

GROWING POWER VERTICAL FARMING FACILITY



TOTAL BUILDING DESIGN ENGINEERING

Architectural Engineering Institute, Annual Student Competition
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EXECUTIVE SUMMARY

Growing Power's recent success and growth of their non-profit organization has led to the need of a new vertical farming facility to enhance their mission of educating the surrounding community on sustainable farming practices. The facility will provide space to demonstrate innovative farming techniques, an area to host large lectures, office space and a market to sell food grown on site. In order for the Growing Power facility to be successful, the defined flexibility, community, sustainability, and economy goals must be achieved (p. 1). The TBD construction partners contributed to these objectives by facilitating design integration, providing an accurate cost estimation, a developed schedule for both design and construction, planning for BIM uses during the facility's life cycle, and cultivating a Lean management environment within the design team and on the construction site.

INTEGRATED DELIVERY

The correct project delivery methods greatly contributes to overall project success and can benefit a growing relationship between TBD and Growing Power for future projects. By aligning Growing Power's goals and expectations with characteristics of different delivery methods, and considering Growing Power's need to mitigate risk, TBD determined the most beneficial delivery method to be Design Build.

DESIGN MANAGEMENT

Proper management of design through the beginning phases of the Growing Power facility, ensures the project progresses addressing the owner's needs and goals. Early construction partner involvement allowed facilitated integration between all design partners with the use of BIM Project Execution Planning, the Last Planner System®, process mapping, and continuous cost tracking, to produce an efficient, intelligent, and effective design for Growing Power.

SITE ANALYSIS

A detailed site analysis of the current Growing Power plot, conducted early in the design phase, identified all existing conditions, including site utility access, existing structures, business operations, neighboring stakeholders, and environmental concerns. The early identification allowed for quality decisions to be made to reduce risks during the construction phase of the project.

RISK MITIGATION

Major constructability concerns of the project assembly were addressed during the planning phase of the project to mitigate risk during construction. Detailed planning for the site excavation, structure, façade installation, interior fit out of the building, and other construction activities allow for the project construction to progress efficiently with minimized risk.

CONSTRUCTION INNOVATION

Management of the construction phase of the project is planned to utilize numerous techniques to improve production efficiency and reduce waste. The management team will cultivate a Lean management approach in a co-located office, prioritizing flow, value, and continuous improvement, with the aid of BIM tools, to turn over a quality product to Growing Power.

FACILITY OPERATION

The innovative technical aspects of the building must be operated and maintained properly in order for the vertical farm to function properly. To maintain the building systems intended level of function, TBD will engage in Growing Power staff education throughout construction, as well as provide detailed asset data containing key information from the BIM.

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GROWING POWER

Growing Power Inc., a national nonprofit organization, was established in 1993 to support surrounding communities and the environment they live in by providing affordable, quality food, grown and distributed with sustainable methods. They aim to better their communities through the education of sustainable farming techniques with hands on experience, technical aid, and live demonstration. Growing Power has found great success in hosting a number of projects to grow food, grow minds, and to grow community. This success has led to a need of a new, sustainable facility to enable Growing Power to influence more communities while promoting sustainable farming techniques.

The new 52,585 square foot Growing Power facility is to be constructed on a plot of land the nonprofit currently owns at 5500 West Silver Springs Drive Milwaukee, Wisconsin. The prominent vertical farming facility embraces four custom designed greenhouses equipped with flexible MEP systems for demonstrations of farming techniques and the allotment of different growing methods; an open floor gathering space for presentations and lectures taking advantage of noteworthy structural feats with an integrated MEP design; and a sustainable, innovative cogeneration heat and power plant providing clean and affordable energy, all wrapped in a façade that provides Growing Power the flexibility of placing the facility in any community, in any climate.

PROJECT GOALS

To produce a project valuable to the owner, TBD project goals were developed to align with Growing Power’s vision of inspiring communities to build sustainable food systems that are equitable and ecologically sound; creating a just world, one food secure community a time. Incorporating those values with TBD’s own project initiatives, four goals were created and prioritized to be carried through the entirety of the design and construction phases of the project: flexibility, community, sustainability, and economy. Prioritizing these goals ensures the development of a project that meets the needs and expectations of the owner. The project goals have been defined as:

PROJECT INITIATIVES

Flexibility



The ability for the facility to be used as a prototype for other possible sites across the country, while meeting the changing needs of Growing Power by providing options for continuous improvement.

Community



Strengthen the community outreach by providing ample space for education and enabling the surrounding population to participate in the growing methods used within the vertical farm.

Sustainability



Create a facility with a manageable lifecycle cost aided by the use and optimization of renewable energy, renewable resources, and sustainable practices in design and construction.

Economy



Provide the best product for the budget developed by Growing Power while continuously providing cost savings and exploring funding expansion.

INTEGRATED DELIVERY

Selection of a project delivery method and contract type is a key aspect of planning, designing, and turning over a successful facility to the ownership partners at Growing Power. Defined at the outset of the project endeavor, the selection of a delivery method can set the stage for the entire project to be successful, based on the goals defined by the entire team. TBD performed an in-depth analysis of 12 potential delivery methods to select the model that would align best with the project and organizational goals of Growing Power of flexibility, sustainability, community, and economy.



DELIVERY GOALS

Prior to choosing a project delivery method, key goals were identified that would indicate project success to the ownership partners at Growing Power. In support of achieving the project goal of economy, control of cost growth and facilitation of early design estimates are an extremely important aspect of the project’s delivery. Growing Power does not necessarily need the cheapest facility possible, but a target value should be defined, with constant measuring against that target throughout design and construction. This approach will be covered in much greater detail in this report (p.6). Engaging in a situation that allows for the facilitation of early estimates will also allow for more accurate quantity takeoff and early procurement of project materials, making for a more sustainable and less wasteful project, both from a material and time standpoint.

Another key aspect of any project is the allocation of risk among the project team. While healthcare and higher education owners may be extremely versed in delivering numerous successful projects and handling large amounts of risk, Growing Power is just starting out with its first major facility. In order to continue its mission, the ownership partners at Growing Power would benefit greatly from transferring risk to other members of the project team.



Finally, TBD strives to maintain a lengthy relationship to ensure the long-term goal of Growing Power to use the vertical farming facility in Milwaukee as a prototype for future expansion. As multiple facilities are constructed across the country, beginning with Milwaukee and Miami, project conditions will become more familiar and team members should be enabled to capitalize on the shared knowledge within the team.

DELIVERY METHOD

After analyzing the aforementioned project goals, it was determined that the optimal delivery method for the Growing Power facility project is a Design-Build (DB) relationship, with schematic documents provided by a project architect to TBD, who will act as an integrated DB team. Design-Build enables all the delivery goals of the project to be met, primarily through the early involvement of construction partners and providing a single point of contact to the ownership team. Involving the construction team early in the design process allows for constant oversight of the project’s economic parameters through definition of a target value and repeated evaluation of the project’s development against the target. Additionally, a DB arrangement minimizes risk to Growing Power by transferring a substantial amount of risk to the DB team through clearer contractual boundaries than a more traditional, less collaborative contract type (fig. 1).

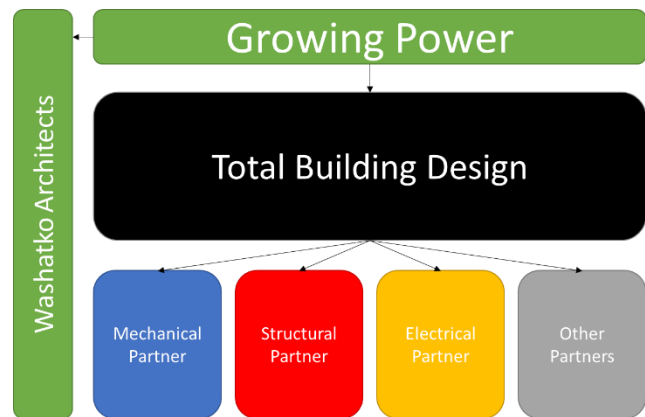


Figure 1. Design Build contract structure

However, a DB arrangement is not without its challenges. For example, the most common risk perception associated with the Design-Build delivery method is a lack of owner control over the design. Through the engagement with a project architect, Growing Power has already taken steps to mitigate the potential risk. With bridging documentation turned over to TBD, the team can maintain the original design intent communicated by Growing Power.

DESIGN PHASE MANAGEMENT

A particular benefit of the design build environment is the involvement of construction partners early in the design process. The insight of team members with a background in project integration and delivery is essential in providing feedback to the design team regarding the relation of the design's development to owner's project control related goals. The construction partners acted to facilitate discussion and collaboration between design partners and to ensure the project's adherence to economic targets. Constant estimation of the design's cost will deliver much more value to the ownership partners at Growing Power at turnover, as opposed to letting the design develop independent of economic information, which often results in cost cutting techniques, rather than true "value engineering."

BIM EXECUTION PLANNING

A key advantage of the involvement of construction management partners early in the planning and design processes of the Growing Power project is the ability to guide the development of a plan for the implementation of Building Information Modeling (BIM) throughout the project. Once initial project goals were defined (Int|1), the management partners engaged in a series of meetings with the team to devise a plan to guide the team, based on the BIM Execution Planning Guide.⁽⁷⁾ At the initial BIM planning meeting, numerous project goals were defined regarding the model's development (SD|XX). Next, common applications of BIM were identified and analyzed for their value to the project, in order to determine whether the uses would be pursued on the project. Lastly, a plan for sharing models and extracting information from the model was developed to guide the team through the design phase.

THE LAST PLANNER SYSTEM®

A highly integrated project team requires a progressive management style in order to deliver a successful project. Instead of dictating deadlines to design partners with little understanding of how those deadlines were adding value to the project or how different systems interacted, TBD's management partners proposed the implementation of the Last Planner System® (LPS), with the entire team's positive response. LPS (SD|IV) is based on the Plan, Do, Check, Act cycle, and consists of techniques that coincide with each step of the cycle. Most notably, the collaborative planning strategy, or pull planning, contained in LPS encourages a more team and goal-oriented approach to design, rather than placing strict deadlines on partners. The use of LPS greatly enhanced the flow of information among team members, and resulted in a much more integrated design process than in a traditional setting (Int|2).

PROCESS MAPPING

While the collaborative planning process was enlightening, considering the much freer flow of information, the result of the process is visually disorganized. To clearly indicate the progression of the project, the agreed-upon plan was translated into a project process flow diagram and posted in the team's co-located office. The plan was organized by the project's numerous design packages (Int|6) and provided the team the convenience of constant awareness of the project's plan.

FINANCIAL ANALYSIS

With the financial aspect of the project being so crucial to the successful delivery of the Growing Power facility, TBD's construction partners made every effort to allow cost to inform the design and keep the team on track with regard to the target value of the project as a whole. The first step of the process development was to conduct in-depth financial analysis of various design options. The vertical farming facility consists of complex integrated building systems, and Growing Power's status as a non-profit organization makes economic analysis even more important to the project's success. Involvement of the construction partners in the design phase provided this key information to both design partners and the facility's ownership team so that decisions could be made that balanced the project goal of economy with the remaining operating goals. An in-depth analysis of a solar array is provided below as a representative of the evaluation that was performed for numerous design options. Additionally, this analysis is illustrative of the work performed for the initial prototype, and is a demonstration of the level of investigation that needs to be performed on a site specific basis in the future.

SOLAR VIABILITY

Early in the design process, TBD explored the viability of an on-site solar array to support Growing Power's goals of sustainability and community by projecting the strong public image of a clean, renewable energy. However, in order to make the design truly beneficial to Growing Power, the array must also achieve the project goal of economy. Through coordination with the construction partners' proposed site layout ideas (D6), the team determined that the best option for the array's placement was as a carport over the facility's parking area, which resulted in an array of 1863 square feet. While this array possesses a theoretical yield of a minimal percentage of the facility's annual electricity demand, as shown in (Elec|4), a financial evaluation was performed to make a more informed recommendation to Growing Power regarding the pursuit of an on-site solar array.

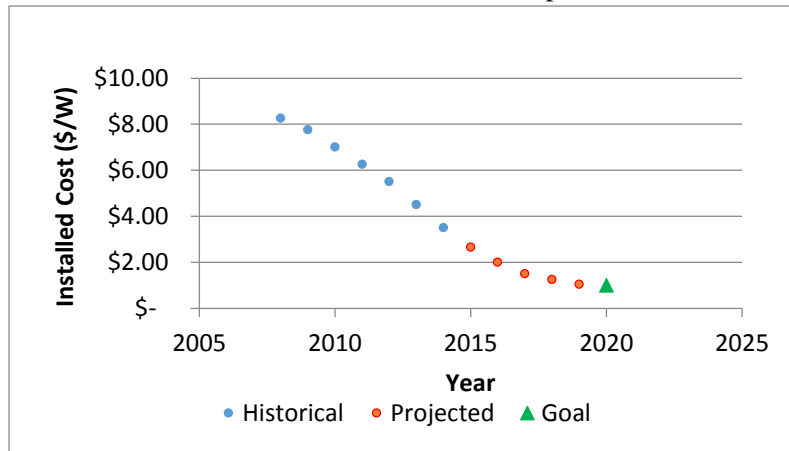
SOLAR FINANCING OPTIONS

Numerous options exist for financing on-site renewable energy such as a solar array, including grants, utility agreements, and tax incentives. The most publicized incentive is provided by the United States Federal Government. Its Solar Investment Tax Credit (ITC) provides a tax credit for 30% of installed costs of renewable endeavors such as a solar array. However, Growing Power's status as a non-profit organization eliminated this option, as the organization does not possess the tax appetite to take advantage of this funding opportunity. However, other prospects exist that would enable Growing Power to possess an on-site solar array to display a sustainable image, such as a tri-party Power Purchase Agreement (PPA).

A PPA is a symbiotic agreement between outside investors, Growing Power, and the local electrical utility that allows all involved parties to take advantage of Growing Power's tax-exempt status. In this arrangement, investors provide the up-front capital to fund the array's installation, maintain ownership of the array, and are also able to take advantage of the federal ITC, thus reducing their initial investment. In return, electricity from the array is sold to Growing Power at a rate that is slightly lower than the market price available from the local utility. This rate is held constant until the deal is renegotiated, which minimizes risk to Growing Power by avoiding price fluctuations. The potential also exists for Growing Power to obtain ownership of the array in the future. A PPA is an option for Growing Power, but the amount of unknowns associated with the arrangement make long-term analysis difficult without any initial discussion.

However, Wisconsin's Renewable Energy Competitive Incentive Program (RECIP) provides an alternative to both the Federal ITC and PPA.⁽¹⁾ RECIP provides funding for up to 50% of a solar array's

initial cost, provided that the array’s initial investment will break even within 25 years. After designing the solar array with panels that generated 14.5 watts per square foot, a Net Present Value (NPV) analysis determined that a total installed cost of \$3.90 per watt would break even in 25 years, thus qualifying the array for the RECIP grant.



According to the National Renewable Energy Laboratory (NREL), installed cost of solar arrays has decreased drastically over the last 6 years and is on track to achieve a target of \$1 per watt installed cost in 2020 (fig. 2). NREL cites an installed cost of \$3.50/W in 2014, with the 2015 cost projected to be about \$2.65/W, which is safely within the allowable cost to qualify for the RECIP grant.

Figure 2. Projected cost of solar installation

In order to make the array economical for Growing Power, the array should pay off its initial investment in a maximum of eight years. Based on net present value (NPV) calculations, (fig. 3, SD|VII) it was determined that the maximum amount that Growing Power can afford to invest initially is \$27,066.75. Assuming a conservative installation cost of \$2.90 per watt in 2015 and maximum funding from RECIP, the remaining cost of the array is \$40,478.91—slightly greater than the amount recommended for Growing Power to invest. However, this provides a fund raising opportunity for Growing Power to secure the remaining \$5730 from community investors before pursuing the solar array, providing a tax credit for those investors and balancing Growing Power’s goals of sustainability, community, and economy.

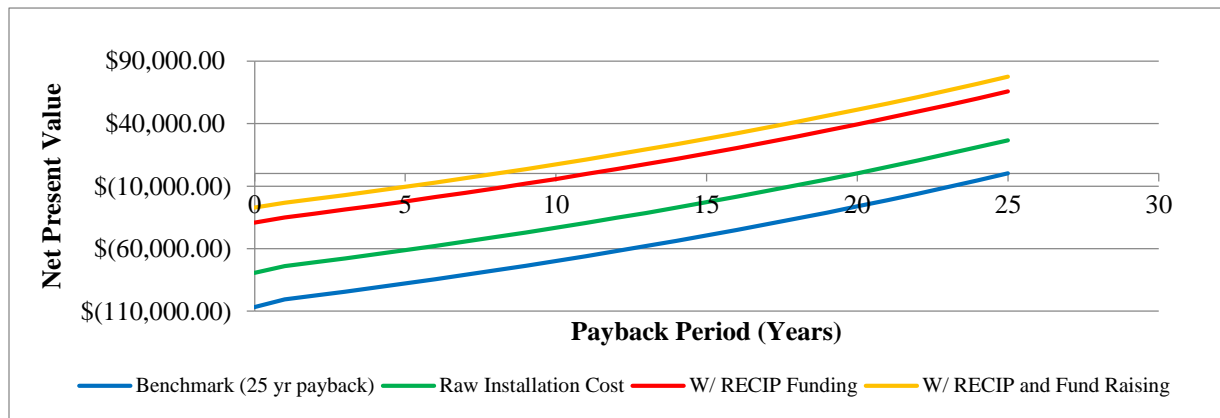


Figure 3. 25 year net present value analysis of 1863sf on-site solar array

Ultimately, through shading analysis, TBD determined that the analyzed solar array did not provide an intelligent outcome. However, the analysis performed on the option is representative of the analysis that was conducted on numerous design options, and was an extremely important step in which TBD’s construction partners engaged to provide Growing Power with reliable information to make intelligent decisions which will lead to a successful project delivery.



COST TRENDING

Once design decisions were made with the help of financial analysis, the project's designed cost could be mapped and tracked, in order to measure the project's development against the targets defined by Growing Power. Tracking costs through the design phase was an extremely important indicator for all partners, as well as a key driver in delivering a successful project to the field construction team and, ultimately, the ownership team at Growing Power. Ensuring that the facility design is aligned with Growing Power's target investment throughout the design phase of the project is a strategy that will pay dividends later on in the project, as the design partners can more intelligently design systems that balance Growing Power's operating goals of community, sustainability, and flexibility, while also delivering a building that supported the economic target.

In order to track project costs, a strategy defined by the Lean Construction Institute (LCI) known as Target Value Design ⁽⁵⁾ (TVD) was employed. This approach dictates that value targets for portions of the facility design are to be thought of as aggressive goals, rather than budgets, in order to drive a leaner approach to design and spur innovation from the team. However, aggressive targets can also inherently encourage a minimalist approach, which provides little value to Growing Power. In order to combat this potential challenge, the team analyzed numerous design options via a decision matrix (D1) to ensure that all aspects of the facility's design were contributing to the overall project goals.

TBD utilized Unifomat II divisions to define cost targets across the project development. Unifomat was chosen for its system-based approach, as opposed to Master Format, in which a single system would

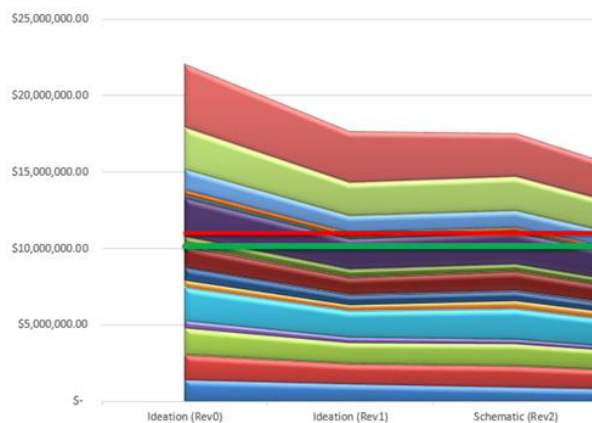


Figure 4. Cost tracking through design phases

likely consist of components spread across numerous divisions. In order to keep the tracking model current and ensure that the entire TBD team had quality, up to date data to keep them informed, a method known as "over the shoulder"⁽⁶⁾ estimating was employed.

Also a technique supported by LCI, the strategy involves performing numerous iterations of the project estimate, documenting changes incurred throughout the facility's development (fig. 4).

Tracking project costs according to Unifomat divisions allowed the team to identify if a single system was experiencing alarming cost growth, and facilitated discussion about tradeoffs that needed to occur, or a justification for the growth. For example, when the team convened to discuss a combined heat

and power (CHP) plant (Mech|10) in the basement, the system was identified as a significant expense. However, based on economic and system analysis, the expense was justified (Mech|11).

Throughout the project's development, a contingency was carried to reflect the management partners' confidence in the cost data. Although TVD typically dictates that no contingency is carried, the management partners understood that there were many unknowns to be developed, particularly relating to the mechanical system of the Growing Power facility. At the project outset, a rough special estimate was performed, leading to a square foot estimate on a space by space basis, leading to custom assemblies (SD|V) and lastly, detailed estimates with the aid of quantity takeoffs performed directly within Revit (SD|VI). Based on the final project estimate, TBD's Growing Power facility is estimated to have a value of \$11.8 million, including a \$1 million allowance for CHP and rainwater harvesting. General conditions (SD|19) are estimated at \$670,000.

SITE ANALYSIS

Understanding all existing conditions is critical to development of an effective and efficient plan of construction for the Growing Power facility. By devoting time to site analysis before the construction phase begins, critical elements can be identified as issues and handled properly, without impacting projected cost or schedule. TBD devoted time for in depth exploration of the existing conditions surrounding the vertical farming facility, enabling quality decision making regarding the construction process.

EXISTING CONDITIONS

The proposed location of Growing Power's new vertical farm facility is found at 5500 West Silver Spring Drive, 20 minutes northwest of downtown Milwaukee, Wisconsin. The site is a neighbor to numerous single family dwellings and a small creek to the north, and a United States Army Reserve Base to the east. The entirety of the southern side of Growing Power's lot touches the sidewalk off the west bound lanes of Silver Spring Drive, which is separated from the east bound lane by a median. The median limits site accessibility to west bound traffic only. The site can be reached using the Silver Spring public bus line which maintains two stops in the community within ¼ of a mile from the site and is serviced by a number of utilities (D10).



Figure 5. Existing Growing Power site

The current Growing Power facility includes two framed dwelling units, two framed garages, one framed barn, one livestock pen, one livestock building, 13 greenhouses, and one combination office/market/kitchen building. Structures lining the east side of the site, including 11 of the greenhouses, the livestock pen, and the combination office/market/kitchen, have been specified to continue to be operational during construction while the remaining structures within the construction site detailed (fig. 5) are to be demolished.

The eight standard penetration tests and lab testing results detailed in the geotechnical report provided from Geotechnical and Environmental Services, Inc. indicates multiple layers of soil on-site comprised of organic fill, organic silt, alluvial silty clay, lean clay and silt. The report dictates the unaltered soils beneath the surface will support a maximum of 1500 psf from building footings.



ENVIRONMENTAL CONCERNS

The construction zone is located in the vicinity of a residential community and a neighboring creek, causing numerous environmental concerns. The management of the active construction site will have a direct impact on the health of the stream's ecosystem and the safety and well-being of the surrounding community. Construction will take place extremely close to Growing Power's existing business hub and greenhouses maintained by their staff. While aspects of construction may impact the operation of the existing business, the activities necessary to run a proper business must continue unhindered during construction.

SITE PLAN

The site plan for the new Growing Power facility was developed to address the concerns raised by existing conditions as well as to create an organized and practical environment conducive to a fluid construction phase. The site plan during construction will not remain static, but shift to reflect the needs of both the workers and the community as construction progresses and is separated into 6 different phases (D6). The site plan provides details specific to the locations of key elements including the co-located trailer, crane location and path of movement, material laydown, mock-up space, site fencing, parking, entrances, and exits. Figure 6 details the site plan for construction during the structural assembly phase.

RISK MITIGATION

To successfully deliver a project, the management team must identify, fully understand, and develop a plan for all constructability concerns of a facility. By defining major phases in construction, and addressing them specifically, the management team was able to mitigate risk, and minimize problems encountered in the field.

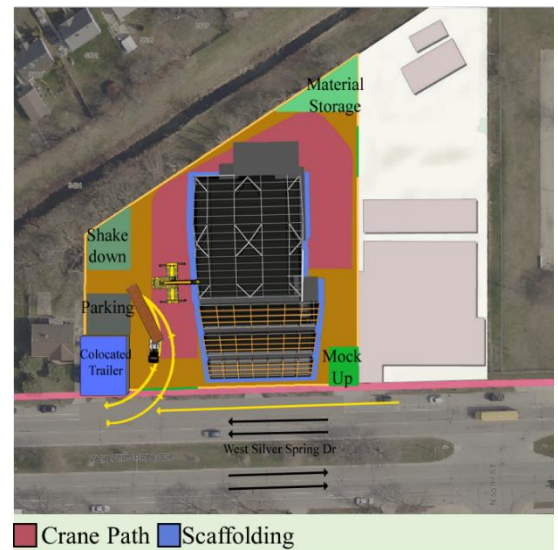


Figure 6. Site plan for façade erection



SITE PREP

Preparation of the site prior to construction is necessary to prepare for the safety of the community and the delivery of equipment, tools, and management trailer. To prevent injury to community members in the area, an 8 foot site fence will be installed around the perimeter of the work zone. The existing Growing Power greenhouse structures must be broken down and removed from the site while simultaneously clearing brush and grading the top soil layer.

EXCAVATION

The highest prioritized constructability concerns of the excavation phase of the project is the high water table and the soil properties, detailed by the geotechnical report provided. This report expresses a water elevation of roughly five feet below surface soils and details type C soil found within boring location to have extremely low cohesiveness and bearing capacity. Using a decision matrix developed by TBD in the planning phase and detailed in the integration report (Int|5), multiple excavation methods were compared and considered, ultimately leading to the decision to slope the site 1.5:1, while utilizing sheeting and shoring where necessary.

SUBSTRUCTURE

The substructure design selected for the Growing Power facility (Struc|10) requires engineered reinforcement of the subsurface soil to provide adequate bearing strength. Prior to the installation of foundation components, Rammed Aggregate Piers® (RAP) are to be driven into the soil to achieve a bearing capacity of 6000 psf. While this affects the scheduled duration of the foundation installation, the activity is necessary for the safety and success of the structural design.



Construction of the substructure assembly must continue while simultaneously addressing the concerns raised by an elevated water table. To allow the installation of the substructure, a pit and sump pump

approach will continuously dewater the site from excavation to the installation of the permanent groundwater collection system (Mech|7) is installed. The temporary site dewatering is to tie into the rainwater collection system, to supplement the amount of grey water available to the building systems (D14).

SUPERSTRUCTURE

The superstructure was designed to take advantage of the benefits of a steel member, metal deck, and structural concrete slab assembly. The majority of the steel beams sized for the project are relatively standard, but three steel transfer elements, specified to be installed above the gathering space to create an open floor plan, create major constructability concerns. The largest of these three cambered beams is to weigh roughly 47,000 pounds and creates the condition for the critical pick of the project. The large size of these steel elements creates the need to focus on the required lead time, the installation procedure, and the steel erection sequence. The abnormally large steel member sizes required an analysis on delivery method to ensure proper scheduling. Working with consultants, a route map from a steel mill in Blytheville, AK, and detailed estimates for permits, interstate police escort, and transport were developed and applied to the Growing Power project (SD|XVII). The size and weight of these elements causes the installation to require the use of two cranes during installation, shown in the critical pick plan (D6), which were sized and selected based on the largest moment applied to them during construction (SD|XVI). The camber specified for the steel transfer elements is designed to offset the loads placed on them, causing the need for precise steel sequencing, deck placement, and concrete slab pours. The steel elements are scheduled to be installed in a work flow explained in the steel sequencing schedule (D7) and are to be followed with the installation of steel decking. The placement of the structural concrete slab must be sequenced to provide the proper loading on the transfer elements, which is addressed by pouring the slab on the third floor after the rest of the slabs have been placed.



INTERIOR FIT-OUT

The interior fit-out of the building, including all the components of the MEP systems, metal stud framing, and finishes, was scheduled with the aid of a Matrix Schedule (D8). This matrix creates a fluid workflow through the building with derived production rates, and enables the building to be turned over in a timely manner.

ENVELOPE

A rainscreen assembly attached to a fiberglass sheathing covered with a moisture barrier is designed to enclose the Growing Power Facility. Detailed virtual mockups of the rainscreen (SD|V) were created through TBD's BIM process to ensure a quality installation with the thermal and moisture performance expected. Physical mockups will also be created on-site to provide testing opportunities as well as display to the surrounding community and Growing Power employees the architectural façade of the new facility. To aid in the appropriate scheduling of the installation procedures, as well as installation times and

Constructability Concerns

Site Dewatering

High water table required continuous temporary site dewatering to be tied into the permanent groundwater collection.

Steel Transfer Elements

Construction sequencing ordered to properly load the cambered steel before structural slabs are poured.

Watertight

Creating a waterproof floor in the greenhouses deletes the necessity of installing greenhouse glazing before watertight milestone.

Building Envelope

Mock-up and production studies conducted prior to project ensure effective envelope construction.

Greenhouse

Construction is to take place separate from interior trades to ensure quality project.

rainscreen crew productivity rates, a detailed production study was conducted by a team of TBD’s trusted managers and incorporated into the management report (SD|XI).

GREENHOUSES

The installation of the greenhouses on the roof of the growing power facility raised waterproofing concerns with the potential to impact both cost and schedule during construction. Working with the design team, the structural and construction partners designed the flooring of the greenhouse to utilize a waterproofing membrane covered with a protection slab, incorporated with bi-level drains (Struc|12). This prevents leaks in the greenhouse from causing water infiltration to the areas below, as well as eliminates the need for the greenhouse glazing to be installed to achieve the facility’s watertight milestone. Waterproofing the greenhouse floor also allows interior finish trades to begin work earlier in the construction process, which reduces overall schedule duration and is reflected as cost savings to the owner.

SITE CIVIL AND LANDSCAPING

Research in the site civil and landscape trades revealed that the local asphalt plants do not operate during the months of October to April, limiting the availability of site paving for the Growing Power facility. It is necessary for the scheduled tasks to reflect this information and allow site paving to take place during the late spring and summer months.

SCHEDULING

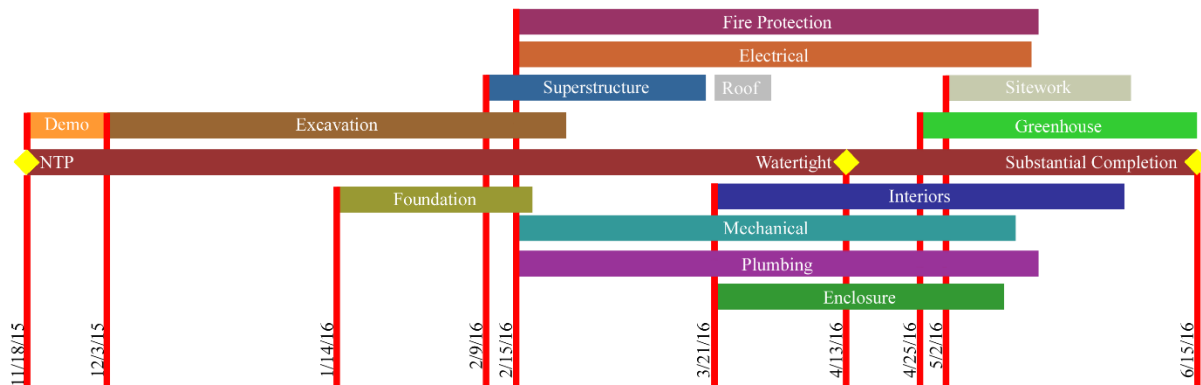


Figure 7. Growing Power facility schedule

The construction of the Growing Power facility, pending notice to proceed, is to start November 18, 2015 and end June 15, 2016—a total duration of 30 weeks. Figure 7 lists the start dates of major construction activities as well as milestone dates, summarizing a detailed project construction schedule (D4).



The Growing Power facility is to be used as a prototype for sustainable vertical farming complexes across the country, and the schedule is intended to be flexible with the development in new locations. The design process for each facility will be unique, but can stem from the original design schedule (D2). Through iteration of the design process for multiple project locations, the process can be refined, shortened in duration, and made more efficient. The design at each location will not be identical, but the majority of the construction process will be similar. By utilizing BIM field and management tracking to track projected production rates against actual production rates, common installation mistakes, and repetitive

quality control efforts, the construction duration is expected to decrease and become more efficient as the schedule is refined project to project.



MATRIX SCHEDULE

Table 2. Interior fit-out activities

1	Duct RI
2	HVAC Pipe RI
3	Plumb Pipe RI
4	FP Pipe RI
5	Pipe Testing
6	HVAC Insulation
7	Pipe Insulation
8	Elec Distribution RI
9	Low Voltage RI
10	Framing
11	Elec Trim out
12	RI Ceiling grid
13	Terminals
14	Lighting Install
15	Drywall
16	Ceiling Tiles
17	FP Trim out
18	Paint Prime
19	Paint Finish
20	Flooring

The interior fit-out (IFO) of the Growing Power facility is suggested to be performed according to a matrix schedule developed with specialty trade consultants in the preconstruction phase. The matrix provides an accurate and detailed plan for the completion of floors 1-4, in roughly 8 weeks.

The matrix schedule (D8) was developed by listing tasks required to complete the interior of the building (table 2) and applying those tasks to predetermined zones within the building. A total of 23 zones were identified, each having roughly the same square footage. Work will be completed in the zones in chronological order, starting on the market level and moving towards the learning and admin spaces on the fourth floor.

Working with trade consultants and utilizing values found in RS Means, average production rates were determined, considering both set up and tear down times. TBD aims to improve the productivity on the site using Lean management tools, an effective flow of work and information, and by prepacking materials and tools for the specified zones into kits. The improvements implemented are expected to increase the production rates (D8) of the specified tasks by a minimum of 10%.

To ensure the feasibility of meeting these goals, the anticipated production rates with an example crew size were applied to the square footage of the determined zones. The calculated durations applied to each zone during scheduling (D8) are capable of being fulfilled by trade contractors. The matrix schedule is a suggested method of completing the interior of the building, and incentives will be applied to selected trades to install material according to the matrix.



PREPACKAGING

To increase productivity and decrease the amount of time and movement waste, all materials delivered to the site shall be prepackaged in kits. A production study conducted by TBD Engineering indicated a 25% decrease in installation time (fig. 8) when materials are prepackaged into kits and easily accessible, compared to moving required materials from stored locations around the site. TBD will translate the benefits defined from the study to the Growing Power facility by requiring the subcontractors to assemble kits of materials.

It should be noted that the effective increase in productivity from kitting materials is not immediate (fig. 8). This method requires a preloading of resources and labor at the early stages of construction to gain the benefit of increased productivity.

Table 1. Construction durations

Project Schedule (wk)	
Construction Duration	30
Excavation	11.5
Foundation	5
Superstructure	5.5
Roofing	1
Mechanical	11.5
Plumbing	11.3
Fire Protection	13
Electrical	13
Enclosure	7
Interiors	10.5
Greenhouse	7
Sitework	4.5

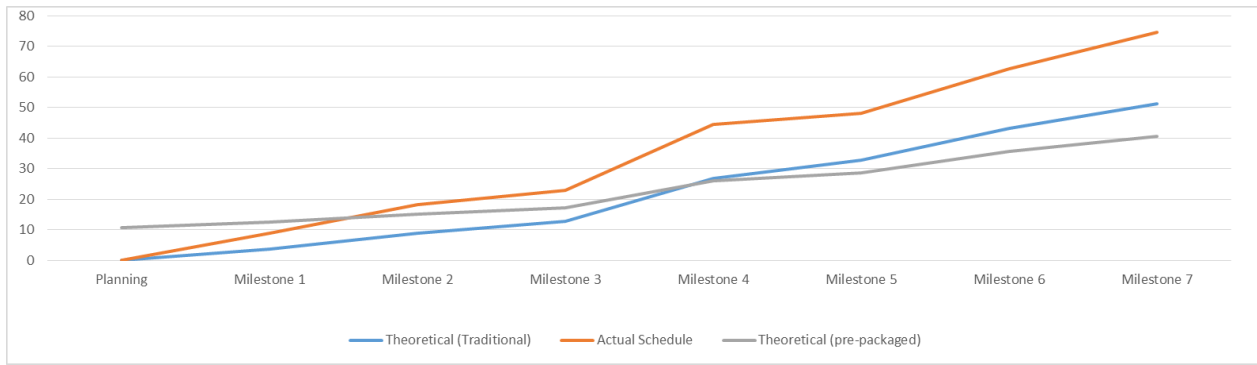


Figure 8. Effect of kitting material on installation time from study

The kits will be prepackaged on-site by the responsible subcontractor and will include all the materials the sub will need to completely construct one of the predetermined zones. This includes all of the materials to be installed, the tools required for installation, and a description of the location/zone the kit is to be placed. The material will lie on a cart picked by the subcontractor and be able to be efficiently moved through the building and material lift.

A kit intended for the installation and finish of the drywall in the determined zones is used as an example.

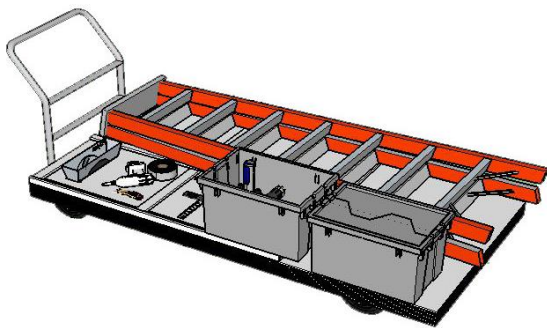


Figure 9. Sample drywall pre-packaged kit

Fig. 9 characterizes a visual representation of a sample.

The workforce will be able to pull tools and material as they are needed. The kits will be assembled to measure and cut for the ceiling, hang the ceiling, and hang the wall (cutting around electrical boxes and lights as necessary.) Crews will then be able to access the tools and materials necessary for finishing the drywall, including compound, tape, knives, and sandpaper.

The delivery and assembly of the kit and materials is to follow the developed matrix schedule (D4), outlined in Table 1, and the Gantt chart schedule (D8).

CONSTRUCTION INNOVATION



The management techniques of TBD upheld on and off of the construction site will ensure a timely delivery and quality product that the project team and owner can be proud of. TBD intends to bring BIM technology to the fieldwork of the Growing Power facility and to use a paperless approach to documentation and information sharing, supporting the project goal of sustainability in design and construction.

CO-LOCATION



The design process found great success in the co-location of design partners as described in the integration report (Int|4). TBD will transfer the practice of co-location by providing one trailer, with an open, uninhibited floorplan for the use of all construction trade partners. Co-location will increase the flow of information between partners on-site and reduce the time waste associated with the traditional RFI process. Locating experienced staff together enables the opportunity of having more input to



challenges that may arise, leading to more creative and efficient solutions. The trailer is to include computers capable of maintaining the design model and field model, to be used for BIM field and management tracking (to track expected productivity against actual installation rates, common mistakes, and to indicate in a field model where rework is needed) and tablets preloaded with model viewing software to view modeled elements in the field. The centralized location for project decision makers also aides in the alignment of team and project goals between personnel.



LEAN APPROACH

TBD will implement Lean construction management techniques to manage and improve construction processes with minimum cost and maximum value while prioritizing the needs of Growing Power and its new vertical farming facility. The Lean culture, grown by TBD throughout the design phase and cultivated on the construction site, creates an environment that emphasizes collaboration, accountability among team members, and adds value as interpreted by the client.

VALUE

The Growing Power facility, to be the best possible product when delivered to the ownership partners, must meet the needs of the organization. A building system, function, or style that does not satisfy some aspect of the business model of Growing Power does not add any value to the project, and is considered muda, or waste. The Lean approach implemented by TBD staff prioritizes the production and acquisition of value, while eliminating project waste. The waste eliminated may include time, material, or money, thus supporting the overarching goals of creating a sustainable project in an economic fashion. Value will be defined by Growing Power staff with direction from TBD. The success of the project and the satisfaction of Growing Power can be improved with their involvement in the construction process.

COST

The implementation of Lean techniques in the field, aimed at identifying value and completing only value adding tasks, with the aid of 3d design models, will ensure that the project is delivered in an economic manner. The process of identifying and resolving clashes virtually, utilized throughout the design phase, will reduce the number of field clashes discovered, limiting the number of change orders during construction. The dedicated professionals of TBD will work to keep the project on budget and will continually monitor expenses, both actual and anticipated, to ensure the project is delivered on track within the defined targets.

QUALITY

Providing Growing Power with a value rich project translates to turning over a quality facility. To ensure a quality project is produced for Growing Power, TBD will enforce its own Quality Management Plan (QMP) (SD|IX). This QMP will enlist the expertise of a Safety and Quality Manager scheduled to be on-site for the 30 week construction duration. The manager will supervise the subcontractors, ensuring the work in place exceeds the quality expectations of the owner. Third party inspectors will be consulted to focus solely on the testing and inspections of material used in construction. The MEP systems in the Growing Power facility are complex and their proper function is necessary to the success of the project.

Management Values

Lean Ideals

Manage the project using lean ideals to increase productivity and reduce waste

Value Adding Activities

Focus effort on value adding activities, while reducing waste

Cost Reduction

Lean techniques and BIM tools ensure accurate cost estimation

Quality Focused

Committed to a quality project though management

Continuous Improvement

BIM Field and Management tracking utilized to improve the project location to location

To guarantee their optimum performance, TBD will practice continuous commissioning throughout the duration of the project, as well as monitor installation progress with 3D design models to ensure proper material placement. The continuous commissioning will identify potential issues during installation, allowing ample time to fix or replace the troubled component before turning the building over to the ownership partners.

FLOW

TBD Engineering has been managing project flow through the design phases of the project. The flow of information between design partners was critical to the development of a high quality project, and contributed to the elimination of wasted time (Int|2). The benefits of an efficient, uninterrupted flow can be applied during the construction phase, and TBD staff intends to bring the concept to the field. The elimination of time waste by flow in the field, increases time added value to the project.

A paperless approach to communication will enable an efficient flow of information while supporting Growing Power's mission of a sustainable project. Electronic linked drawings and a 3d model will be made available to subcontractors and reviewable on-site from mobile BIM boxes and tablets provided to TBD employees. The visual representation of the expected deliverables in the model will provide direction to the men and women in the field. Providing the drawings electronically will not only increase accessibility to required information, but it will ensure all parties are working on the same drawings and increase the speed at which their drawings are updated.

The design phases found great success using the Last Planner System®. TBD will continue to use this collaborative planning process on the construction site to improve the flow of materials and information while making the construction process more predictable. The master schedule has been set by TBD (D4), but Pull Planning, led by TBD staff and key subcontractor leaders will plan the details of construction in Weekly Work Planning meetings. The subcontractors will engage in planning a four week look ahead schedule to clearly identify any scheduling issues to resolve problem before they arise. The weekly planning meetings, in addition to daily foremen meetings, will be used to monitor the progress of the subcontractors. Progress will be monitored using a plan percent complete analytical method and BIM field and management tracking to create accountability of schedule commitments while offering a learning experience to the team by identifying and offering solutions to missed commitments.

CONTINUOUS IMPROVEMENT

The Lean approach to construction allows for the continuous analyzing and improvements of workflows and processes, complementing Growing Power's goal of a creating a flexible prototype facility. Not only will the processes be refined during the construction of Growing Power's flagship vertical farm, but they will also be refined during the construction of the similar facilities nationwide. The continuous improvement of the Lean practices will lead to the reduction of mistakes, an efficient scheduling process, and ways to identify and deliver value to Growing Power. The benefits of TBD Engineering's Lean approach will continue to add benefits to the developed prototype facilities constructed across the country.



SAFETY

A Site Specific Safety Plan (SD|X) will be provided to every contractor on the construction site to be delivered to their crews. All subs are required to adhere to the specified safety plan. PPE usage will be strictly enforced by all parties and require every person on-site to utilize hard soled boots, safety vests, eye protection, gloves, shirts with sleeves, and hard hats. A full time safety manager will lead and enforce all safety policies. TBD, through the planning stages of the process has identified pedestrian and

automobile flow for the duration of the project. To encourage a culture focused on personal safety, specific policies will be enacted. To continually monitor and improve working conditions, subcontractors will not be affected by negative consequences when reporting near misses. Near misses will be vigilantly monitored, and flexible policies enacted to remedy dangerous situations before a lost time injury occurs. Safety will not only be the concern of a construction manager, but a concern to all parties involved in the project.

FACILITY OPERATIONS



The life cycle of a facility is comprised only minimally of the design and construction phases. The operation phase is, by far, the most substantial phase of a facility’s life cycle, both by the mere time aspect and the financial expense of maintaining the systems housed within. In order maintain continued success as defined by the goals of economy and sustainability, TBD has engaged in practices throughout the design phase, which will continue into construction, that will provide valuable information to Growing Power and ensure the continued success of the organization.



STAFF EDUCATION

Numerous options exist for facility maintenance, including service plans provided by mechanical installers and third party maintenance solutions. However, given the nature of the Growing Power organization, it was determined that neither option would contribute to the goal of economy as much as the alternative option of training existing Growing Power staff to maintain the new facility’s equipment. Throughout the installation and commissioning process, the construction team will engage Growing Power’s staff in training on the facility’s equipment to familiarize the members with the equipment’s operation. In addition, operations and maintenance handbooks and schedules, as well as information from the BIM will be provided to Growing Power’s staff in order to make the maintenance of the facility as efficient and streamlined as possible.

BIM TURNOVER

As defined in the BIM Project Execution Plan (Int|7), facility management was a major goal toward which TBD strived throughout the design process. Just as the Building Information Model (BIM) guided the design and construction partners through the planning and design phases of the project, it can also be extremely valuable during the operational phase of the Growing Power facility.

However, digital models can be extremely complex to navigate, especially with a facility as complicated as Growing Power’s. The true value to a facility’s operational staff is derived from the information embedded in the model. In order to provide Growing Power with this information to efficiently operate the facility, TBD will provide spreadsheets containing key attributes about the facility’s assets upon turnover (fig. 10).

The spreadsheets were developed similar to the Construction-Operations Building Information Exchange, but more specific toward applicable data defined by a prominent research University’s facility management

group.⁽⁸⁾ The matrix (D1) defines key attributes to be recorded for each equipment, divided into design, construction, and commissioning phases. The validation of previous effort ensures that Growing Power is provided accurate data at turnover, enabling the ownership partners to continuously evaluate its operation and improve upon the vertical farming prototype as multiple facilities are erected nationwide.

ASSET SCHEDULE- HEAT PUMPS		
Equipment ID	Subclassification (Select)	Cooling Coil Capacity
WSHP-41	WSHP	44400
WSHP-42	WSHP	32500

Figure 10. Sample asset attribute spreadsheet