Integration | Construction | Mechanical | Electrical | Structural

GROWING POWER
VERTICAL FARMING FACILITY

TOTAL BUILDING DESIGN
ENGINEERING

Architectural Engineering Institute, Annual Student Competition
Registration Number: 04-2015

TB
GROWING POWER INC.

EXECUTIVE SUMMARY

Growing Power's recent success and growth of their nonprofit organization has created a need of a new vertical farming facility to enhance their mission of providing equal access to healthy, high-quality, safe and affordable food for people in all communities. 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 project goals defined as flexibility, community, sustainability, and economy, must be achieved through an integrated design approach, prioritizing efficiency, mutual trust and respect between partners, and an openness to collaboration. Total Building Design approached and completed the design of the vertical farm with an integrated process embraced by all team members, which resulted in a quality facility for Growing Power.

INFORMATION EXCHANGE

Integration was empowered through an efficient and effective method of information exchange, intricately mapped though team collaborative planning sessions with the aid of the Last Planner System®. TBD utilized a co-located space and various methods of digital communication, including virtual information exchange between different design partners' modeling software, to create and maintain a valuable flow of information.

DECISION MAKING PROCESS

To ensure all major design decisions benefited the Growing Power organization and their goals, as well as confirm that the most advantageous decisions were made, a decision matrix was created to analyze the value added to the project by design solutions. Continuous cost tracking throughout the design phases enabled cost to influence decisions across all design partners' scopes, and target values to be shifted from one Unitformat II section into another.

INTEGRATED DESIGN PACKAGES

To create an environment of simultaneous discipline design focus, 5 design packages were identified, grouping spaces of similar intended use together. The 5 distinct packages were created with synchronized design by all parties, enabling real time coordination, integration, with clash resolution and system integration input from all team members concurrently.

BUILDING INFORMATION MODELING

Support for an integrated design process was provided by Building Information Modeling (BIM) tools and processes. The TBD design partners engaged in BIM Project Execution Planning to take full advantage of the potential added value by identifying BIM goals and clearly explaining the processes required to achieve those goals and the information exchanges associated with them.

INTEGRATION POINTS

The facility developed though an integrated approach took determination, input, and creative problem solving from all team members, specifically with development of the rainscreen façade system, the unique greenhouse design and analysis, and the redesign of the gathering space without the visual interruption of unnecessary columns. Through facilitated, integrated design management and coordination, and value driven effort, a cost effective facility aligned with Growing Power's current goals and the potential for organizational growth, was produced to be turned over to the ownership partners at Growing Power.

TABLE OF CONTENTS

PROJECT INTRODUCTION

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 though 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 expectoration 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.

AN INTEGRATED TEAM ENVIRONMENT

A highly integrated project team environment is widely viewed as a solution to many of the issues prevalent in the Architecture, Engineering, and Construction (AEC) industry. Although TBD has recommended a Design-Build (DB) approach to delivering the Growing Power facility (CM|2), the philosophy of Integrated Project Delivery and its core principles can be applied to any project to improve the process and the product. An integrated team environment was essential in order to support the project goals on a facility as complicated as that being pursued by TBD and Growing Power. TBD defined a number of key factors that would enable the philosophy of IPD to thrive in the team setting, driving a more efficient process and delivering more value to Growing Power.(5)

Mutual trust and respect, an openness to collaboration, and a sense of security without judgment were identified as essential contributors to a successful team and the delivery of a successful project. By establishing TBD early in the planning and design process as one team comprised of equals (fig. 1), a culture defined by a lack of judgment input was maintained through the course of the project's development. This culture provided the potential to contribute greatly to the success of the team, as evidenced through examples such as TBD's initial planning stage, dubbed Ideation (p. 2).

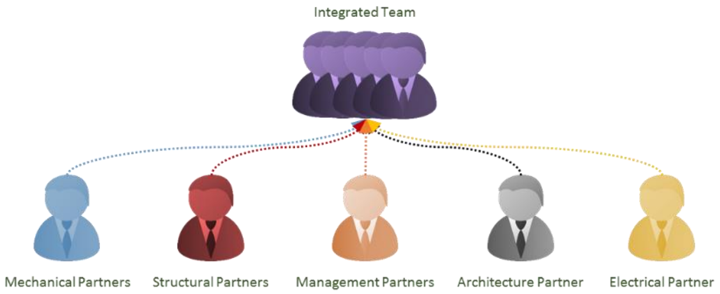


Figure 1. TBD integrated, flat team organization

Numerous tools were employed to support the team's efforts to function and communicate as a highly integrated entity, such as the implementation of a modified version of the Last Planner System® (LPS), a map of the overall project process, team co-location, the development of Integrated Design Packages, and a goal-oriented decision making process. Driven by a team of management partners who brought useful industry experience in the field of project integration, the combination of these techniques was designed to eliminate waste from the design process by facilitating and maintaining effective communication among TBD team members. The integrated process ensured that the end product was a sustainable, economic prototype that will enable Growing Power to connect with and educate the surrounding community for years to come.

INFORMATION EXCHANGE

The development of a free and open flow of communication is extremely important to any integrated team such as TBD's. Communication is a major cause of conflicts among project teams throughout the industry, and TBD engaged in multiple tactics to combat this potential challenge. In addition to supporting team integration, both the Last Planner System® (SD|II) and team co-location proved to be immense assets in aiding effective communication between partners. While face to face communication was strongly preferred, TBD also planned for the inevitable situation where all partners were not able to attend project meetings by defining alternative, digital communication techniques.

COLLABORATIVE PLANNING

The Last Planner System® was identified in the preliminary planning phase of the project as a tool that would support TBD's integration efforts by allowing the team to develop a project plan in a collaborative manner. LPS was founded on the “Plan, Do, Check, Act cycle,” and is designed to facilitate communication among team members much more effectively than a more traditional, deadline-oriented scheduling strategy. The Last Planner System® is comprised partly of a master scheduling phase, followed by implementation of the pull planning technique. The practice of involving the entire team in collaborative planning sessions proved vital to the project’s development, as it generated an attitude among team members of adding value to the project to support Growing Power, and created a more intimate connection between team members and the project plan.

PROJECT PHASING

The planning and design phases of the project were broken into four main categories: Ideation, Scheming, Development, and Iteration (fig. 2). The division of the design process allowed for the team to clearly define milestones, enabling predictable and trackable design progress. Ideation kicked off the project with numerous brainstorming sessions. The opportunity to create without limit, based on the business model of IDEO and Walt Disney Imagineering’s “Blue Sky” principle (13), produced innovative ideas like installing waterwheels in a rainwater collection system to produce electricity, or implementing a heat and power cogeneration plant in the basement of the facility. During the Scheming phase, these ideas were refined by evaluating them against the project goals, as well as investigating feasibility as interpreted by the TBD partners, and the impact implementation would have on other ideas. The theoretical processes were defined further in Development by detailing the idea in the building and analyzing its effect on the total building assembly and its influence towards the project goals. The bulk of the design process was encompassed in the tasks completed in the Development phase. As a final check on the progress the TBD team made during the design process, iteration was used as a period of review and reflection. The developed ideas were analyzed to ensure they were the best option for the Growing Power vertical farm and beneficial towards the enhancement of Growing Power’s vision.

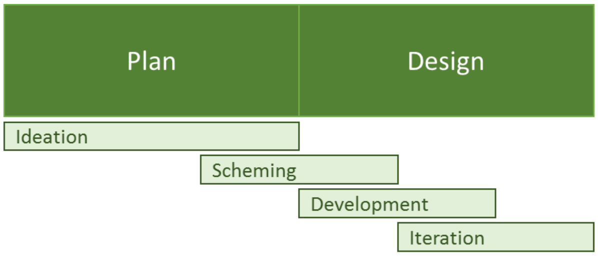


Figure 2. TBD’s collaboratively developed project phases

PULL PLANNING

The second portion of the Last Planner System® that TBD implemented was the pull planning technique, which reverses the planning process. Instead of scheduling from a start date forward, pull planning begins with a future milestone and works backward, so that information is pulled from downstream customers. By using sticky notes detailing a partner’s commitment and what he or she needs to keep that promise (fig. 3), the process created a more collaborative environment for TBD by generating an attitude among the team of adding value to the design process. Additionally, collaborative planning sessions generated more social commitment to the plan, and the displaying of the agreed-upon plan with sticky notes on a wall in the team’s office served as a constant reminder to all partners of their commitment to other team members, the project as a whole, and, ultimately, to Growing Power.

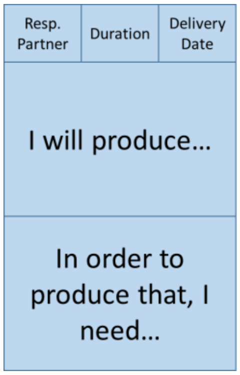


Figure 3. Sample pull planning sticky note

Figure 4. Informal LPS implementation

The initial implementation of the pull planning technique posed a challenge due to many design partners' lack of familiarity with the strategy. To familiarize the team with the concept of pull planning, TBD engaged in an informal simulation in which the team applied the method to plan and execute the construction of a small tower out of children's interlocking toy blocks (fig. 4). This initial session enlightened many team members to the importance of effective exchange of information to the delivery of a quality design, as even something as simple as a tower of blocks did not go as smoothly as the team had envisioned. Throughout all four phases of TBD's planning and design process, pull planning sessions (fig. 5) were held on a weekly basis to plan the development of the team's Integrated Design Packages (p. 6). Several key exchanges of information occurred during these sessions that would not have normally taken place, such as the interaction between mechanical, structural, and construction partners in the design of the floor slab system of the Growing Spaces (p. 12) and the plenum of the Gathering Space (p. 14).

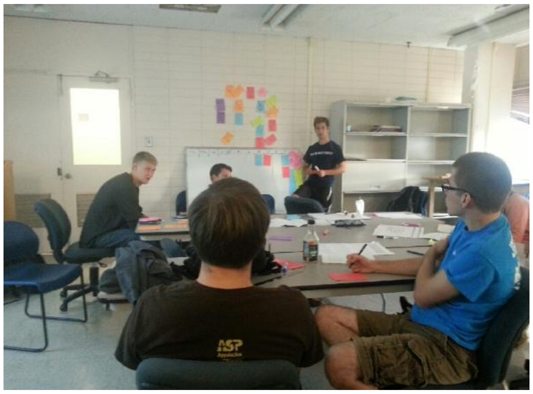


Figure 5. Snapshot of TBD collaborative planning

MAPPING PROJECT PROCESSES

Mapping project processes is a technique often used by the research community in order to understand project development and establish a baseline plan against which to measure actual progress. Although collaborative planning through LPS is a great facilitator for information exchange, a logical process flow diagram, (fig. 6, D2) is beneficial in enabling all partners to visually understand how each fits into the broader picture of developing an integrated design. As a form of documentation of the collaboratively developed plan, the process map allowed the team to look ahead to understand the overall direction of the team. Process mapping is an important tool to support team integration, which allowed TBD to eliminate waste in the design process and support all four major project goals.

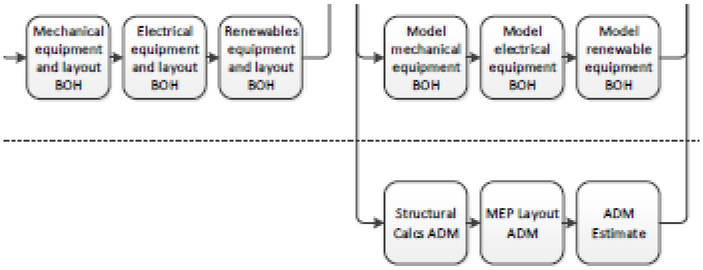


Figure 6. Snapshot of TBD project process map

CO-LOCATION

The location of essential team members in a common space significantly contributes to an integrated design process by making team members easily accessible for questions, responses, and spontaneous integrated design sessions. Throughout the entirety of the planning and design phases, TBD team members utilized an easily accessible, secure, co-located office for the majority of effort towards the Growing Power facility design. The space had enough room for all team members to work comfortably, held all team computers and drawing tables, had ample wall space for the hanging of relevant material, and contained a meeting space complete with a SMART Board (fig. 7).

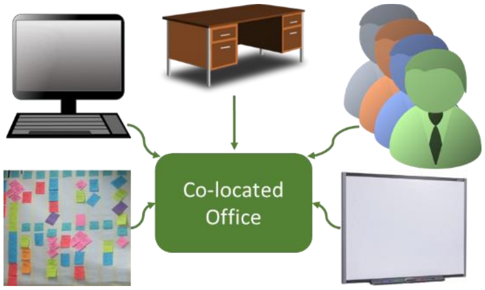


Figure 7. Components of co-located office

Locating the team members in the same room also permitted the opportunity to witness the development of the design as it was created. This kept all pertinent players informed of the design and its process while simultaneously alerting them to their required deliverables necessary for the advancement of design. Co-location also enhanced design by providing continuous review by multiple team members, ensuring an optimized product.

FACE TO FACE COMMUNICATION

Whether team members were working on the Growing Power project, or other individual projects, an enormous portion of their time was spent together in the co-located office space, which allowed for frequent face to face interaction between all team members, the team's preferred method of communication. Not only did face to face interaction contribute to the team building process of TBD, which in turn developed trust in team members, but also enabled effective flows of information through verbal communication. Everyone could be reached quickly if a question pertaining to their field of expertise arose, and the questions were promptly answered. The co-location of the team also opened all conversations to input from other team members, allowing them to provide aid from their own perspective, resulting in spontaneous, integrated design sessions.

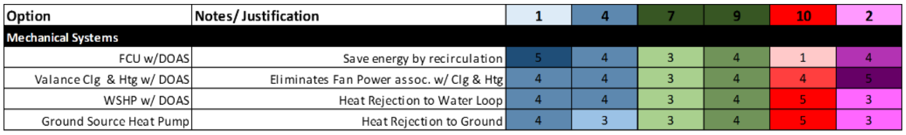
DIGITAL COMMUNICATION

While face to face interaction was the preferred method of communication, it was not always an available option. An effective transfer of information is necessary to the success of an integrated design project and communication channels must be clearly identified to easily reach team members. TBD identified four methods of digital communication to be used during the planning and design phases of the project to reach team members and information (fig. 8). The electronic files created during design, including plans, research articles, calculations, spreadsheets, and reports, were uploaded to Box, a secure online file sharing and cloud content management service. Any file a team member uploaded to Box could be viewed by the entire team, creating a way for information to be pulled quickly when needed without direct contact between partners. The model files were the only files not saved to cloud storage, but were instead saved locally on a secure server. Cell phones were utilized when questions needed to be answered or decisions needed to be made quickly with the input of one individual. Publicly displaying the cell numbers of the team members provided the option to be contacted when needed. GroupMe, a mobile group messaging app, was an agreed-upon method to reach all partners simultaneously. This became a highly useful tool for decision making that required the input of a group when not all team members could be present in the co-located office.

Figure 8. TBD digital communication methods

DECISION MAKING PROCESS

In order to ensure that all major decisions were made in support of the defined project goals of economy, sustainability, flexibility, and community, a decision matrix was conceived that facilitated team analysis of those decision (fig. 9, D1). TBD's decision matrix discouraged design partners from producing a system that they were familiar with, by encouraging the exploration of multiple options to design a facility that most effectively balanced all project goals. After developing a list of ideas, the design partner most familiar with the system



Option	Notes/ Justification	1	4	7	9	10	2
Mechanical Systems							
FCU w/DOAS	Save energy by recirculation	5	4	3	4	1	4
Valance Clg & Htg w/ DOAS	Eliminates Fan Power assoc. w/ Clg & Htg	4	4	3	4	4	5
WSHP w/ DOAS	Heat Rejection to Water Loop	4	4	3	4	5	3
Ground Source Heat Pump	Heat Rejection to Ground	4	3	3	4	5	3

Figure 9. Snapshot of TBD decision matrix

evaluated each option against the four primary project goals, as well as secondary intra-team goals. Final decisions were made as a collective unit, and consisted of discussing the tradeoff that took place between the system options and how they contributed to each goal.

To support Growing Power’s goal of delivering an economic facility, cost trending was also used as a tool to inform design decisions. Management partners employed the use of “over-the-shoulder” (11) (OTS) estimating in order to maintain an accurate database of the design’s cost. The OTS strategy involves defining design milestones to perform a detailed financial estimate of the design to date. Each system of the facility was tracked independently and charted on a graph (fig. 10, D3), and constant evaluation of the project’s total value against Growing Power’s defined target allowed the team to identify if any portion of the facility was experiencing an alarming trend in cost growth, and facilitated numerous discussions throughout the design process. For example, the design and installation of an on-site combined heat and power (CHP) facility was identified early in the design process as a potential option to support Growing Power’s goal of community, but represented a significant portion of the mechanical system’s target value. This design option triggered further discussion and justification from an economic standpoint, and was ultimately accepted (M|10). Throughout the planning and design process, a contingency was carried to account for potential unknowns, inversely reflecting the level of confidence in the evaluation of the current estimate against the design target.

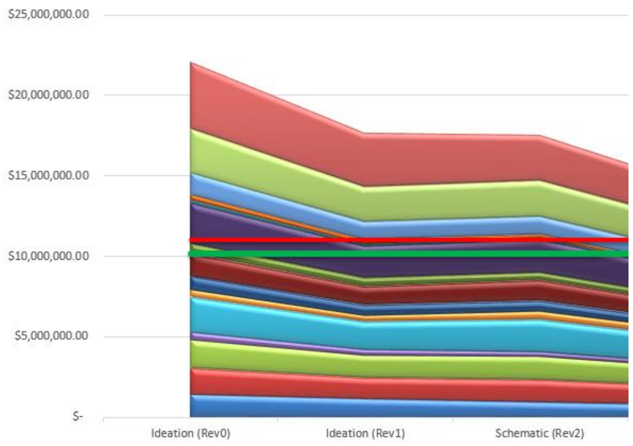


Figure 10. Evaluation of project cost against established target

INTEGRATED DESIGN PACKAGES

Rather than designing the entire facility independent of each other’s progress, TBD chose to group similar space types into Integrated Design Packages (IDP). After analysis of the desired program, TBD identified five major IDPs within the footprint of the facility (fig. 11, SD|III), and identified the enclosure as another key IDP. Throughout the design phases, the team targeted efforts on one specific design package at a time, creating more interactions than a traditional design strategy. Working within the IDP better displayed the interactions among building systems and facilitated discussions within the team regarding potential conflicts. The near real-time discovery and resolution of collisions between systems allowed for much quicker design progression, as the team spent less time in traditional coordination meetings and more time detailing and developing the facility design.

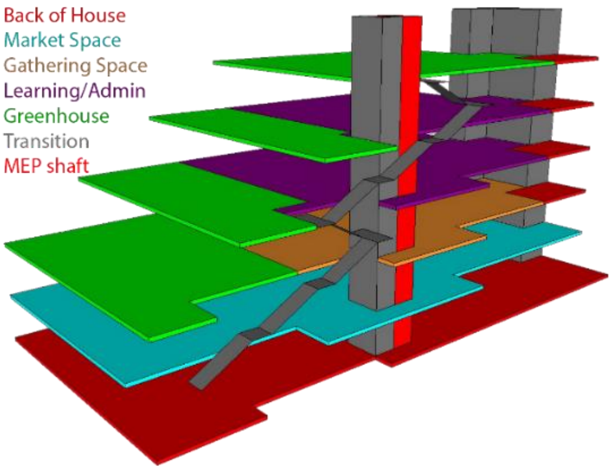


Figure 11. TBD Integrated Design Packages

BUILDING INFORMATION MODELING

Building Information Modeling (BIM) is both a tool and a process that is designed to support the integration and flow of information among team members. The application of BIM is becoming the new standard of practice in the AEC industry, although the quantification of the value it adds is difficult due to varying levels of implementation on a case by case basis. However, promising data was produced from a case study of the Pegula Ice Arena, which earned a 2014 BIM Award from the American Institute of Architects, where research measured a savings of over $1 million. (3) However, the power of BIM is not limited to achieving only goals related to economy, but can also allow the team to develop a more sustainable building through energy analysis, utilize the information to improve upon the initial prototype, and help further Growing Power's mission of educating the community.

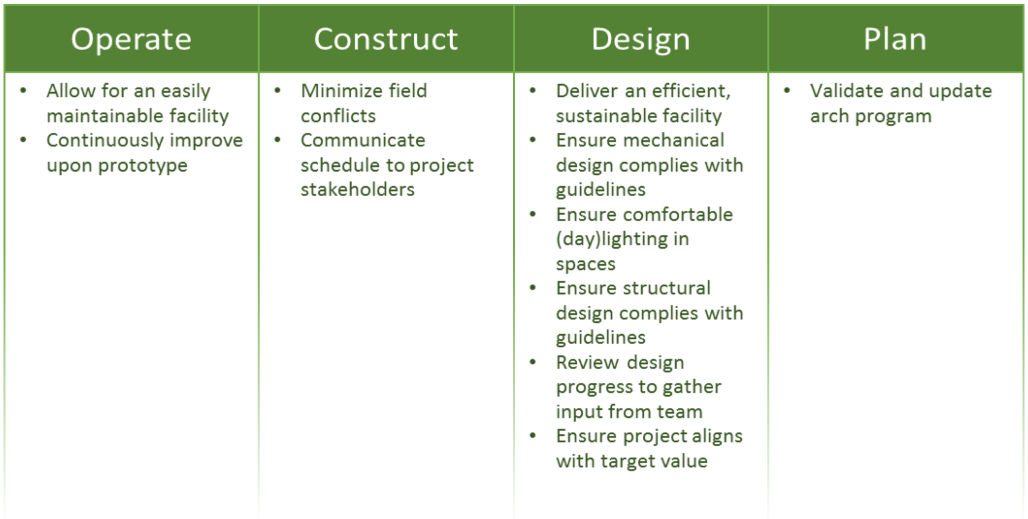
BIM EXECUTION PLANNING

In order to take full advantage of the value that can be added through the use of BIM, a plan was put in place for the implementation of the tool throughout the lifecycle of both the project and the facility (SD|IV). Utilizing the BIM Project Execution Planning Guide (11), TBD developed a detailed plan for the utilization of BIM throughout the project, following a process consisting of defining BIM goals, identifying BIM uses, and recognizing how information should be exchanged between the different tools.

BIM GOALS AND USES

A key aspect of the Planning Guide is the idea to "begin with the end in mind." Instead of identifying how BIM can add value to a project from the planning phase forward through design, construction, and operations, reversing the process ensures that each use of BIM is working toward an end goal, and that developed information is leveraged to improve design communication and integration

A key goal for TBD was to allow for the Growing Power facility designed in Milwaukee, WI to be a flexible prototype that is continuously improved upon with each new facility's construction in a different location. As such, the efficient operation of the facility was seen as paramount to the success of the overall project. Goals were then identified for the construction of the building, and through the design and planning phases (fig. 12, SD|IV).



Operate	Construct	Design	Plan
Allow for an easily maintainable facility Continuously improve upon prototype	Minimize field conflicts Communicate schedule to project stakeholders	Deliver an efficient, sustainable facility Ensure mechanical design complies with guidelines Ensure comfortable (day)lighting in spaces Ensure structural design complies with guidelines Review design progress to gather input from team Ensure project aligns with target value	Validate and update arch program

Figure 12. TBD BIM goals, planned with the operation phase in mind

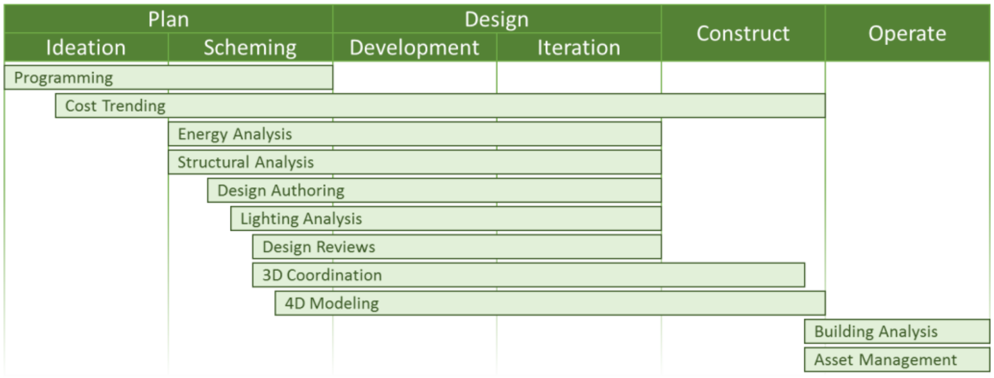


Figure 13. BIM uses per project phase

After clear definition of the goals TBD strived to achieve through the implementation of BIM, applications of different tools were identified to support the pursuit of those goals, (fig. 13, SD|IV). The primary uses were divided by lifecycle phase, and further by TBD's four custom phases which fit into the more generic "planning" and "design" phases.

BIM PROCESS AND INFORMATION EXCHANGES

With the goals and uses defined for the implementation of BIM throughout the Growing Power facility's lifecycle, a process was undertaken to define how the partners' models needed to develop and how software would interface to perform each of the BIM uses. To begin, a high-level process was modeled for the team (fig. 14) in order to guide the implementation of the BIM efforts, beginning with preliminary programming and energy modeling. Once designs were authored, they were synchronized to an integrated central model, where review, coordination, and analysis could take place, aiding the iterative, integrated nature of TBD's design process. In order to support the design authoring portion of the models, the AIA's Level of Development (LOD) matrix (14, 15) was utilized along with AIA's LOD Specification.(16)

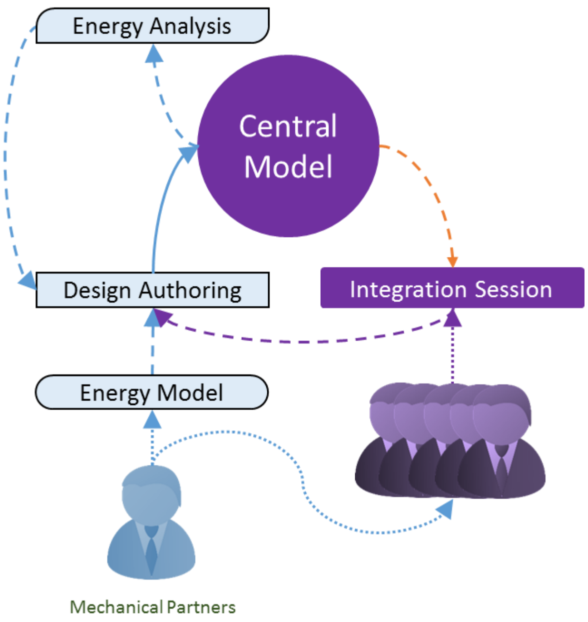


Figure 14. Sample BIM process

TBD designed specific information exchanges to leverage the software at hand, partaking in a detailed session defining how information could be extracted from the intelligent model and used to run simulations and analyses (SD|V).

DESIGN INTEGRATION

The result of Total Building Design's integrated team processes is a highly integrated facility to turn over to the ownership partners at Growing Power. While the entire building required efficient coordination and communication, three key aspects of the design stood above the rest as considerable focused efforts of the team. The context of the facility is extremely important when analyzing its interior systems, as were the facility's enclosure, the community gathering space, and the growing spaces.

BUILDING CONTEXT

In order to engage design partners in a more focused approach, the program described in schematic documents provided to TBD was categorized into integrated design packages (p. 6, SD|III) based on the intended use of the space. After analyzing the schematic documents, the project goals, and internal team goals, five distinct design packages were identified: growing spaces, administration and learning space, gathering space, market space, and support spaces, or back of house (fig. 15).

Figure 15. TBD Integrated Design Packages

TBD designed the Growing Power facility to take advantage of iconic architectural features and innovative, sustainable integrated building systems. The result, is a multi-use facility comprised of four terraced growing spaces (green) that showcase a flexible layout of aquaponic farming techniques (SD|XI), connected to the interior spaces with specially designed view corridors. Additionally, the facility will include two levels of educational and administrative space (purple) to actively support Growing Power's goal of community education and outreach. Below the administrative and learning spaces is a level of gathering, also designed to enhance Growing Power's outreach in the community with ample space for lectures, presentations, and storage to support a flexible layout. The storefront of the facility invites community members into Growing Power's market (cyan), which sells the sustainably grown produce from the growing spaces above. To support the entire facility, a back of house area (basement, not shown) includes space for shipping and receiving, a workshop for the creation of plant beds, and mechanical and electrical zones. All packages are connected by a grand hybrid switchback staircase to unite the operation in connecting the surrounding community to all aspects of Growing Power. The facility (fig. 16) is supported by a rigid steel frame (red), conditioned with a water source heat pump distribution system (blue), and features efficient LED lighting controlled by occupancy and daylight sensors (yellow).

Figure 16. Rendering of Growing Power facility

Building Enclosure Design

Figure 17. Virtual mockup of rainscreen

The selection of an enclosure impacts design decisions for all team members, as well as defines the image of the Growing Power organization to the surrounding community. Multiple options for an enclosure were considered during the planning and design phases using TBD's decision matrix (D1) to ensure the final selection supported project goals of flexibility, sustainability, economy, and community. After thorough analysis, a rainscreen assembly (SD|VII) was determined to be the most beneficial for the project needs, especially supporting Growing Power's goal of flexibility. The rainscreen system (fig. 17) consists of metal studs, an exterior fiberglass sheathing layer, moisture barrier, Z-furring channel, rigid insulation, and architectural façade panels. Numerous components of the rainscreen, such as the insulation, can be adapted based on specific locations' project conditions, supporting Growing Power's effort to use the facility in Milwaukee as a national prototype. Additionally, the enclosure is easily constructed (CM|9) and alleviates maintenance issues, like efflorescence and moisture penetration, associated with other systems. The rainscreen system created easier collaboration between the construction, structural, and mechanical partners since the wall could utilize multiple insulation R-values without added challenges to the respective systems.

Rainscreen Backup System

The rainscreen assembly permits a great deal of flexibility in the design of its structural backup, allowing for either CMU or steel stud backup depending on the specific load case of a certain location (Struc|13). The system designed for Growing Power in Milwaukee consists of steel studs which reduced the enclosure's backing weight, aiding in the economization of the structure's perimeter beams and slightly increasing the usable interior space. The specific arrangement of studs was verified using AISIWIN structural modeling, but the stud size, spacing, and strength is also a flexible aspect of the rainscreen's backup. The wind loads of Miami-Dade County pose a situation that requires consideration for high wind loads, but the flexibility of the rainscreen's backup allows the assembly to be an effective enclosure in all locations.

Moisture Protection and Insulation for any Climate

The differentiating characteristic of the rainscreen theory is to prevent moisture from penetrating the enclosure, which usually occurs due to an air pressure differential across the enclosure created by windy conditions. Positive pressure created outside the enclosure in these conditions results in moisture being driven into the wall cavity in more traditional enclosure systems. The rainscreen assembly eliminates the pressure differential across the exterior wall through an open joint assembly—

Equal Pressurization Barrier

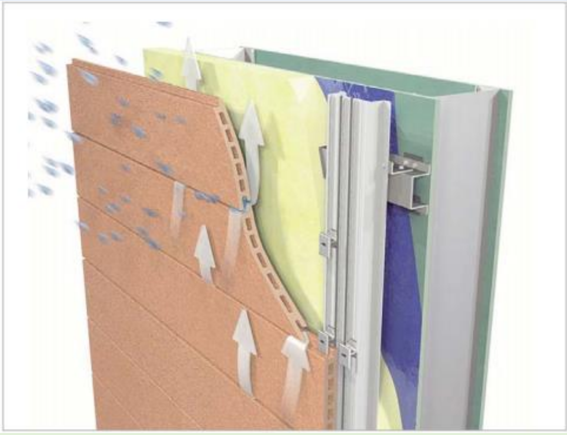


Figure 18. Equal Pressurization Barrier Section

The rainscreen system acts as a double line of defense in building moisture penetration. The architectural panels block driving wind, which equalizes pressure across the assembly and avoids pressure driven moisture penetrations into the facility (SD|VII) essentially leaving small gaps between façade panels. By allowing rain and air between the façade panel and the bulk of the rain screen's thermal and structural backup system, an equal pressure is achieved across the wall, which aids the traditional moisture barrier in keeping the Growing Power facility safe from moisture penetration, (fig. 18).

Additionally, the rainscreen's utilization of rigid insulation outside the fiberglass sheathing layer allows for the enclosure to be thermally efficient in any location. The R-value of the insulation can be designed for any specific location based on the heating and cooling loads of the region. To simulate the flexibility, TBD modeled the Growing Power facility in both Milwaukee and Miami with Trane TRACE 700, allowing the team to analyze the rainscreen's performance against the baseline ASHRAE 90.1, which proved that the rainscreen can meet the baseline in both locations with a simple upgrade of the rigid insulation layer. In fact, the assembly can greatly outperform the ASHRAE baseline in both climates (fig. 19, Mech|2).

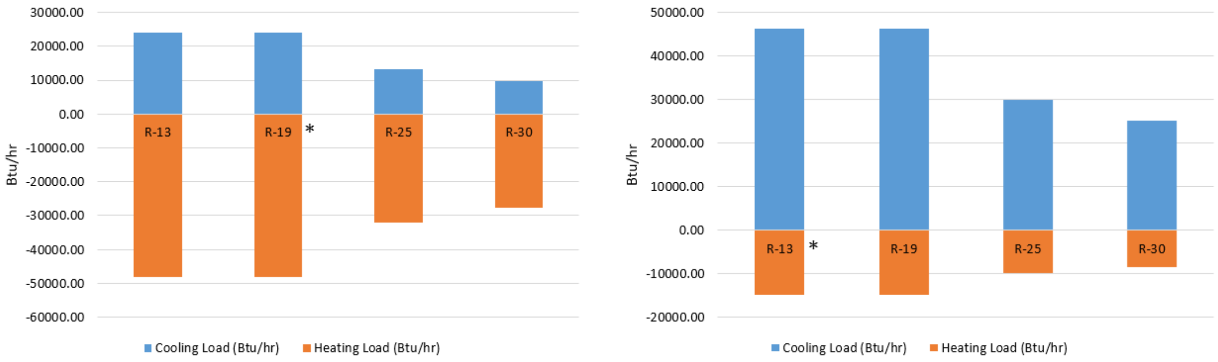


Figure 19. Heating and cooling loads of Milwaukee (left)and Miami (right)

ARCHITECTURAL CONTEXT

Although the rainscreen assembly provides many benefits through its equal pressurization theory and the flexibility of its backing system and thermal performance, a major impact of the facility's enclosure is its architectural style's perception by the surrounding community. TBD chose a terracotta façade panel for the majority of Growing Power's prototype in Milwaukee due to its natural composition and reflection of the community in which the facility is to be located. The terracotta panels also complement the sizing and placement of the glazing (fig. 20).

Analysis in DAYSIM and Trane TRACE 700 resulted in the selection of a glazing panel with an appropriate U-value and solar heat gain coefficient to reduce heat and cooling loads of the facility, supporting Growing Power's goal of an economically operable facility while maintaining the architectural integrity of the facility's façade (Elec|10). Furthermore, the team investigated the use of vertical fins on the east and west facades to block direct, low-angle sunlight from penetrating the facility's interior spaces and further reducing the heating and cooling loads, resulting in slightly reduced energy consumption.

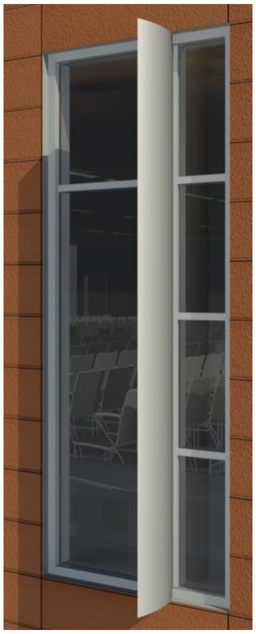


Figure 20. Façade complemented by glazing

GROWING SPACES

Growing Power's primary mode of community outreach and education is through the demonstration of sustainable growing techniques. Currently, this process takes place in multiple greenhouses on-site, which are vital in order for the organization to provide "important opportunities for individuals and communities to network with each other as they work in partnership to promote food security and environmentally sound food production practices." The success of the vertical farming facility depends significantly on the ability for all four greenhouses to operate efficiently. As a space for the growth and maintenance of plant life is also heavily reliant on various building systems, the greenhouses were a major point of integration throughout TBD's design process (SD|VIII).

ORIGINAL DESIGN

The original design for the Growing Power facility, contained in schematic documents provided to TBD (fig. 21), included four levels of rooftop greenhouses to support the organization's efforts to educate the community through demonstration of different growing techniques. While understandably an effort to provide an economic solution for Growing Power, the specified pre-manufactured greenhouses left TBD room for improvement. The rooftop greenhouses originally specified for the Growing Power facility rose to a peak height of 26 feet above the finished floor and consisted completely of exterior glazing. Through extensive research and analysis with various BIM tools, TBD made the decision to investigate redesigning the growing spaces to allow for optimum plant growth, a safe and flexible layout of aquaponic systems, reduced conditioning costs, and the creation of an iconic architectural statement when viewed from the surrounding community.

A MORE EFFICIENT GROWING SPACE

TBD's initial investigation of the specified pre-manufactured rooftop greenhouses suggested that the space contained an unnecessary volume of space to condition, an inefficient plant layout, and excessive glazing (Elec|5). Further research also indicated that the pre-manufactured greenhouses could not be reduced to a favorable height while maintaining the necessary fire rating to comply with IBC code (Struc|11). TBD discovered that a custom greenhouse structure could be designed that contained less volume and a more efficient glazing layout, allowing the mechanical system to more efficiently condition the space without negative impacts on the natural light reaching the plant beds within the space. Additionally, a custom-designed greenhouse structure provided the potential to take into account multiple locations' load cases, resulting in a more prototypable space.

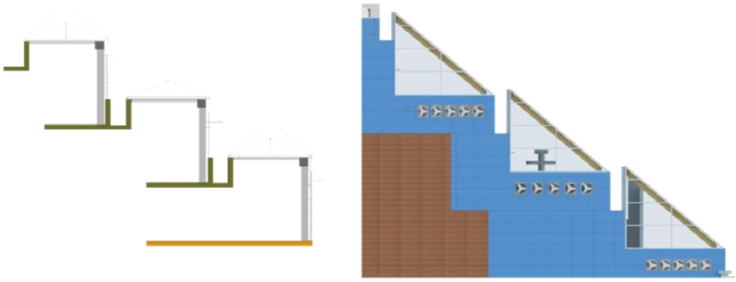


Figure 21. Elevation comparison of original greenhouse (left) and TBD custom design (right)

In order to minimize the roof structure's effect on the natural light obtained by the plant beds, multiple concepts were devised and analyzed simultaneously in DAYSIM and RAM to ensure both their structural integrity and their impact on natural light reaching the plant beds (Elec|6). While large steel elements could have been easily designed and implemented, their negative impact on the plants' lighting significantly hindered the greenhouse's ability to operate efficiently, detracting from Growing Power's goal of an economically operated facility to educate the community. The final design consisted of a glulam structure, sized as narrowly as possible to allow an optimum amount of light to reach the beds and provide a greenhouse design that is as conducive to efficient plant growth as possible. The use of heavy timber also alleviated the fireproofing concern regarding the greenhouse roof (Struc|11), and provided a unique architectural feature in the use of a sustainable material in the sawtooth profile of the greenhouses (fig. 21).

Further daylighting analysis proved that the original design contained excessive glazing that created a greater conditioning load than necessary. In order to increase the thermal resistivity of the greenhouses' walls without negatively impacting the plants' growth, the facility's rainscreen façade was carried from the main portion of the building to the east and west sides of the greenhouse, as well as partially up the south wall (REF).

A FLEXIBLE FLOOR LAYOUT

Another major goal for TBD was to provide Growing Power with the flexibility to install and demonstrate a variety of growing techniques throughout the rooftop greenhouses. An aquaponic system (Mech|3) was a targeted system and provided numerous challenges and constraints to the flexibility desired. The tanks designed for the aquaponic system account for a large load on the structural slab, requiring the slab to be designed for much higher live loads than normal (Struc|4) in order for the tanks to be placed anywhere in the greenhouse and to allow Growing Power the flexibility to place an aquaponic system in the greenhouse on any level.

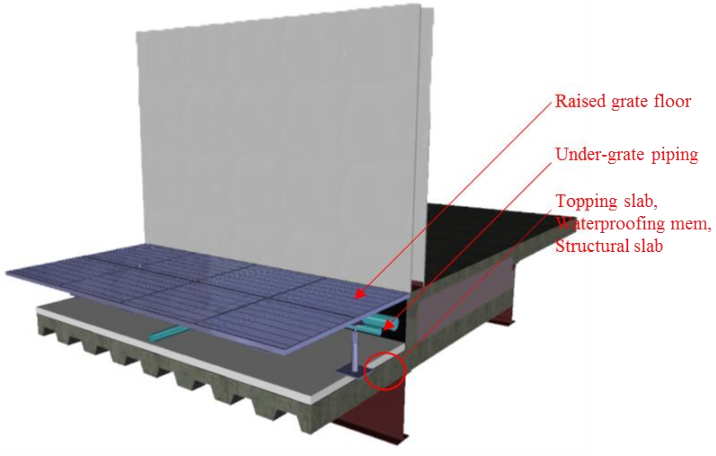


Figure 22. Detail view of TBD's greenhouse floor system

An aquaponic system also consists of a great deal of water piping at the floor level, posing a safety hazard for those exploring the space. As an educational tool for the community, safety was a vital consideration for the growing spaces. To reduce the amount of piping resting on the greenhouse floor, TBD designed a unique, grated floor system that allowed the pipe to be routed under the raised grate (fig. 22, SD|X). Coincidentally, the plenum below the floor grate also created space to run conduit and other mechanical piping, removing as many obstructions as possible from blocking the plants' sunlight.

As the greenhouses were designed to house numerous systems containing vast amount of water, water leakage was a major consideration that needed to be taken into account throughout the design's development. After investigating multiple options, a solution was designed providing two layers of defense against water penetration into the Growing Power facility (fig. 22, Struc|12).

EFFICIENCY THROUGH AN INTEGRATED APPROACH

While the introduction of pre-manufactured greenhouses could provide a much lower up front construction cost, their implementation left room for improvement with respect to the project goals of community education, flexibility, and long term economy. TBD's integrated design approach led to the creation of a greenhouse design that more effectively supported those goals. Through the definition of an Integrated Design Package consisting strictly of the growing spaces on each level, TBD focused efforts of all team members on the greenhouses at once, devising a solution that benefitted all design partners, but most importantly Growing Power. The use of various analysis tools was essential in order to balance the needs of each building system and the plant life within, and the communication facilitated by collaborative planning sessions provided pertinent information to all team members as the design developed, allowing TBD to design a flexible space to house numerous types of growing systems, while efficiently conditioning the space and quickening the facility's watertight milestone.

GATHERING SPACE

Growing Power exists not only to grow food, but also to grow the local community in which the facility and organization are situated. A key support to the goal of community outreach and education is the Gathering design package, highlighted by the completely open plan Gathering Space located on the facility's second floor.

ORIGINAL DESIGN

The schematic documents provided to TBD included the aforementioned space on the second floor of the Growing Power facility. However, while the original plan was spacious enough to host a large gathering of people, the columns in the plan created a visual and physical obstruction of the space (fig. 23). TBD fully agreed with the placement of the gathering space in the context of the facility—the second floor is slightly less public than the market below, but much more so than the private education and administrative spaces above. However, in order to support Growing Power's goal of community involvement and outreach, TBD identified an opportunity to improve upon the original design for the gathering space by removing two interior columns (SD|XII). The removal of the interior columns resulted in more usable space for seating in a large presentation setting, as well as uninterrupted views to those seated farthest from the presenter. The team proceeded with the decision to support Growing Power's goal of community with the understanding that developing a successful design would take great effort by all partners and a highly integrated approach.

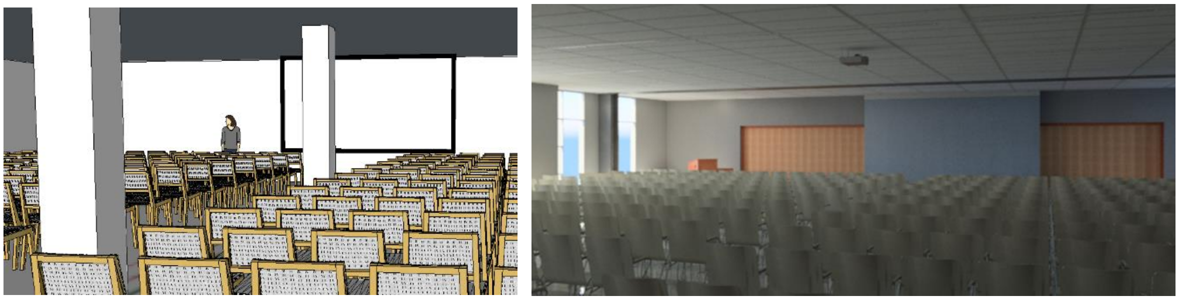


Figure 23. Comparison of original design for Gathering Space (left) and TBD's open plan (right)

TBD IMPROVEMENTS AND CHALLENGES

By focusing the entire team on the Gathering Space design package at the same time, communication was facilitated through the use of collaborative planning (p. 3). This ensured that the design process went as smoothly as possible by identifying key points of interaction that needed to occur in the process. The integrated planning session determined that the first step of redesigning the open Gathering Space was to begin with a discussion of installation sequencing and shipping logistics to ensure that any structural element that was designed supported the construction sequencing plan, or that the plan could be altered to make any necessary accommodations.

In the scheming phase of the Gathering Space's development, the team convened to discuss options to overcome the challenge of eliminating the two interior columns. This discussion resulted in numerous design guidelines for all systems to be integrated within the plenum space, such as the idea that the structural members needed to be shallow enough to allow duct to pass

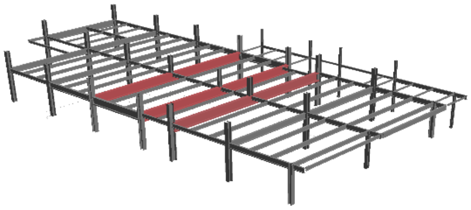


Figure 24. Transfer girders (red) open the Gathering Space floor layout

between the steel and the space's ceiling, or deep enough to safely cut through the members.

Figure 25. MEP linear scheme to coordinate with girders

Through the extensive use of RAM modeling, TBD determined that the best option to transfer the facility's load to the exterior columns was through the utilization of three transfer elements, (fig. 24, Struc|7). With the understanding that these elements had the potential to consume most of the plenum space, TBD designed a linear scheme of mechanical and electrical equipment and fixtures that fit between the locations of the three transfer elements. The size of some mechanical equipment posed a potential challenge with the reduced plenum space, so the team determined that space along the exterior walls could house the heat pumps feeding the space.

With a schematic layout devised, TBD moved forward developing the integrated design. Again the targeted approach of the team proved extremely beneficial, as all partners modeled their designs simultaneously, with the structural layout slightly leading the MEP system layout. Coordination views developed in Revit (fig. 26), also proved invaluable to the team in the modeling process, as they allowed all partners to author their design within the context of the entire, integrated space. Continuous coordination by all design partners significantly reduced the number of conflicts that needed to be resolved in coordination sessions (SD|VI).

The decision to open up the space also resulted in challenges to be overcome during the construction process. Structural members of the depth and weight utilized in the Gathering Space are not rolled at all steel mills, and lengths exceeding that of a standard semi-permanent trailer require permits to travel on various highways, presenting the potential for significant added costs. Additionally, the massive members posed a challenge in that they were preliminarily identified as a potential to be the project's critical pick (CM|9). However, extensive research resulted in solutions to all challenges, as TBD identified a mill in Arkansas and fabricator near the Milwaukee site, with a path routed by a shipping partner that resulted in a nominal transportation fee (CM|9).

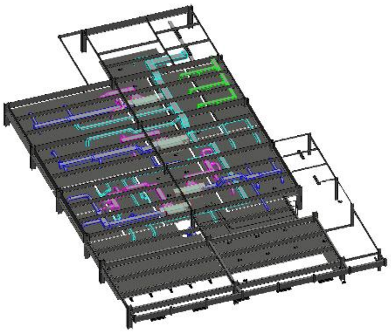


Figure 26. Coordination view in Revit

EFFICIENCY THROUGH AN INTEGRATED APPROACH

Utilizing TBD's integrated design approach and BIM technology, a solution beneficial to all designed systems and the building as a whole was created. While the original design contained in schematic documents was undoubtedly a simpler option to construct and an attempt to provide a more economic design, TBD determined that its design left room for improvement, specifically in its contribution to the space's community education aspect. While altering the design to feature a completely open second floor created multiple challenges, the strategies implemented by the team allowed a successful design to be achieved. Through the definition of a specific design package, TBD focused all design partners in the space at once. The utilization of collaborative planning facilitated important discussion regarding the interactions between various design systems, resulting in such ideas as making the transfer elements either deep enough to cut through or shallow enough to run air distribution between the steel and the ceiling. The end design's linear lighting and mechanical scheme (fig. 25) was the result of a defined "coordination view" in each design partner's virtual model, allowing the team to continuously coordinate the space to alleviate any possible issues, or catalyze discussion among the team.