. Each card is then organized into its respective category based on the action that is being peformed.

The collaboration category is used for items that require completion by other engineering disciplines. For example, the mechanical engineers needed to decide the location of their equipment before the structural engineers could take the equipment loads into account. In this example, a card named "equipment locations" was created by the mechanical team. Upon completion, they added the information to the card, moved it to collaboration, and tagged the structural members in the card.

Collaboration board - Another collaboration tool used was a 'sticky note' board used to identify tasks currently being performed and ask and answer questions needed for the progression of the project. This collaboration board cultivated communication between team members and is shown in Figure CE.4. As illustrated, the three categories used were:

- I Need
- Questions For
- I'm Working On

Each discipline was assigned a sticky note color and space on the board to place questions and requests. When information was needed from another team member, a sticky note was filled out using the team color and placed next to the discipline from which the information was requested (the example shown in figure CE.4 is the structural team asking for greenhouse dimensions from the mechanical team). The same process was used if team members had questions for one another; however, the sticky notes would be placed next to the 'Questions For' space on the board. Lastly, current tasks in progress were identifed by writing the task on a sticky note along with the initials of the responsible person which provided real time status design progress information .

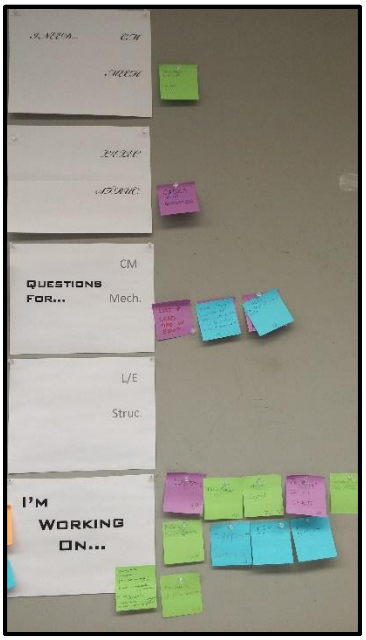

FIGURE CE.4: COLLABORATION BOARD

Use of the collaboration board was multifaceted. Depending on the situation it might function as a tool for:

- Communication
- Problem Solving
- Task Tracking
- Generating Solutions

An example is as follows:

A precast concrete panel assembly was chosen to accommodate the R-value needed by the Mechanical Engineers. When presented with the precast concrete panel selection, the Construction Engineers saw a unique opportunity to facilitate a safe workspace in lieu of paying for temporary railings. They then posted a note asking the Structural Engineers about the building stability if the panels were hung before the elevated slabs were poured. The Structural Engineers responded the steel members on the perimeter non-composite to make the idea plausible. This significant point of integration between the two disciplines aided greatly in the construction sequencing and is explained further in the **[Integration Report Section 3.0]**.

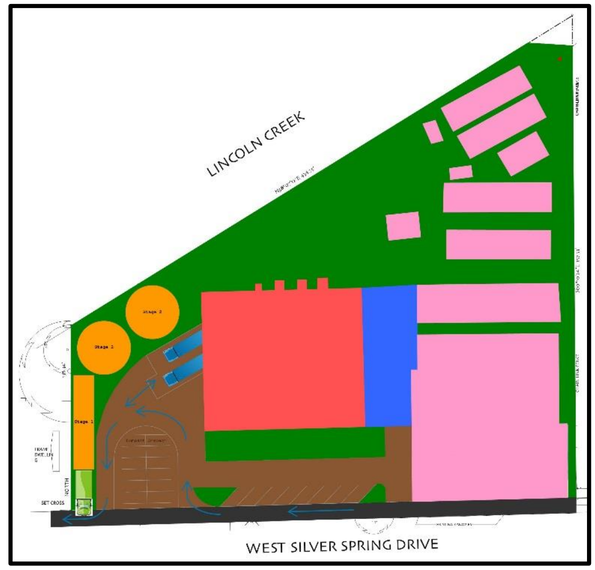

FIGURE CE.5: FINAL SITE PLAN

Personality Analysis - To identify the strengths and develop a deeper understanding of the team members, the Construction Engineers required each member to take two personality assessments. The results were analzyed to show how the selected collaboration methods would facilitate team chemistry and help the Construction Engineers to manage the team in the most effective manner. Through the analyses it was learned that a majority of the team was capable of effective communication; however, a few team members would need assistance in collaboration because of differences in mindset (Overview of the Four Temperaments 2014). This topic is illustrated and explained further using visuals in Appendix B.

5.0 Existing Conditions

The future location of the Growing Power's Vertical Farm sits on West Silver Spring Drive across from residential housing and is lined to the north at an angle by Lincoln Creek. The angle results in an irregular site shape that had to be taken into account when planning the site logistics for construction, deliveries, and overall layout. Currently, the Growing Power site consists of greenhouses, livestock housing and a store (Drawing CE102, Diagram 1). Growing Power has requested to keep the greenhouses along the east side of the site and plans to maintain their current use, while the remainder of the structures on the site were to be demolished to make room for the Vertical Farm and other associated spaces.

During construction, the remaining space will be utilized for lay down areas, material deliveries to the site, crane movement, and coordination between the activities and site traffic (Drawing CE102, Diagram 3). As shown in the site plan (Figure

CE.5), after construction is complete, this space will be utilized to aid Growing Power in their overarching missions of growing food and educating the community (Drawing CE102, Diagram 4).

5.1 Site Utilization

The two small structures located in the northwest corner of the site will be used as on-site job offices for the duration of the construction project. This will eliminate the cost of constructing trailers and connecting temporary utilities. At the completion of construction, those buildings will be demolished to make room for paving installation of an anaerobic digester. During the final week of construction, the Synthesis team will station themselves on the first floor of the building. Protective materials will be used to cover all finished surfaces. Figure CE.6 below illustrates the location of the on-site offices in orange on the Project Demolition Plan, while the other buildings and trees are marked with a red and white hatching for demolition during this initial phase of the project.

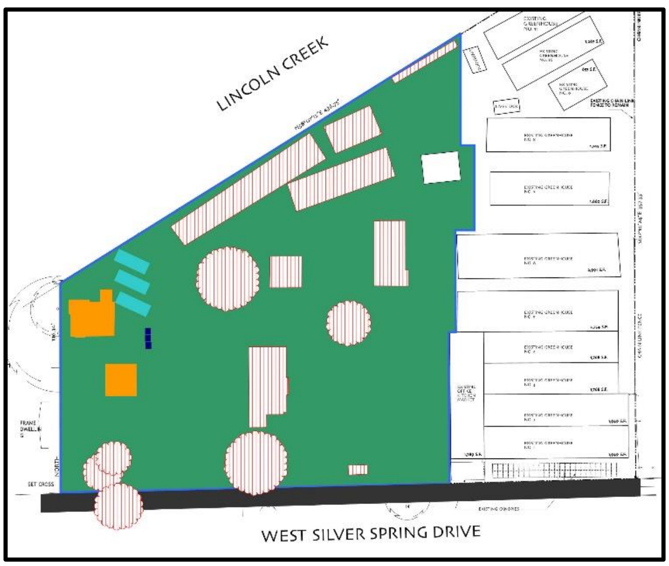

FIGURE CE.6: DEMOLITION PLAN

Synthesis must maintain the 60/40 ratio requested by Growing Power in the competition provided program statement. This ratio symbolizes that 60% of the site is utilized for growing while 40% is paved and unable to be grown upon. PolyPavement was chosen as the finish in all parking/traffic areas in order to minimize paving on site. The product allows for the creation of a pavement-like surface by compacting and hardening dirt already on site. There are no chemicals the mixture that will harm the area around or under the pavement (Evironmental 2015). No asphalt will be used on the Growing Power site and the parking area will have a natural appearance consistent with the site function (PolyPavement is illustrated in Appendix I).

Another critical site design decision was to push the building away from the street in order to create room for the canopies outside of the market. These canopies provide a means by which to bring the market outside when weather accommodates. Strategic placement of the outdoor work space between the new building and the existing greenhouses was chosen to connect the spaces and provide easy and quick access. The layout integrates the outdoor and indoor spaces and provides Growing Power with a usable and efficient facility.

In addition to the items mentioned above, the Synthesis team is installing a groundwater well in the northeast corner of the site. This system requires the temporary removal of one 'hoop house' that will be reinstalled and restored to its initial condition. Once the system is installed, there will be no impact on the Growing Power facilities. A full visual of the Synthesis Site Utilization Plan can be found in Drawing CE102.

5.2 Subsurface Conditions

Some major concerns were identified during the site analysis. First, the geotechnical report revealed multiple layers of cohesive and non-cohesive soil types underneath the building site along with the presence of organic materials, see the **[Structural Report Section 12.1]** for more information. These types of soils are undesirable for building foundations due to the possibility of erosion and settlement. Synthesis has accounted for the placement of geo-synthetic fabric under all temporary roads on site to aid in combatting erosion. Second, the water table level is located from 8-12 ft. below grade. Considering the slab on grade at a depth of 11 feet, the Structural Engineers needed to design a foundation system to overcome the water table issue. The solution will be discussed in more detail in the following section. Lastly, the team declared the soil as contaminated with asphalt and has included proper disposal of materials and soils removed during excavation of the basement, foundation, and pavement areas. Engineered fill will be used in these areas. Site conditions combined with the irregular site shape necessitate excavation tactics and foundation wall types to ensure the building will not be effected by settlement and water level.

To assist in counteracting possible differing site conditions, a geotechnical representative will be on site during the beginning phases of construction. The team is aware of the additional cost and has accounted for it in the budget. The Synthesis team feels the cost is justified due to the limited soil information available to the project team. There is a contingency included in the budget of approximately $100,000 to help account for any unforseen site conditions. The Synthesis team developed a Shared Savings Clause that will encompass this contingency along with the Design and Construction contingency of $600,000. This clause proposes a 50/50 split between the Owner and Synthesis for any contingency not spent during the design or construction phases of the project. The purpose of Shared Savings clause is to incentivize Synthesis to save money where possible without compromising the quality of the product.

6.0 Building Characteristics

6.1 Substructure

To overcome the present soil conditions and high water table, Synthesis has designed a multi-component foundation system for the Vertical Farm. The first component is the excavation technique. Originally, the Construction Engineers were planning for soldier pile and lagging so that the wall could be used as formwork for the cast-in-place concrete foundation wall; however, due to the footing sizes needed to support the foundation walls, it was determined this would not be an efficient solution. The team decided to switch to steel sheet piling, which is a repetitive process that consists of installing sheet piles three feet outside the entire building footprint. It relies on a proper layout of the sheets so that they will interlock and the system will retain the soil and the water present within that soil. The sheets are driven into the ground with vibratory hammers to the desired depth prior to excavation and remain in place until the foundation walls are installed. Once the sheet piling is installed, the footprint will be excavated to the necessary elevation below grade. When compared to soldier pile and lagging, sheet piling was quicker to install and ultimately less expensive because the material could be rented. Also, the sheet piles can and must be removed because the material is re-used multiple times by the rental company. Since the materials are not consumed, this system proved to be more environmentally-friendly and aligned more closely with the Growing Power and the Synthesis goals.

The next component of the substructure is GeoPiers, which are a newly developed system primarily used when the soil bearing capacity is not adequate to support the loads in the building structure. Originally, the structural team looked into spread footings but it was discovered that the footings overlapped and therefore the team progressed into a mat slab. After investigating the mat slab possibility and realizing its cost implications, the Synthesis Construction and Structural Engineers decided to mitigate the water pressure rather than just account for it. By using a GeoPier system to increase the soil's bearing capacity, the team was able to design smaller footings within the building footprint. This reduces both cost and material used for the foundation system.

In conjunction with the GeoPiers, Synthesis has designed a drainage system consisting of a corrugated pipe that will be installed around the entire perimeter of the building between the sheet piles and the foundation wall. The piping will be installed before the engineered backfill is placed and compacted. It will connect to a duplex sump pump located in the bottom of a shaft that can be accessed in the basement. The pumps will be located between the footings to remove water from around the building and carry it into the building's grey water system. A single entry point for the piping to the sump reduces the number of penetrations through the foundation wall.

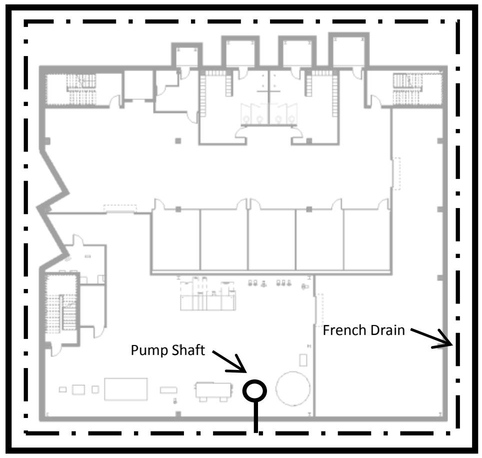

FIGURE CE.7: FRENCH DRAIN DETAIL

The building footings are then constructed on top of the GeoPier system and covered in six inches of the coarse fill explained within the phasing portion of this report. The basement slab is then poured on top of the fill and the foundation walls are

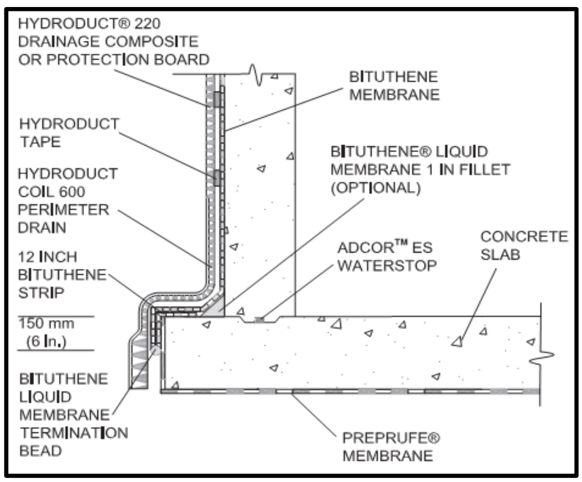

FIGURE CE.8: FOUNDATION WATERPROOFING DETAIL constructed on top of the slab. It is important to note that there is a waterproofing and drainage board located on the outside of the foundation walls to facilitate water movement to the French Drain system that surrounds the building footprint (shown in Figure CE.7). A detail of the waterproofing assembly contained within the foundation is shown in Figure CE.8 (Waterproofing – Detail Drawings 2014).

6.2 Superstructure

The Synthesis team chose a composite steel structure that sits on concrete spread footings to be the main structural system. This steel system was selected for the superstructure of this facility because of its ease of adaptability compared to using concrete. Steel allows for larger spans that provide the most flexibility with floor plan design when considering aniticpated future changes to the building as well as adjustment of the prototype in other locations. Synthesis felt steel was the best discipline when considering these realistic possibilities.

The building is also equipped with four towers along the north face of the façade that are part of the natural HVAC system. The Structural Engineers have designed a system that will accommodate the towers by creating additional structure that ties into the building's steel structure to support the portions of the towers that extend above the building itself.

With regards to constructability, the steel frame of the building effectively reduced the project schedule and gave the Synthesis team flexibility when deciding on a façade type. The steel superstructure also allowed the team to efficiently solve challenges such as the differing floor heights due to the UFAD system in parts of the floors. All braces in the structural system are eccentrically braced and not moment frames to reduce welds needed and create a safer and faster construction atmosphere on the Growing Power construction site. Also, as previously mentioned in this report the perimeter steel is non-composite to allow the precast panels to be installed before the elevated slabs are poured.

6.3 Market

The Vertical Farm houses a Market where plants grown within the building will be sold. The indoor market space is primarily accessible via the main entrance to the building located on the south facade. The space was created to draw the community into the Growing Power facilities in order to help spread their mission and cultivate awareness in this community. Directly in front of the building is a space called the 'Grand Outdoor Central' area. The Market will flow into this area during the warm months of the year when the large glass doors can be opened. This will increase the visibility of Growing Power and pique the interest of the community. The space is intended to be inviting to the local residents as well as visitors touring the building and site.

With regard to the constuction of this space, the ceiling will be exposed (as shown in Figure CE.10) to give the space a feel of efficiency and productivity. The exposed ceiling creates a fairly simple construction process in this area of the building. The main concern is to ensure that the exposed ceiling is uniform and that all designs were coordinated in an aestethically pleasing and efficient manner. Coordination was orchestrated through the use of Clash Detection by the Construction Engineers, which is illustrated in Appendix L. As an integrated team, Synthesis worked through this concern together and provided the desired outcome. The ceiling will be painted a uniform color so the different items along the ceiling do not distract from the items being sold in the spaces below.

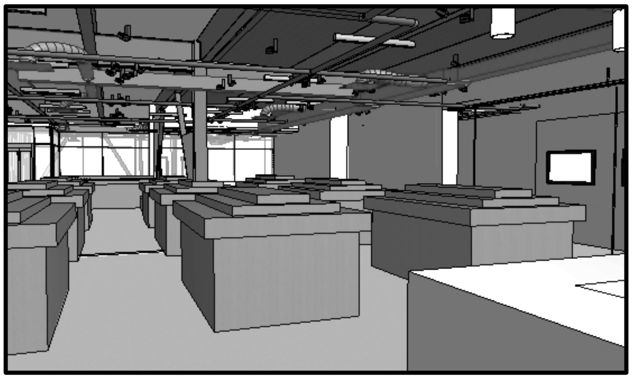

FIGURE CE.9: MARKET RENDERING

6.4 Greenhouses

The greenhouses (shown in Figure CE.10) are a key feature to the Growing Power facility. Through integration between the design disciplines, Synthesis developed an efficient and constructable growing ecosystem. Their purpose is to showcase the diversity of plants growing systems within a vertical farm and to aid Growing Power in determining preferred growing methods.

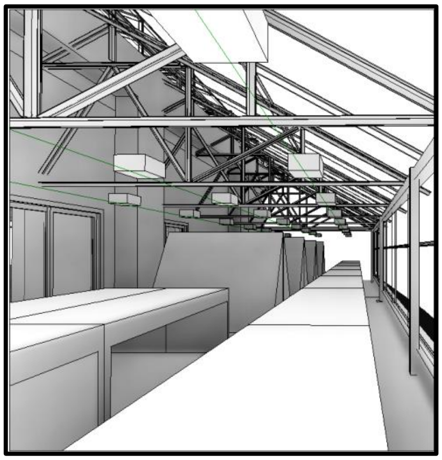

FIGURE CE.10: GREENHOUSE RENDERING

With regards to the construction of these spaces, the main concern is the collaboration required between the design disciplines and the trades in order to successfully create this space. The critical items within these spaces are the trusses shown in the rendering above and the polycarbonate panels that provide an airtight seal to the exterior of the greenhouses. The trusses are designed so they can be assembled off site, trucked to the site, lifted into place, and then connected. This means less connections work on site which decreased the project schedule and increases safety. There is a CMU wall along the back of each greenhouse to provide the correct fire rating at that building division. The CMU wall will need to be constructed before the steel trusses are installed within the greenhouses.

All Synthesis design disciplines have collaborated to create a "Greenhouse Module." The "module" refers to a section of the greenhouse that correlates to half of a structural bay. This consideration was made to allow for easy adaptation of the Milwaukee prototype when built in other locations. An added benefit of this "module" system is the repeatability for the construction workers on site. In each greenhouse tier of the building there are six "greenhouse modules" except on the fifth floor where the amount is doubled. A detailed schematic drawing and analysis can be found in Appendix K.

6.5 Engineering Systems

Mechanical ▲ $

The crucial components of the mechanical system are the Raised Access Flooring (RAF) areas in floors two-four (section shown in CE.11) and the four Natural HVAC towers that are placed strategically at the rear of the building (section shown in Appendix M).

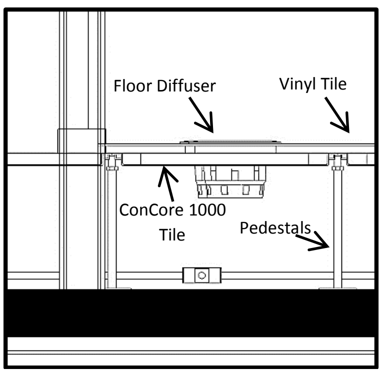

FIGURE CE.11: RAISED FLOOR SECTION

The RAF areas utilize Under Floor Air Distribution (UFAD) for conditioning the spaces. As a collaborative team, Synthesis strategically decided which spaces could contain UFAD and which could not due to the risk of contamination (from plant transport within the building). A plan showing an example of this layout can be found below in Figure CE.12 and further information regarding airflow within the UFAD system can be found in the **[Mechanical Engineering Report Section 9.5]**. In the areas that have RAF there will be vinyl flooring with releasable adhesive used as the floor finish to allow easy access to the UFAD.

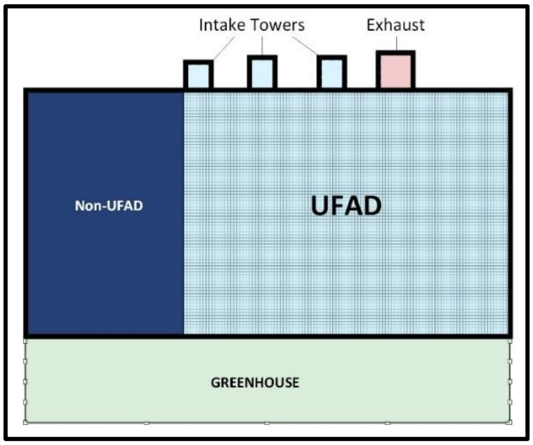

FIGURE CE.12: NON-UFAD VS. UFAD FLOOR

This system allowed for integration with the Synthesis Electrical Engineers so that the electrical systems could be run underfloor. In most spaces, ceiling work in each room is limited to the sprinkler system and lights. Where condenser water must be run above the ceiling for the chilled beams, the amount of pipe is minimized to reduce overhead work. An in depth scheduling sequence for these areas can be found in Appendix G. When considering the towers at located at the building's rear, the Synthesis Construction Engineers wanted to ensure that all areas of the towers are accessible for cleaning and maintenance. In order to accomplish this, an access door has been provided above and below each damper along with a ladder that runs down inside of each tower. These access doors will be constructed with locks to limit Growing Power security concerns. See Appendix N for the testing and commissioning that will be performed for the UFAD system.

Electrical ▲ $

The electrical system within the Growing Power facility ties in very closely to the mechanical system. Power taken from the digester's micro turbine is run to the building for use rather than pulling power off the grid. When looking at the big picture of the electrical system, the key component is its basis in the SmartBuilding ideal. This idea provides the owner with a system that is tracked and easy to manipulate in order to maintain the most efficient building possible. Emergency wiring within the electrical system is not required because he power comes from the microturbine in the basement, which runs on biogas or natural gas.

Lighting fixtures that will be used for emergency purposes have a two hour battery pack to be used in life safety situations. The key portion to the electrical system with regard to constructability is the fact that the electrical distribution wiring and data is run within the utility plenum whenever possible. The installation of a portion of the wiring on the ground rather than using ladders creates a safer and faster work environment for the electricians on site. It is also important to note that the electrical system was downsized considerably due to the fact that the mechanical system uses pressure differentials to move most of the air in the building. Downsizing the electrical system promotes less wiring throughout the building as a whole.

Where possible, the electrical rooms are stacked on top of each other. This is the case for basement, second, third, and fourth floors. The tactic of stacking these rooms allows for faster vertical runs throughout the building. Also, the initial electrical room was in the far north part of the building and required more wire to be run that translates to a higher material and labor cost for the electrical system. This room was moved to the west side of the building in order to combat these costs and make the system more constructible as a whole. The new electrical room location is close to the greenhouses is also beneficial to the schedule and budget because the required 480 volt wire and conduit needs to be run a shorter distance.

Structural

The building system chosen by the Synthesis Structural Engineers was a steel framed building with concrete foundations and CMUs used for shaft wall construction. There were crucial decisions that needed to be made by the construction engineers for each of these system components. Considerations for the site foundation were mentioned previously within this report under Site Logistics - Phase 1: Excavation. With regard to the steel frame, the type of crane needed to erect the steel and where it would be placed was was a primary consideration (Appendix H). The plan below labelled as Figure CE.13 illustrates the crane's reach relative to the building footprint and steel laydown area on site.

The biggest constructability concern within the structural system revolved around the towers along the back of the building that assist in the efficiency of the passive downdraft/updraft system. The material choices for the towers were carefully discussed between all Synthesis team members and the solution was to construct the towers out of steel and hybrid shear walls clad in Exterior Insulated Finishing System (EIFS). The major construction concern was with the portions that extend above the top of the building. To combat this concern scaffolding was erected that surrounds each tower to allow for a safe and efficient work area. The scaffolding provides access to the entire tower façade for CMU and EIFS

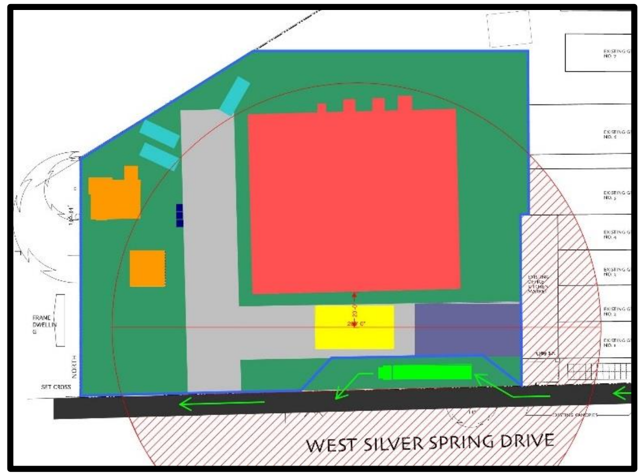

FIGURE CE.13: SITE LAYOUT WITH CRANE RADIUS

installation. The coordination of this work is facilitated by removing the scaffolding as the EIFS is installed on each tower from the top down.

Construction

As mentioned earlier in this report, the Synthesis construction team performed an analysis to determine what crane should be used on the growing power site. First, the team had to look at different crane types and determine which matched the conditions on site the best. After analyzing these disciplines it was determined that an All-Terrain Crane was the best fit for this job. An All-Terrain crane was chosen because of its ability to move in poor soil conditions, such as those on the Growing Power, Milwaukee site. The visual below indicates the location of critical steel pick. Using the distance shown below and a Top of Steel elevation of 55'4" (shown in Figure CE.14) it was determined that the crane would need to carry 3200 lbs.

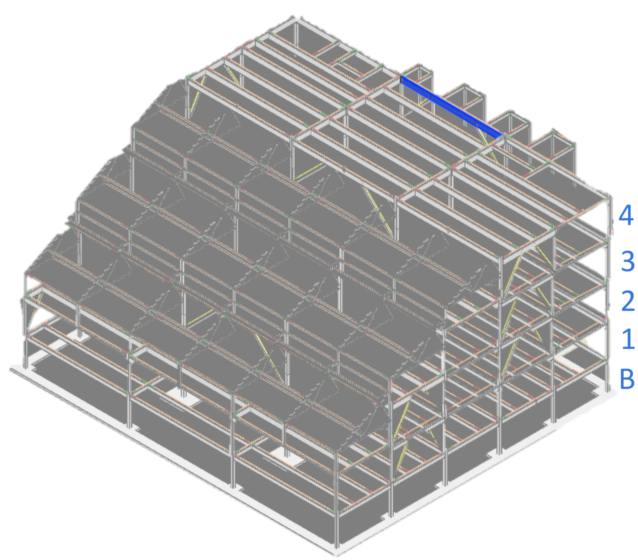

FIGURE CE.14: LOCATION OF CRANE CRITICAL PICK

throughout the pick. In addition to carrying that weight, the crane also needed to be able to reach 120 feet in the N-S direction and 52'6" feet in the E-W direction. The team decided that it was crucial to add capacity to the crane to ensure the possibility of more than one piece of steel being lifted at one time. This is a normal practice by steel erectors to increase efficiency.

Due to the required capacities, it was determined that a 120 Ton All Terrain crane would be adequate for the steel erection on site (All Terrain Cranes 2015). This 120 ton crane would be placed at an optimal position of 20 feet from the front of the building to allow for a single crane placement throughout the erection process. In order to place the first floor, the main boom would be extended to 104' which would allow the crane to pick the steel at 20' from the center pin. Once the first floor is erected, the jib would then be utilized for the further and heavier picks. More visuals and details of this analysis can be found in Appendix H.
The number of variables involved in the erection of the precast insulated concrete panel façade system resulted in Synthesis deferring to the installation company for crane sizing. Synthesis has accounted for the installers to provide their own crane in the installation cost. The Construction Site Logistics Plan (Drawing CE102 diagram 3), displays a path for this mobile crane to move around the building perimeter. The path is required to be at least 15 feet away from the building footprint because of the effects that this point load has on the footings.

7.0 Budget and Schedule

7.1 Project Budget

The Vertical Farm project budget has been estimated at $11,700,000. This budget accounts for the cost of construction, general conditions, staff wages, and additional fees. A summary of the budget breakdown is displayed in Table CE.1 and the detailed breakdown can be found in Drawing CE101.

This summary outlines the major components of the construction cost and shows how the other sections weigh into the budget. The construction engineers were able to track the budget by comparing initial square foot estimates to more specific estimates based on the design as it developed. These comparisons were helpful because the estimated cost was lower than the previously determined budgets.

Synthesis designed this building with its lifecycle cost and payback period considered more heavily than a low initial cost. The team decided from the start that this building was not meant to be designed similar to an ordinary office building or educational facility, but to make a statement regarding building energy efficiency and sustainability. Keeping that principle in mind, it was determined that Synthesis wanted this building to function efficiently and effectively for the Growing Power client. In order to meet that goal, the team wanted consider all aspects of a budget rather than just initial cost. Taking the potential operating budget into account will provide Growing Power with a more usable design as a prototype to fulfill their wish to build across the country. An in depth analysis of this lifecycle analysis can be found in Appendix D. Also found later in this report is an in depth cash flow analysis outlining costs throughout the construction schedule so Growing Power has a better idea of how money is being spent throughout the project duration.

TABLE CE.1: BUDGET SUMMARY

Building Component	Cost	% of Sub
Substructure	$ 779,989.00	7.8%
Shell	$ 2,031,599.00	20%
Interiors	$ 2,530,201.00	25%
Services	$ 3,537,117.00	35%
Equipment & Furnishings	$ 242,590.00	2.4%
Special Construction	$ 887,577.00	8.9%
Building Sitework	$ 18,960.00	0.2%
Subtotal	$10,028,033.00	
General Conditions	$ 689,823.00	
Synthesis Contingency	$501,402.00	
Owner Contingency	$100,281.00	
Fee	$ 350,982.00	
TOTAL	$11,670,521.00	

7.2 Design Schedule

The team began the 6 month design process by extensively researching vertical farming and studies that have been done on possible systems for this building type. Gathering this information early allowed for quicker system selections. The upfront investigation allowed the team to remain on track throughout the remainder of the design process and meet their final submittal deadline. One of the tools the team used extensively in order to stay on schedule was Trello. Trello is the collaboration tool introduced in Section 4.2. The ability to control due dates and tasks within Trello allowed for the design to be planned in a more manageable manner and ensured each design discipline adequate time for their respective deliverables.

7.3 Construction Schedule

Synthesis developed a schedule that maps out the tasks for the duration of the project, beginning with the Notice to Proceed and finishing with the Project Turnover which results in a 7 month construction duration. Table CE.2 displays a summary of the schedule capturing the dates of the major components of the building's construction process (a detailed Gantt Chart can be found on Appendix E).

TABLE CE.2: SCHEDULE MILESTONE DATES

Activity	Start	Finish
Notice to Proceed	08/03/15	08/03/15
Permitting	08/03/15	08/14/15
Procurement	08/03/15	10/16/15
Ground Breaking	08/14/15	08/14/15
Site Preparation	08/14/15	08/27/15
Substructure	09/01/15	11/11/15
Superstructure	10/12/15	12/28/15
Façade	11/03/15	12/07/15
Interiors	12/08/15	04/22/16
Commissioning	01/22/16	03/03/16
Certificate of Occupancy	04/11/16	04/11/16
Landscaping & PolyPavement	03/21/16	03/30/16
Digester Installation & Prep	03/29/16	05/02/16
Project Turnover	05/02/16	05/02/16

The Synthesis Construction Engineers have declared that the Notice to Proceed will be received on 3 August 2015. Three weeks permit processing will follow and lead into the construction process. The property is zoned as PD (Planned Development) and therefore will not need to be rezoned before permits are applied for. That allotted permitting time frame places the breaking of ground for demolition to be on 28 August 2015. The site work will begin with the demolition of the buildings marked as 'to be demolished' on the site plan and then move into the installation of the sheet piling. Once the sheet piling is installed it will be possible to safely excavate the basement while dewatering the building footprint. Once the footprint is excavated and dewatered, the team will then begin the construction of the building substructure. Upon completion of substructure, the construction of the steel superstructure and precast concrete façade will begin. Once the building is enclosed and protected from the elements, the interior spaces will be constructed. After the interior is complete, the Synthesis team will complete the closeout, punchlist, and apply for a Certificate of Occupancy. This paperwork will be done while the site is prepared for final grading, paving, and the demolition of the buildings being used as trailers. During the week that the landscaping is occurring and the additional week the digester is being installed, the Synthesis construction team will be reduced and manage the project without job site trailers. This is possible because of the close proximity of the jobsite to the Synthesis headquarters. When the digester is complete and operating, the building will be turned over to Growing Power with all the information needed to efficiently run the building.

7.4 Project Controls

Phasing

Phase 1: Excavation

The Synthesis team had many reasons for originally selecting a Soldier Pile and Lagging system for excavation; however, when the Synthesis Structural and Construction Engineers analyzed the soils report for 5500 West Silver Spring Drive, the team members realized the soil is mostly comprised of organic material and the water table is considered 'high'. Due to those facts, it was determined that there would be high water pressure loads on the foundation walls and risk of uplift in the floor slab. It was also found that due to poor soil conditions, stepping back the excavation on site would prove to monopolize the laydown area available for construction. These reasons led the team to look for a way to remedy these issues in the most cost effective way. After careful analysis, the team chose to use a Sheet Pile system with Geopiers underneath slab footings (for more information, see **[Structural Engineering Report Section 12.3])** and a duplex sump pump below the slab.

By utilizing the excavation and foundation systems listed above, Synthesis has provided Growing Power with a more cost effective and efficient foundation system that can be translated to many locations around the country. It is also important to note that due to the organic matter in the soil composition, and the possibility of asphalt contaminants, Synthesis will be removing any soil excavated from the site and bring in a more suitable fill for site utilization. This fill will be a coarse aggregate with 2 inch maximum diameter and many fines. The material mentioned is easy to compact and work with but allows for water to drain easily which is crucial to the success of the Synthesis foundation plan.

Phase 2: Superstructure/Building Envelope

During the erection of the superstructure and the building envelope, the Synthesis site will contain two different cranes (one during each erection process). Coordination between the trades during the superstructure installed process is located in Appendix F. One of the cranes will be used to erect steel (the crane analysis for this crane can be found in the Construction section of this report and Appendix H) while the other will be used to place the precast façade panels and polycarbonate greenhouse glazing. This process will require careful collaboration and planning from Synthesis and the two subcontractors involved. All material will be elevated to above the correct working plane before the boom of either crane is swung into the building footprint to prevent damage of any materials. It is also important to note the material laydown area relative to the location of the cranes (illustrated in the Site Logistics Plan in Drawing CE102). Once placement of the steel and panels are complete, each respective crane will be removed from the site. Building stairs will be erected as each level is reached so that the staircases can be utilized by the construction workers on site. In addition to the staircases, the Synthesis Construction Engineers have decided to install and permit the elevator as soon as the area can be dried in. Permitting the elevator for construction will allow use the elevator by the construction team to move construction materials and negate the necessity to purchase a hoist for the site. Synthesis has accounted for the additional cost to re-permit the elevator for owner use in the budget presented in this report.

Phase 3: Building Interiors

The Synthesis team will begin to prepare the exterior areas for pavement and landscaping concurrently while constructing the interior spaces. With regards to the interior spaces, Synthesis has developed a detailed schedule to illustrate the progression of each type of space. It is crucial for the team to pre-plan the interiors as much as possible due to the complexity between the types of spaces and the need to be account for different slabs. One example of the progression in a space is illustrated in detail in Appendix G. The example illustrates the sequence of items that require installation in conjoining classrooms on the 3rd floor. Detailing the schedule for this space was crucial because it includes many different systems and is the most complex room in the building with regard to components.

Cost Control Plan

The Construction Engineers were conscious about the costs of the Vertical Farm throughout the design process and strove to ensure that the building would be constructed with the latest innovative ideas at affordable price. In order to ensure that the cost was possible, the Synthesis Construction Engineers created a cost control plan to illustrate spending as construction progresses so that Growing Power has a better idea of how the cost is distributed across the project duration. This cost control plan was developed by creating a cash flow diagram and analyzing the diagram to find where the budget has the potential to fluctuate. The full version of this cost control plan can be found in Appendix C. In addition to the cash flow diagram, the Synthesis team also found a means of obtaining compensation for some of the innovative technologies and sustainable practices implemented in this building. Using a worksheet from Focusonenergy.com (summarized in a spreadsheet in Appendix C) it was determined that the Synthesis team could receive up to $8,500 from Focus on Energy to aid in the cost of this project.

Lifecycle Cost

Due to the nature of the Growing Power facility and the mission of both Synthesis and Growing Power, the team decided early on that a lifecycle cost analysis of the equipment would be beneficial to the project team and owner so that the true cost of the equipment over time would be apparent. An analysis of the major mechanical equipment was chosen to ensure that the system selected was worth the upfront cost. A summary of this payback analysis can be found in the Table CE.3 and the full analysis can be found in Appendix D.

TABLE 3: PAYBACK ANALYSIS SUMMARY

System	Annual Profit
Electricity	$204,427
Waste Disposal	$45,990
Natural Gas	$29,554
Solid Fertilizer	$47,450
Sales from 40% Increase in Crop Production	$22,456
Annual Total	$349,877
Payback of Quad Generation in Yrs.	4.6

Schedule Control Plan

Similar to the concerns with regards to cost, the Construction Engineers wanted to ensure that the schedule would be maintained during the project duration and not delayed due to unforeseen conditions. All the major lead time items were loaded into the schedule with their respective durations to make sure that they were accounted for within Project Schedule. A traditional Gantt Chart was produced after creating a basic scheduling sequence. Together, the schedule and cash flow plans will create a well-rounded analysis of the construction process to ensure that the Synthesis team is prepared for all aspects of project delivery.

8.0 Site Logistics

A safety fence is located around what has been determined as the site boundary. The boundary lines were established to ensure that Growing Power can maintain working on the east side of the lot with minimal disturbance. The site fencing will be moved once throughout the project duration. All fencing will remain the same except when the groundwater wells are installed in the North East corner. This site fencing will have two gates for construction entry with guards at each gate to ensure no pedestrians find their way into the construction zone. The Synthesis Construction Engineers have included protection of the pedestrian sidewalk in their budget and will ensure not to obstruct this area and/or impede traffic throughout the construction project.

The Synthesis Construction Engineers have developed logistics plans for the three major site changes that will occur during the project: Demolition, Excavation, Construction, and Turnover. These logistics plans can be found in Drawing CE102. While the site fences will change once and site layout in the construction zone will have 3 phases, the flow of traffic on site will not be altered during the construction of Growing Power's headquarters.

9.0 Sustainable Construction

The building created by the Synthesis design and construction team was found to achieve a LEED accreditation level of Gold. With a minimum of 73 credit points calculated using the LEED v4 checklist made available by the USGBC, the team is a mere 5 points short of LEED Platinum (LEED v4 for Building Designg and Construction 2015). As the project progresses, the highest accreditation is achievable. The completed checklist can be found in Appendix Q.

9.1 Waste Management

Growing Power and Synthesis believe strongly in the management and elimination of waste on the construction site. The team has designated an area within the site limits for the proper disposal of waste along with an area for collecting recyclable materials (see Drawing CE102 diagram 3). Based on the building design materials, the team has decided to recycle the following on-site: metals, concrete, masonry, plastics, gypsum board, and cardboard.

Waste Management, Incorporated offers many services to assist with disposal of waste and recycling materials on construction sites. The company has also developed tools for tracking the material recycled known as DART, or Diversion & Recycling Tracking Tool. Synthesis will be taking advantage of the convenience of using DART for the Vertical Farm project. The data gathered by the tool can be used to create charts and statistics to help inform the public of the project's environmentally-friendly impact and to further show the importance of Growing Power's and Synthesis' values. DART provides the team with information about recycling in the city as well as around the globe. Access to the data will allow for the development of statistical facts that could help market project applications intended to help the environment and efficiency of the building's construction. The data can also assist future projects by realizing the Vertical Farm construction success.

DART will also be used to assist the team with document submittals for LEED credits as the team pursues accreditation for the building. The tool creates reports that can be easily uploaded to the online system used by the Green Building Certification Institute (Construction Services 2015).

Synthesis has exercised ways to reduce the waste produced on the job site including the use of prefabrication. Prefabrication allows items to be constructed in a controlled environment that produces better quality of the items than may be produced if built on-site with the added benefit producing less waste. Producing better quality with less waste translates to saving money. The project schedule also benefits from prefabrication because it will require less time to install the items than if they were fully constructed on-site. The greatest savings in the schedule can be seen if the prefabricated items are along the critical path as demonstrated in the Growing Power facilty.

See Appendix I for further analysis of the Project Waste Management and Recycling Plan.

9.2 Material Selection

The Synthesis design and construction team made sure to account for the team's goals and Growing Power's goals as for building materials were selected. While aspiring to design a building that Growing Power will be proud of, the team also refrained from spending large amounts of money on high-dollar materials where it was not fully justifiable.

To assist with the sustainability of the building and project as a whole, the Construction Engineers assisted in the material selection by verifying the items could be shipped from within a reasonable distance of the site. All attempts were made to keep delivery costs to a minimum. Advanced determination of the shipping origin of materials provided the information necessary for the team to to select the materials most beneficial for the building's efficiency, appearance, and cost.

The team also worked to eliminate waste on site by having as much of the materials as possible cut before being brought onto site for installation. This was especially important when contemplating more expensive materials; for example, the polycarbonate panels used for the exterior envelope of the greenhouses and the precast concrete panels for the building façade. As mentioned in the previous section, Synthesis is planning to reduce the waste produced by this project and recycle materials that would have been waste. Having items cut off site eliminates the possibility for that waste all together.

9.3 Education

In order to align with Synthesis' goal of using the building as a teaching tool, the team has also developed ways to educate Growing Power employees and the public about the building as it's being constructed. This is being accomplished by placing a chain link fence around the site so the site and the transformation the are visible to the public while taking place.

Another way the Synthesis team is planning to educate people while during construction is by advertising and conducting public tours during certain times within the process. Growing Power and the public will then have the opportunity gain first-hand knowledge about the building transformation. Synthesis hopes that the employees taking this time to learn more about the systems that run the building, they will know how to maintain and use it properly. There will be an extensive training session for the mechanical systems that is available in the Mechanical Engineer Report; however, the construction tour should give the workers an overview of the systems so that they enter the training sessions with some knowledge.

10.0 Testing and Commissioning

This building contains systems that are very innovative and, in some cases, have never been done before. Testing of these systems is critical to the function and lifespan of the Vertical Farm. Along with designing and planning the construction of the building to produce the best possible quality of work for the needed air-tight enclosure, testing of the UFAD, passive down draft, and passive updraft systems, the Synthesis Construction Engineers have compiled the information necessary to ensure that the UFAD system will be as efficient as possible. In order to do this, there are a few integration points that the Synthesis team has discussed and addressed and they are as follows: minimize items that cross plenums, create details for fire protection within the plenum, maximization of amount of items that can be run under floor in the plenum in order to minimize overhead work above the raised access flooring. These are all items that needed to be addressed during the design process to aid in the efficiency of the UFAD system. In addition to those design considerations, there were also a few items that needed to be verified during the installation of the trades in the raised floor and also after the raised floor is installed. The items that must be checked after the trades under floor have completed their work are the following:

- Underfloor cleaning (twice, rough and final)
- Underfloor inspections
  - Caulking wall penetrations
  - Sealing conduit
  - Sealing transfer ducts through plenum boundary
  - Verifying door thresholds are tight

The items that must be complete after the raised floor is installed and before the tests are done are as follows:

- Tape where raised floor meets slab
- Tape where raised floor meets exterior walls
- Tape where raised floor meets interior walls
- Cover all slot diffusers
- Resilient tile must be attached to the access flooring

After construction, there are certain tests that need to be conducted in order to verify that the system is operating as intended for building use. The Synthesis team will be performing a test after all items listed above are taken care of and the resilient tiles are installed. During this test, the total leakage rate cannot exceed 10% and it must be done for each 'sub-plenum' individually.

11.0 Safety

Synthesis is very aware of the importance of safety in the construction industry on a project site. For this project, the team is taking advantage of the opportunity to incorporate the concept of Prevention through Design. Implementing this idea assists in reducing the time and money normally invested to create a safe environment for the construction workers and other staff members on the site.

One example of Prevention through Design consists of using the precast concrete panel façade system as fall protection. The team developed a panel layout that allows for them to take the place of installing stanchions and cable along three sides of the perimeter of each floor (North, East, and West). Figure CE.16 depicts the panel layout for the East Façade of the building. For this to be possible, the construction process is sequenced so that the panels are installed following the steel structure; therefore, only the individuals erecting steel, those connecting the panels, and the workers installing the corrugated decks will need to be tied off. This will allow for all remaining crews to perform their work without the restriction of being tied off and will save time and money that can be put towards other components of the building.

FIGURE CE.16: PRECAST PANEL EAST FACADE LAYOUT

The use of precast panels also aides in creating a safer site by reducing the amount of work needed to construct the façade. The process of actually casting these panels will be performed off site in a more controlled environment.

Similarly, the use of RAF within the building allows for more work to be done on the ground (underfloor) rather than overhead. This translates to decreased necessity for ladder work and therefore a safer work environment. Work on the ground is not only safer but more efficient and can be considered a schedule advantage to the use of an access flooring system.

Site Specific Safety Plan – Before starting construction on-site the construction engineers will create a Site Specific Safety Plan with each of the following items:

- Emergency Contact List & Map
- Project Hazard Analysis
- Synthesis Safety Plan
- Weekly Safety Inspection Checklist
- Safety Compliance Procedures
- Safety Hazard Notification
- Hot Work Permit
- Lock Out/Tag Out Procedures
- Evacuation Plan
- Contractor Safety Certificate
- Project Safety Orientation Plan

12.0 Location Adaptation

In order to align with the Synthesis goal of adaptability of the building to other geographical locations, the construction engineers chose 4 geographical regions to analyze, consisting of one city each. Utilizing location factors from RS Means, the cost of the Milwaukee prototype has been translated into an estimated cost for each area assuming that the systems remain the same. In addition to the cost analysis, the construction engineers have developed a key construction concern for each area to consider before relocation.

12.1 Southeast: Miami, FL

ESTIMATED COST: $10.2 Million Dollars

KEY CONCERN: Adverse weather conditions (all objects must be secured at the end of each work day in case high winds occur in the area because the items pose a threat to life safety and work in place)

12.2 West: San Francisco, CA

ESTIMATED COST: $12.6 Million Dollars

KEY CONCERN: Unionized labor force is the majority of firms available for hire in the area which could increase cost more than already accounted for

12.3 Northeast: Washington, DC

ESTIMATED COST: $11.2 Million Dollars

KEY CONCERN: Congestion in DC area would complicate deliveries and require specific delivery schedules in order to avoid traffic delays

12.4 Southwest: Dallas, TX

ESTIMATED COST: $9.8 Million Dollars

KEY CONCERN: Unskilled labor force could be a concern for specialized systems contained in the building

13.0 Software Usage, Document Control, and Interoperability

During the design and construction processes software and document control are paramount. Throughout design, the Synthesis team utilized Revit as the collaboration tool to ensure that the design was up to date and everyone was on the same page (a full visual of the software utilized during design can be found in Appendix P). When design is complete, the Synthesis team will use the Revit files to create PDFs of all drawings needed for successful construction of the Growing Power facility. The team goals were carried into the project delivery by utilizing a paperless construction process. This will be executed through the use of Bluebeam and its diverse list of functions and capabilities.

Paperless - Instead of producing numerous paper sets of drawings on site, all revisions and RFIs will be posted in a folder structure within Dropbox and accessible to all project team members. This process also ensures that everyone is working of the same drawings i.e., that they are looking at the correct version and not one that was printed weeks ago and is out of date. In order to commit to this mission, a 'collaboration station' is included in the project budget. This configuration consists of a TV screen, and computer modem within a construction safe box. All project team members will have access to this tool in order to ensure around the clock drawing availability on site. In addition to the drawing revision process, Bluebeam will also be utilized for submittal reviews throughout the project. In a function called 'sessions' a subcontractor will be required to start a session and invite team members to review the submittal. This function allows all team members to mark up a submittal in real time by assigning each person a color. Once the review process is complete and the session closed, Bluebeam creates a PDF compilation of all the changes made to the submittal that can be used for project records.

14.0 Conclusion

Throughout the design process, the Synthesis team has made a concerted effort to meet the design goals developed at the beginning of the project. In addition to these goals, the construction engineers of Synthesis have strived to meet their own discipline goals throughout the process. The following is an outline of how the construction engineers feel they have met both the overarching Synthesis goals and the discipline specific goals as well.

Educational

Through the use of barriers that allow viewing, and community construction tours, Synthesis has opened the site up as a learning facility during construction.

Ecological

By utilizing materials that are prefabricated offsite, the Synthesis construction engineers have eliminated a large part of waste on site. In addition to that reduction, the team has also utilized a DART system to manage waste and recycle as much materials as possible rather than sending recyclable materials to a landfill.

Adaptable

The innovative construction techniques and common materials used on this site can easily be translated to other sites of similar size. This will allow the building to be constructed in other locations that may differ with regards to space and resources.

Construction Engineering Goals

1. To construct the building in a way that assures good ***quality***
   - This is achieved by the use of a detailed quality control and testing and balancing plans.
2. To build an ***efficient long-lasting*** building
   - This is accomplished by the effective installation of all engineering systems contained within the building.
3. To create a building which the ***learning experience*** and environment would thrive
   - Through transparent construction and the use of the DART dashboard, the community is able to watch the entire construction process from start to finish.
4. To utilize ***innovative construction methods*** that can be adapted to other geographical locations
   - This is done by efficiently using space around the building and utilizing materials that are common in multiple geographical locations.
5. To ***guide*** the designers throughout design and construction
   - Through collaboration and team management, the construction engineers aided the design engineers in their development of an innovative and efficient building.

In conclusion, the collaboration and team chemistry at Synthesis has aided in the development of a Design Development Submittal for Growing Power, Inc. By achieving both the construction and team goals, the Synthesis team has aligned with Growing Power to create the most innovative and self-sustaining building possible.