PENN STATE AE SENIOR THESIS 2011 - 2012

SENIOR THESIS FINAL REPORT

Technical Analysis Areas and Breadth Topics

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Construction Management

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RIVER VUE | NEW LUXURY APARTMENTS RENOVATION| PITTSBURGH, PA

RIVER VUE APARTMENTS

New Luxury Apartments Renovation

300 Liberty Avenue, Pittsburgh, PA 15222

ARCHITECTURAL FEATURES

River Vue Apartments is the innovative reuse of the former Commonwealth of Pennsylvania State Office Building that was constructed in the 1950s.

- The building reflects a more modern architectural style.
- Modern materials, such as metal and marble panels, are a consistent theme throughout the architectural features.
- A new bronze-colored window system will become a key feature.

CONSTRUCTION

- The construction process will begin with the demolition of all the existing walls and MEP systems.
- As the site work begins for the new parking garage ramps, new utility lines and patios will be constructed.
- During site work, interior features will be installed starting on the basement floor and moving up to the sixteenth floor.
- Turnover for the basement through fifth floors will be available in April 2012, and the entire building will be turned over by October 2012.

STRUCTURAL SYSTEM

- The existing steel superstructure and concrete floors are preserved.
- New additions include upper and lower parking garage ramps, bracing steel frames, and in-fills needed at the existing elevator shafts not used for building transportation purposes.
- For the new balcony slabs, the existing slabs on deck will be removed and replaced with 5-5/8" normal weight concrete slabs with 1-½"x 20 GA composite deck.

MECHANICAL SYSTEM

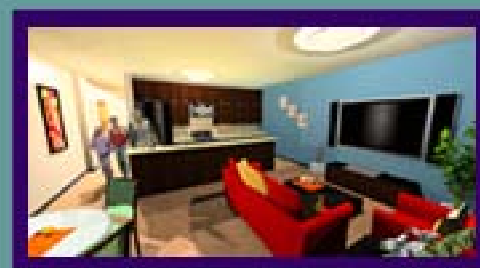
- The single air-handling unit will feed the mechanical chase to each floor's main corridor, which will run up one of the former elevator shafts.
- Two 200-GPM boilers will be installed, and a 1024-GPM heat exchanger will collect residual heat and conserve energy.

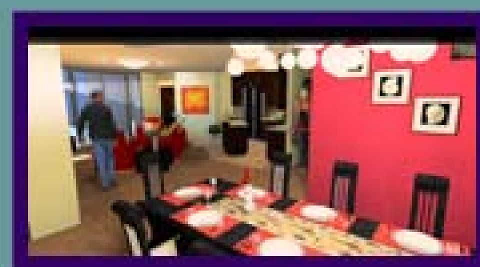
ELECTRICAL SYSTEM

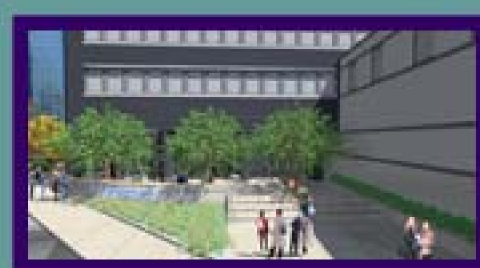
- The electrical system will operate on a three-phase 120/208-V system.
- It will use the existing 300-kW generator and emergency diesel generator.
- Electrical power will be brought into the building's 2000-A switchboard from a ground bus duct and will be distributed up through the building.

PROJECT INFORMATION

Gross Building Area: 295,000 SF
Number of Stories: 16 stories above grade and basement
Number of Apartment Units: 218 units
Total Project Cost: $28,248,910
Construction Dates: June 13, 2011 to October 2012
Project Delivery Method: Cost Plus Construction Contract







PROJECT TEAM

Owner: River Vue Associates, LP
Architects: Design 4 Studio, Inc. and Intelligent Design Group (IDG), LLP
General Contractor: Turner Construction Co.
Structural Engineer: Whitney Bailey Cox & Magnani, LLC
Civil Engineer: Gateway Engineers
MEP/FP: Claitman Engineering Assoc., Inc.
Hazmat: L. Robert Kimball & Assoc., Inc.

River Vue Turner

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River Vue Associates, LP and Millcraft Industries, Inc.

My Family and Friends

Executive Summary

The Senior Thesis Final Report is intended to explain the four technical analyses implemented on the River Vue Apartments (River Vue) project. The theme for this senior thesis capstone project is to incorporate value engineering techniques, such as energy conservation and overall building quality, into River Vue's design and construction that are a financial benefit to River Vue Associates, LP (RVA).

<u>Technical Analysis #1: Photovoltaic Glass Window System Implementation</u>

River Vue is scheduled to achieve LEED Certification upon completion. However, very few sustainable design and energy production techniques were used. The goals of this study were to develop a photovoltaic (PV) glass window system and to determine the financial and energy feasibility of incorporating it into the existing electrical system. This analysis showed that Pythagoras Solar's PV glass unit (PVGU) was not a recommended investment for RVA because the energy savings would not allow them to receive the initial cost of the system back within the PVGUs' 25-year lifespan.

<u>Technical Analysis #2: Green Roof System Implementation</u>

As previously stated in Technical Analysis #1, very few sustainable design techniques were used. The goals of this study were to develop a resident-accessible green roof system, analyze the structural impact of the load-bearing green roof, and determine the financial feasibility. This analysis showed that the LiveRoof® Maxx System would be a beneficial investment to RVA. A structural analysis revealed that the existing roof would need upgrades to accommodate the green roof's weight. A feasibility study showed that a rent increase was needed to accommodate for the yearly roof maintenance and loss of third-floor apartment costs.

<u>Technical Analysis #3: 3D Laser Scanning Technology Implementation</u>

Several constructability challenges occurred on the River Vue project including as-built drawing inconsistencies and coordination issues. The goals for this study were to analyze the effects of using three-dimensional (3D) laser scanning technologies to evaluate existing building conditions and to determine the financial feasibility. Even though 3D laser scanning technology could be very beneficial during the preconstruction and construction phases, from a cost standpoint, the results show that implementing this technology is not feasible for RVA.

<u>Technical Analysis #4: Lighting Occupancy Sensor Control System Implementation</u>

At the PACE Roundtable event, industry professionals discussed many key topics about energy management, a critical industry issue, and its techniques for residential buildings like River Vue. The goal for this technical analysis was to research new ideas for electrical and lighting systems that are energy efficient, but simple enough for the occupants of the building to use the system correctly. This analysis showed that Sensor Switch's WSD-PDT is a recommended investment. The feasibility study, with the rebates/incentives in Pittsburgh, PA, showed that the system would recover its initial cost within 5 ½ years of the occupancy sensor's 15-year lifespan.

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1.0 Project Overview

1.1 Introduction

River Vue Apartments (River Vue) located in Pittsburgh, PA, is the innovative renovation of the former Commonwealth of Pennsylvania State Office Building. Across from Point State Park, in an area commonly, referred to as the Golden Triangle, these new luxury apartments will offer its residents best views of the city. The existing building was constructed in the 1950s and renovated in the 1980s. Through the simplicity and clarity of its form, it reflects a more modern architectural style. Modern materials, such as metal and marble panels, are consistent architectural features throughout this building. Since the building's project is mainly an interior renovation, the metal and marble panels will be conserved. Table 1 describes the general information and project details for River Vue.

Table 1: General Building Information

Building Name	River Vue Apartments
Location	300 Liberty Avenue, Pittsburgh, PA 15222
Construction Type	Renovation, 1B
Building Occupant Name	RVA
Occupancy Type	R2 Private Apartments S2 Parking A2 Coffee Shop A3 Party Room & Recreation Room
Gross Building Area	295,000 SF
Number of Stories	16 stories & basement
Number of Apartment Units	218 units
Construction Dates	June 13, 2011 – October 2012
Total Project Costs	$28,248,910
Project Delivery Method	Design-Bid-Build

Looking at the building's functional interior components, River Vue will include a two-story, interior, valet-parking garage on the basement and first floors of the building. This parking garage will have the capacity for 208 parked cars by the utilization of mechanical double-stacking parking lifts. Also, all of the new mechanical and electrical systems for the entire building will occupy the remaining space on the basement floor. Even though most of the first floor is engrossed by the parking garage, several other spaces will complete the function of this floor. These spaces include the new building lobby with elevator access, a small retail space of approximately 1,900 SF, a sales office, and other required accessory areas such as tenant mail boxes for the apartment residents.

The second floor improvements will consist of 18 one-to-two bedroom apartments with a common elevator lobby and corridor connecting the two main egress stair towers. Also, a building party/media room and a small fitness center will be provided for the apartment residents. Floors three through fourteen will consist of 15 one studio and one-to-two bedroom apartments with a common elevator lobby and corridor connecting the two main egress stair towers. A mix of flats, walk-up and studio apartments, and one-to-three bedroom apartments will utilize the fifteenth and sixteenth floors. On these upper floors, each unit will have a private exterior inboard balcony.

There are also several functional exterior aspects to this building. The redesigning of the front plaza will provide residents and retail customers a place to sit and enjoy the outside environment of Pittsburgh. Also, changes to the back of the building will occur to provide access to the valet-parking garage.

1.2 Project Location

The site of River Vue is located in the city of Pittsburgh, across from Point State Park. The aerial image below, Figure 1, shows the location of the River Vue project circled in white. Situated on a corner lot, River Vue's site is located next to and across from several existing structures including: the Pittsburgh Post-Gazette building (1) , the Wyndam Grand Pittsburgh Downtown Hotel (2), and the Gateway Center Parking Garage (3).

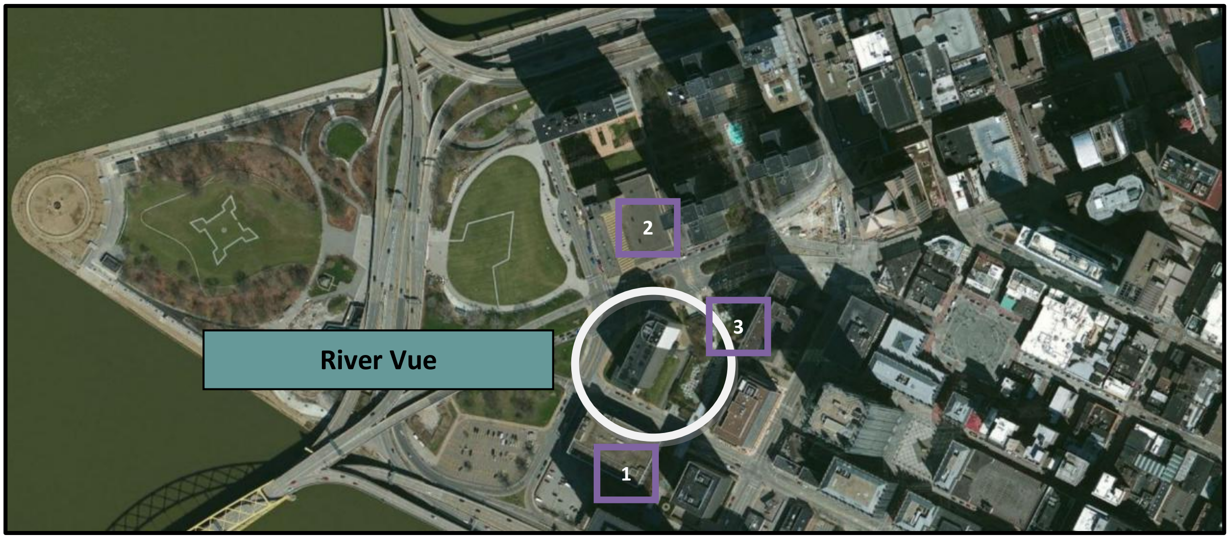

Figure 1 – Arial View of Project Location from Flash Earth

Since it is located in an urban area, the River Vue's construction site's space is limited. Therefore, no parking is available onsite. Project personnel and labor workers are able to park in the Gateway Center Parking Garage or in any other parking garages and parking areas located throughout the city. In addition, one of the main issues with the project's site is that it is located at 300 Liberty Avenue in downtown Pittsburgh, which has some of the heaviest vehicular and pedestrian traffic. Shown on the Existing Conditions Site Plan in **Appendix A**, public pedestrian traffic is the main concern because two sections of the sidewalk around the perimeter of the construction site are closed to the public. The closing of the sidewalks is to ensure that all pedestrians are safe when commuting past and around the outside of the site. Regular public vehicular traffic is not a main concern; however, the metered parking spaces on the south side of the building are closed as well due to construction site access and deliveries.

1.3 Client Information

For the River Vue project, the owner is River Vue Associates, LP (RVA), located in Canonsburg, PA. They are an affiliate of Millcraft Industries, Inc. (Millcraft). Since information about RVA is unavailable at this time, this section of the technical assignment will include information about Millcraft

According to the company's official website, "Millcraft Industries, Inc. is a Pittsburgh-based real estate developer and management company with a fifty-year history of successfully creating and maintaining prominent large-scale office, retail, and mixed-use developments. Millcraft's Real Estate Division is a multi-million dollar operation, which has participated in and directed a variety of real estate ventures, including sustainable mixed-use projects, historical renovations, commercial office buildings, retail centers, hotels and restaurants, and residential development" ("Our Company" et al.).

In the Pittsburgh market, apartment buildings are properties in high demand. Therefore, the main reason Millcraft is building this facility is to develop a residential apartment building in one of the most convenient locations in the city of Pittsburgh. The company is expecting young professionals and families to rent the downtown apartment units which will offer its residents one of the best views of the city.

There are several quality, schedule, cost, and safety expectations for the project.

Quality: One of the main concerns for Millcraft is the quality of the finished building. As a company, it is important to develop a project to the highest quality in looks and function. For the new look of River Vue, new operable bronze-colored panels will be used for the window system and new recessed balconies on the top two floors will be installed. For the function of the new building, tenants will have apartment units that average roughly 850 SF and other amenities such as a fitness center, media and recreation room, retail shops, and valet parking. In addition, new mechanical, electrical, plumbing, fire protection, and roofing systems will be installed into the building to provide the highest quality of MEP/FP building systems.

Schedule: The construction of River Vue started on June 13, 2011. Pre-leasing for potential tenants began in early fall 2011. Since occupancy into the new apartment units is phased, the schedule of the project is another main concern for the owner. As construction is completed per floor, in April 2012, roughly 30 apartment units will be ready for occupancy starting with the lower floors. If the schedule of construction is changed or delayed, it affects the move-in periods for the tenants and overall completion date of the project. For instance, the schedule can be delayed because of sequencing issues for the mechanical, electrical, and plumbing systems and the interior finishes of the individual apartment units. These issues are of interest to the owner since full completion and occupancy of the River Vue building is expected to be in October 2012.

Cost: Since cost is a concern, it is necessary to develop a budget that meets the requirements for Rive Vue. Millcraft expects to spend roughly $40 million on the project; however, the total project cost, estimated by Turner Construction Company (Turner), is to be approximately $29 million.

Safety: For all of Millcraft's projects, safety is expected to be maintained during the construction and the permanent use of their buildings. The owner of River Vue has trusted Turner to develop a safety plan for the construction site that follows all necessary regulations and codes. Turner's main goal is to keep personnel onsite and pedestrian and vehicular traffic around the site safe at all times.

For Turner, the key to completing the project to the owner's satisfaction is to execute Millcraft's quality, schedule, cost, and safety expectations and to keep them in mind as the main priority.

1.4 Project Delivery System

The project delivery system is a HUD-92442-A Cost Plus Construction Contract. RVA holds different contracts with three of the main project team companies and a contract with a mechanical and hydraulic engineering company for the hydraulic parking car-lift system. RVA holds a cost plus construction contract with Turner to provide general construction services. Also, for the parking car-lift system, RVA has an assumed lump sum contractual relationship with Harding Steel, Inc. based on their interactions. Even though these main contracts are held with RVA, there is communication between the three main project team companies. This communication system is shown in Figure 2 below.

For the new luxury apartment renovation's design, two private architectural firms, Design4Studio, Inc. (D4S) and Intelligent Design Group, LLP (IDG), were hired to perform the design in contract with the owner. These firms have developed a joint venture. It is a special-purpose partnership that combines the resources, assets, and skills of the two firms. The two architectural firms' lump sum contracts with RVA include the AIA Document B181-1994 "Standard Form of Agreement between Owner and Architect for Housing Services," including the HUD Amendment. In addition, the architects have assumed lump sum contracts with the structural engineers (Whitney Bailey Cox & Magnani, LLC), MEP/FP engineers (Claitman Engineering Associates, Inc.), and civil engineers (Gateway Engineers). These lump sums are agreements to perform the design work for a fixed price regardless of the cost. These engineers have a strong communication system between each other and the architects for coordination.

Since they are completely removed from the design process, Turner was not active in the project until the construction phase. After the competitive bidding period was over, Turner was awarded the project to only provide general construction services. They are not providing construction management services because there is no construction manager for the River Vue project. To RVA, Turner assumes "full responsibility for the construction of the project within the specified time and within full accordance with the contract items. Coordination and direction of all the tasks and activities of the various subcontractors and agencies involved with the construction phase are other distinctive functions of the general contractor" (Clough, G. Sears, and S. Sears 12-13).

In addition, Turner hires various qualified specialties contractors to complete this particular work. This work includes concrete, earthwork, electrical, masonry, mechanical, and other types. Even though Turner is performing their own concrete work for the interior metal deck in-fills, Brayman Construction Corporation and Modany-Falcone, Inc. are performing the project's other concrete work. Brayman

Construction Corporation is placing the concrete for the exterior foundations, and Modany-Falcone, Inc. is placing the concrete for site paving. There is not a contract between the subcontractors and the owner. Since information is not available at this time, it is assumed that these subcontractors have lump sum contracts with Turner based on their interactions.

For Turner, maintaining insurance and bonds with their chosen subcontractors is very important. The subcontractors must maintain All-Risk Builder's Risk Insurance, and they must hold Commercial Automotive Liability Insurance, Commercial General Liability Insurance, and Workers' Compensation and Employers' Liability Insurance. Also, these subcontractors, along with Turner, are responsible for performance and payment bonds. These types of bonds "primarily act for the protection of the third parties to the contract and guarantee payment for labor and materials used or supplied in the performance of construction" (Clough, G. Sears, and S. Sears 174 and 178).

In Figure 2, the project delivery system and the contract types are appropriate and logical for the River Vue project. Since its complexities lie in demolition, abatement of asbestos, and installation of new building systems, it is very important to have a general contractor that is experienced in the construction industry. Turner's reputation as one of the nation's leading construction companies and their experience with developmental construction in the Pittsburgh area makes them the right candidate for the new luxury apartment renovation project. Also, the qualified subcontractors they have chosen to perform the specialties work are appropriate as well.

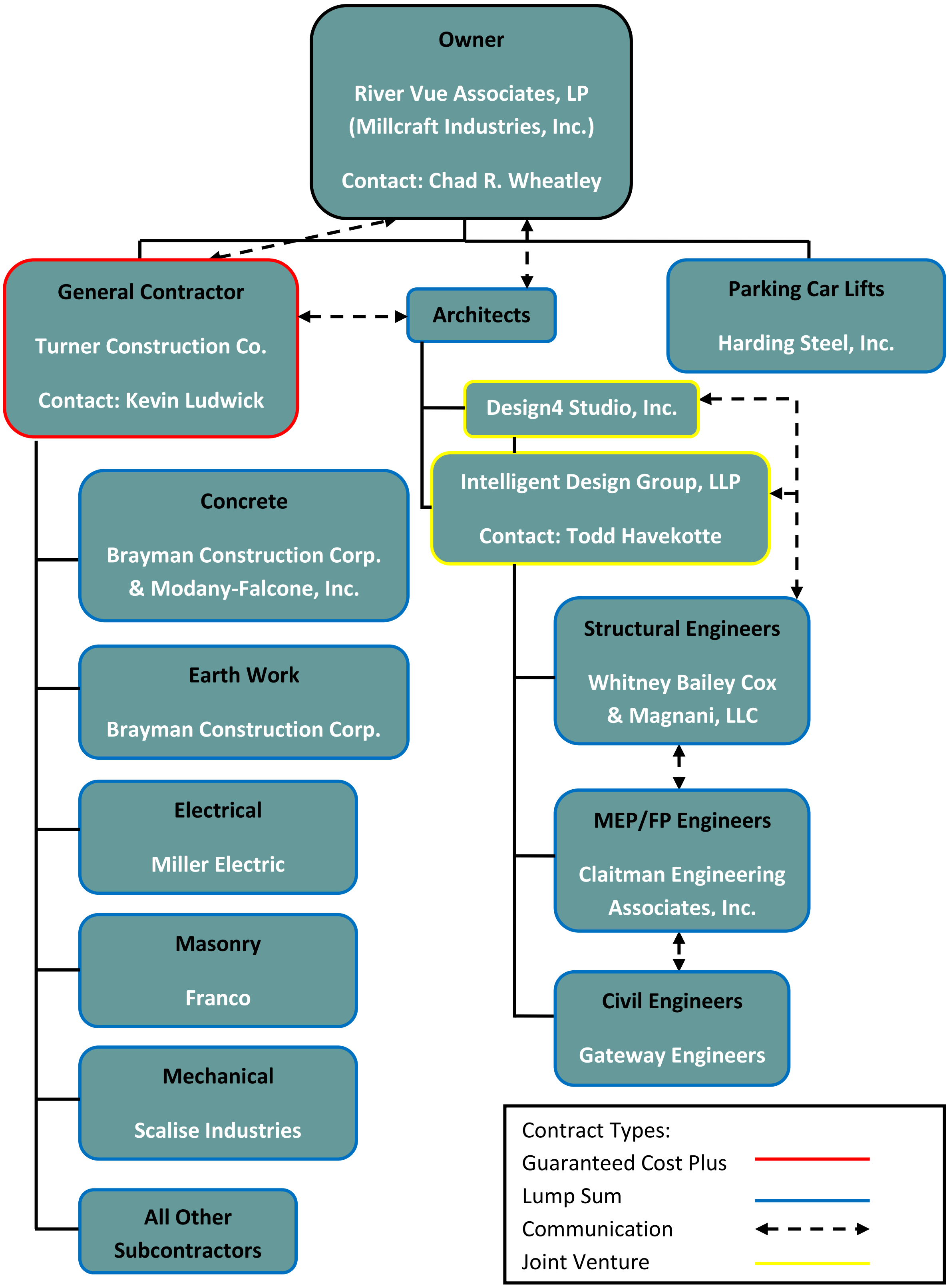

Figure 2: Project Delivery System for the River Vue Apartments Project

1.5 Project Team Staffing Plan

According to Turner's official website, their Pittsburgh office's goal for their projects is to "provide their clients with the highest level experience, staff, and resources in the construction industry" ("Pittsburgh Building the Future" et al.). With this goal in consideration, Turner develops the staffing plans for their projects based on the experiences of the staff members and the project's size. Figure 3 shows the staffing plan diagram for the River Vue project. Since the staffing plan developed for this project is smaller compared to other projects of the same size, it reflects the level of complexity of the project.

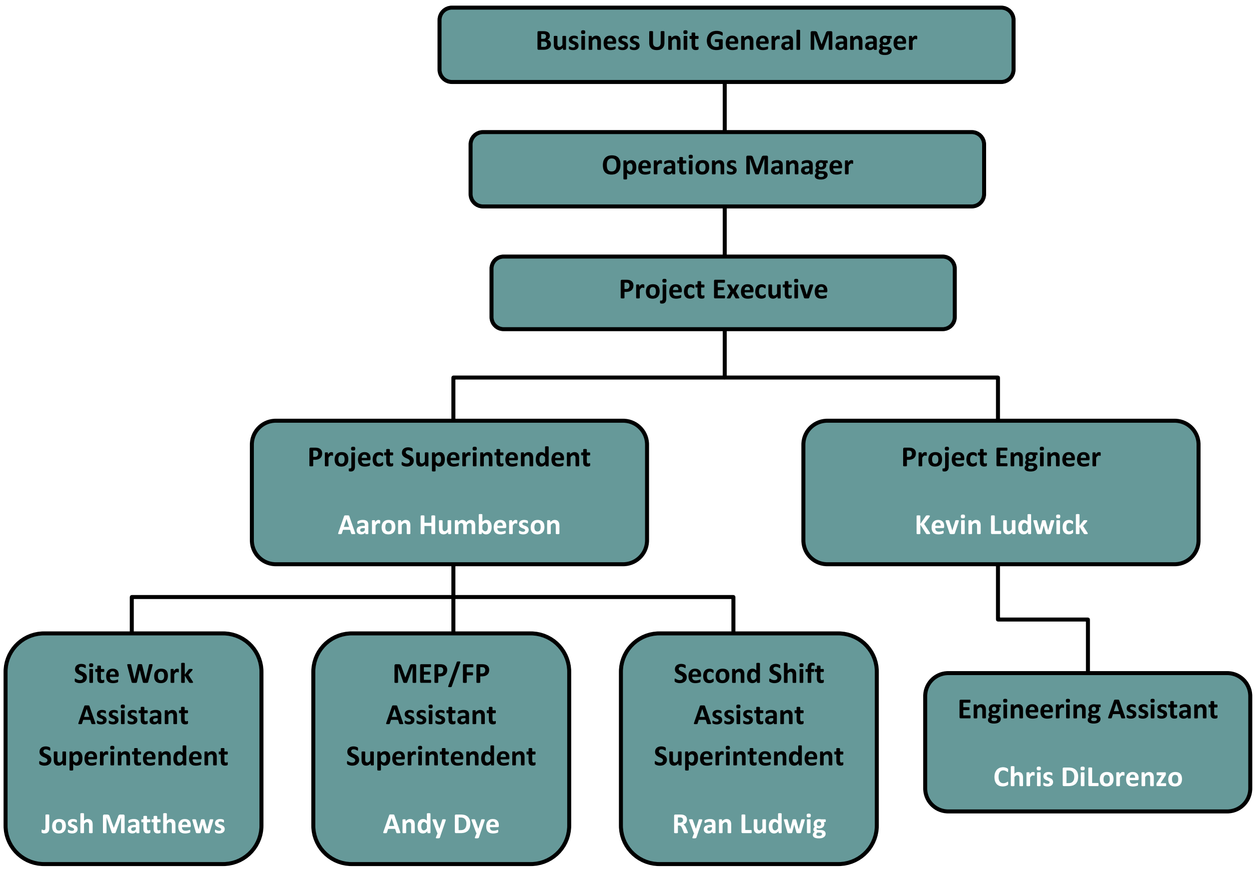

Figure 3: Turner Construction Co. (General Contractor) Staffing Plan for River Vue Apartments

The staffing plan diagram starts with the management staff, which includes the business unit general manager, operations manager, and project executive. These staff members are usually assigned several projects at a time. Therefore, their offices are located at the main Pittsburgh office headquarters to ensure that they are available to discuss and work on their other projects. However, they visit the River Vue project's site on a regular basis to track its progress and hold progress, safety, and conflict resolution meetings with the field staff.

For this particular project, the field staff includes the project superintendent, site work assistant superintendent, MEP and FP assistant superintendent, second shift assistant superintendent, project engineer, and engineering assistant. These staff members take care of all the components that are a part of the construction progress, including major construction issues that may occur onsite. Therefore, their offices are located on the jobsite usually in onsite trailers. However, while excavation work is occurring, Turner's field staff is occupying the building's future retail space for their office space. When the retail space needs to be renovated, the field staff will move into onsite trailers. In addition, any daily safety related issues that occur during the construction process can be handled by the experienced field staff members.

2.0 Design and Construction Overview

2.1 Building Systems

2.1.1 Demolition

Before the construction process of River Vue began, demolition throughout the whole existing building needed to be completed. There are several building elements and materials that needed to be removed. These elements and materials include the existing interior walls to accommodate the new layout, walls that were flushed with existing adjacent surfaces, floor materials including adhesives and tack strips, doors, door frames, door hardware, ceiling tile, gypsum-board bulkheads and ceilings, and light fixtures. A view of the interior demolition is shown in Figure 4.

Figure 4: Interior Demolition on 1st Floor

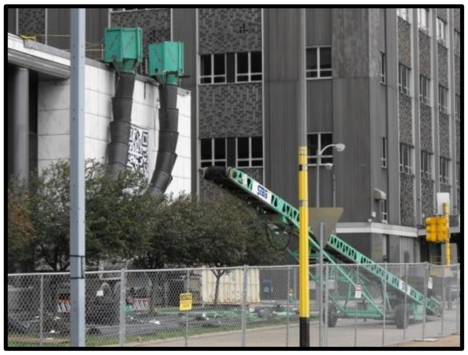

Figure 5: Lower Roofing System Demolition

More elements and materials included casework, toilet partitions, three existing elevators, existing stairs, and railings. Also, all of the mechanical, electrical, plumbing, fire protection, roofing, and window systems' elements were demolished for the installation of new systems. A view of the lower roofing system demolition is shown in Figure 5. In addition, since the existing structure is the only element that remains, shoring and bracing was provided to prevent any displacement of structural elements, shifting, or collapse. After the removal of these materials and building elements, the disturbed areas were repaired. The disturbed floors, walls, and ceilings were repaired with finishes to match existing conditions. Paint or any finishing adjacent surfaces eliminated any and all visible evidence of modification during the demolition process.

2.1.2 Environmental Hazards Abatement

Hazardous material consultant L. Robert Kimball and Associates, Inc. determined all of the asbestos containing materials and other environmental hazards existing within the building. The other environmental hazardous materials consist of fluorescent lamps thermostats, thermometers and switches containing mercury, chlorofluorocarbons in refrigerator/HVAC units, electronic equipment, lead based paints, oils, and lubricants. It is extremely important to correctly remove and dispose of these hazardous materials. For example, if these materials are not removed and disposed of correctly during renovation, they can release airborne asbestos fibers into the air. These fibers can cause harm to the labor workers or to future tenants.

2.1.3 Structural System

Once demolition and asbestos abatement were completed, the existing structure of the building is the main building component preserved and reused for the renovation of River Vue. Therefore, this section of the report will analyze the existing structural steel frame system and new additions to the structural system.

Existing Structural Steel Frame System: The existing structure of the building is composed of a steel superstructure with concrete floor slabs. In detail, the typical structural steel column sizes used throughout the building are W8s, W10s, and W14s with the weight ranging from 43 lb/ft to 264 lb/ft. For the structural steel beam sizes, the typical sizes are W8s, W10s, W12s, W14s, and W16s with ranging weights. Also, W24s and W30s are the steel beams that are part of the roofing system. With ASTMA992 steel specifications, the W shaped beams and columns are designed to have the yield strength of FY = 50 kips/in^2.

Concrete Floor Slab Breakdown: For the existing second floor, the concrete slab system is 5 $^5/_8$" thick. Low roof construction consists of 1 ½" x 20 GA wide rib galvanized Type B roof deck. In addition, for the existing third through fourteenth floors, the concrete slab system is 5 $^5/_8$" thick.

For the fifteenth floor, the existing concrete slab system is 5 $^5/_8$" thick. To accommodate for the new balcony slab, the existing slab on deck will be removed and replaced with the new 5 $^5/_8$" normal weight concrete slab with 1 ½" x 20 GA composite deck. For the sixteenth floor, the existing concrete slab system is 5 $^5/_8$" thick, and the new stair system will include hangers. After cutting the existing steel required, full "T" double shear connections will be applied to the new steel. The existing slab on deck will be removed and replaced with the new 5 $^5/_8$" normal weight concrete slab with 1 ½" x 20 GA composite deck in order to accommodate the new balcony slab.

New Structural Steel Additions: The additions to the structure are the new bracing steel frames and the in-fills needed at the existing elevator shafts. These frames will not be used for building transportation purposes, and the new brace frames will consist of W17x21.5s for each set between the different column lines. One brace frame will connect two columns that are 10 ft apart, and the other braced frame will connect two columns that are 26 ft apart. Each braced steel frame will be attached together in the middle with a required ½" filler plate, and they will be connected to the columns with four ½" gusset plates. In addition, two of the former elevator shafts are used for mechanical and electrical routing and another elevator is in-filled with concrete. Therefore, steel was needed for this additional load. In the elevator lobby area, all new steel beams to support the concrete in-fill are W8x17s and designed to have the yield strength of FY = 50 kips/in^2.

Crane Details: For the River Vue project, numerous hydraulic truck cranes will be utilized throughout the duration of the project for new additional steel placement as well as for other aspects of the construction. The cranes will be brought in on an as-needed basis for one-day operations, and they will be placed on the east or west sides of the building. These operations include removing the old chillers from the basement, installing the new steam vault at the north end of the site, moving any rooftop equipment to the roof, and placing any large equipment that might be installed on the upper floors. Since the size and model of the cranes used on the site is based on the lifted materials' weights and lifting locations, this section of the report discusses the assumed crane size and model that reflects the given information. All of the crane information was found on Manitowoc Cranes' official website ("Grove Products" et al.). The assumed crane model is a Manitowoc Grove GMK4100B hydraulic truck crane with a rated capacity of 100 U.S. ton and a main boom length of 167 ft.

2.1.4 Cast-in-Place Concrete

Cast-in-place concrete was used for two main parts of the renovation. The first main part was the new basement and first floors garage ramps located on the east side of the building. Since this concrete was exposed, work formwork was used to ensure continuous and smooth forms. The elevators' concrete in-fills required cast-in-place concrete that utilized paneled formwork. For these parts of the construction, the formwork was designed and constructed to maintain its form and to be used within its tolerance limits outlined in ACI 301-05. Also, the concrete was placed using a concrete truck and pump. Therefore, the formwork had to accommodate the pressure exerted by the pump.

2.1.5 Mechanical System

Heating, Ventilation, and Air Conditioning (HVAC): For the entire mechanical system of the building, the major component is the single 26,300 CFM air-handling unit located on the roof. Hidden behind three new curved and perforated stainless steel panels, the unit will serve two supply risers and two exhaust risers. Also, it will be feeding the mechanical chase located to the east of the unit. In one of the former elevator shafts, this chase will run all the way through the building. From the chase, it will break out and feed each floor's main corridor.

Plumbing: The existing mechanical system components, such as chilled and hot water supply and return piping, will be demolished and replaced. To heat the water for the building, two 200 GPM boilers will be installed with a connection to pumps that will distribute the water to the various spaces, especially the 218 apartment units. Each apartment unit is handled by an individual heat pump. Also, a 1,024 GPM plate heat exchanger will collect residual heat and conserve energy for the mechanical system.

Fire Protection: Located at the northwest corner of the building, the fire service entrance will serve the building from one standpipe (Stair A). Each floor will be fully installed with dry sprinklers spaced evenly throughout the areas. The pressure of the dry-pipe system will be maintained from the fire pump located in the fire pump room on the basement floor. Also, 6" dry standpipes will be installed in each stairwell, and fire alarms connected to the emergency power system will be placed throughout the building.

2.1.6 Electrical System

During the first phase of construction for the project, all of the existing electrical work was demolished. However, the existing 300-kW generator and emergency diesel generator remain in their current location on the basement floor. These power feeders are used for temporary power during the construction phases. In addition, the electrical system will operate on a three-phase 120/208-V system, powered by the main electrical room on the basement floor. Electrical power will be brought into the building's 2,000-A switchboard by Duquesne Light Company, an electric service provider, at a voltage of 208 V from a ground bus duct located on the north side of the building. After serving the 100-A, 225-A, and 400-A panel boards, the service will split for house power and tenant service. Then, the power will be distributed up through the building to serve each apartment unit. Also, more functions of the system include: a non-fused disconnect switch for the hydraulic lift system pump, power to the motorized door, continuing bus duct and conduit to the floors above and below each floor, and power to the sprinkler-head trace.

2.1.7 Façade

Dark metal panels, marble panels, and glazing are the main components incorporated into the existing building's facade. The 2" thick marble panels on the first and second floors and the 1 ¼" thick aluminum panels covering the rest of the building, shown in Figure 6, are supported by existing 8" CMUs, existing continuous vertical steel tees, and insulated by 2" rigid insulation. Varying window sizes create the new glass window system with 1" thick tempered glass. The new glass bronze-colored window systems is insulated and installed to match the existing window system. The architects were responsible for the window system change. Since the existing dark-tinted windows matched the dark-paneled architectural features of the building, they wanted to lighten the tint of the windows. They believed this would bring more natural daylighting into the apartment units and lighten the dark exterior architectural features.

Figure 6: View of Curtin Wall

2.1.8 Sustainability Features/Techniques

RVA and all the members of the project team determined the overall project goal is to achieve a LEED certified rating on the River Vue project. There are several main design features and construction techniques that contribute to the building's LEED Certification. Table 2 shows a breakdown of the River

Vue project's qualifications for each category on the LEED Project Checklist for New Construction.

Table 2: LEED 2009 for New Construction and Major Renovations				
YES	**?**	**NO**	**Category**	**Possible Points**
14		12	Sustainable Sites	26
6		4	Water Efficiency	10
9	2	24	Energy and Atmosphere	35
3		11	Materials and Resources	14
9		6	Indoor Environment Quality	15
1	1	4	Innovation and Design Process	6
2		2	Regional Priority Credits	4
44	**3**	**63**	**TOTAL**	**110**
Certified: 40 to 49 points				

Design features that contribute to the LEED Certification goal include alternative transportation, low-absorbing roofing material, and thermally insulated glazing. Specifically, several bicycle racks installed in the building's garage and the short distance to the Pittsburgh subway station on Liberty Avenue will contribute to the alternative transportation goal for River Vue. The roofing system will consist of a white-colored thermoplastic polyolefin (TPO) membrane used to decrease the amount of heat absorbed by the material. Also, the thermally insulated glazing for the new window system will reduce the amount of heat gain within the building from natural daylighting.

Construction techniques that contribute to the LEED Certification goal include pollution prevention, building reuse, low-emitting materials, and construction waste management. Pollution prevention is executed through specific construction activity such as controlling airborne dust generation and low exhaust emissions due to encouraging alternative transportation. Since this is a renovation project, materials and resources will be reused. For instance, over 75% of the existing walls, floors, and roof will remain for the completion of this building. Also, low-emitting materials will be used to achieve certification such as adhesives, sealants, paints, coatings, flooring systems, composite wood, and agrifiber products. Another construction feature used on this project will be construction waste management. This operation will be coordinated by the general contractor to confirm that the recycled material removed is the proper content. To ensure all LEED requirements for certification are fulfilled, a LEED Accredited Professional (Integrated Holistic Design, Inc.) will monitor the project by following the contract documents and consulting with the general contractor.

2.2 Project Cost Evaluation

The actual construction costs are based on the final estimated values produced and provided by Turner. Table 3 shows the costs of each major building system. All of the cost per SF information is derived from the total renovation project size of 295,000 SF.

Project Parameters:

Gross Building Area = 295,000 SF

Actual Building Construction Cost:

For the actual building construction cost, several line items of the cost plan were excluded. These line items include:

- Earthwork = $360,346
- General Requirements/Indirects = $2,304,344
- Lawns and Planting = $53,555
- Roads and Walkways = $59,976
- Special Construction (Demolition/Abatement) = $2,108,507

Actual Building Construction Cost = $23,362,182

Actual Building Construction Cost Per SF = $79.19/SF

Total Project Cost:

For the total project cost, all line items of the cost plan were included.

Total Project Cost = $28,248,910

Project Cost Per SF = $95.76/SF

Major Building Systems Costs:

Table 3: Major Building Systems Costs

System	Total Cost	Cost Per SF
Concrete	$800,854	$2.71/SF
Masonry	$153,268	$0.52/SF
Steel/Metals	$1,106,064	$3.75/SF
Mechanical	$3,138,415	$10.64/SF
Electrical	$3,754,401	$12.73/SF
Plumbing/Fire Protection	$3,612,350	$12.25/SF

2.3 General Conditions Cost Estimate

***See Appendix B for General Conditions Estimate and Take – Off Notes**

Table 4 shows the general conditions estimate broken down into four different factors and the corresponding total estimated costs. These values are an approximation obtained from the standard estimating manual, RS Means Facilities Construction Cost Data 2010, and altered by the Pittsburgh, PA location factor. They do not represent Turner's actual values.

Table 4: General Conditions Estimate Summary				
Item	**Unit**	**Quantity**	**Total Incl. O&P**	**Total**
Project & Staff Personnel Costs	Week	63	$20,154.57	$1,269,738.15
Construction Facilities & Equipment Costs	Week	63	$1,489.98	$93,868.55
Temporary Utilities Costs	Week	63	$3,011.55	$189,727.46
Miscellaneous Costs	Week	63	$14,825.01	$933,975.62
			TOTAL	**$2,487,309.78**

The Project and Staff Personnel factor includes the business unit general manager, operations manager, project executive, project superintendent, project engineer, site work assistant superintendent, MEP/FP assistant superintendent, second shift assistant superintendent, engineering assistant, and site laborers. The Construction Facilities and Equipment factor includes storage boxes, office equipment and supplies, temporary construction fencing, dumpsters, temporary portable toilets, etc. The Temporary Utilities factor includes field telephone set-up, the land line telephone bill, temporary power, the temporary construction water bill, etc. The Miscellaneous factor includes insurance, progress photographs, permits, commissioning, and clean-up.

To get a better understanding of how much each factor contributes to the general conditions estimate, a pie chart of the percentage summary is shown in Figure 7. Project and Staff Personnel make up the majority of the estimate with Miscellaneous Items, Temporary Utilities, and Construction Facilities and Equipment as the remainder.

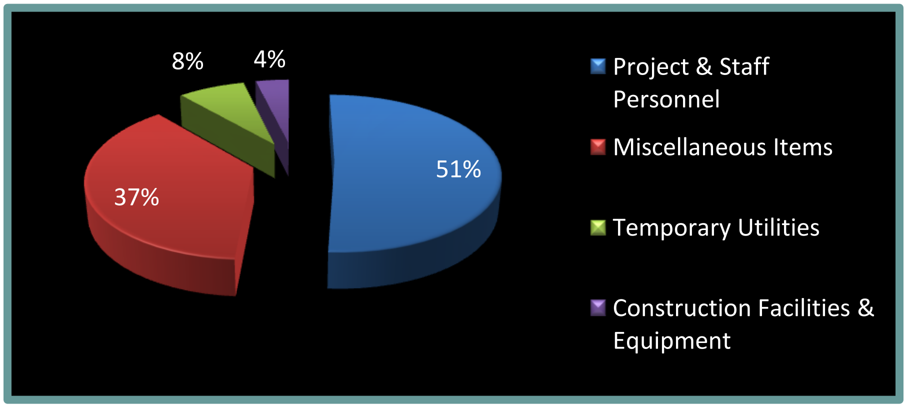

Figure 7: General Conditions Estimate Percentage Summary

2.4 Detailed Project Schedule

See Appendix C for the Detailed Project Schedule

2.4.1 Preconstruction

After reviewing the submitted proposals and meeting with the proposing design teams, RVA determined that DS4 and IDG were the most qualified firms to design River Vue. The two architectural firms developed a joint venture. On February 10, 2010, the architects were authorized to begin design activities with RVA's management team. Official work on the schematic design started on February 15, 2010 and design development started on April 4, 2010. After the construction documents were completed on July 9, 2010, RVA approved the design and the documents. Then, they proceeded to the procurement phase.

2.4.2 Procurement

On July 9, 2010, RVA announced the River Vue project to bid for general construction services. They held a mandatory pre-bid meeting and offered an optional pre-bid walk-thru of the project. By 2:00 PM on July 30, 2010, the general construction bid was due to RVA. After reviewing the submitted proposals, RVA awarded the project to Turner's Pittsburgh office on September 9, 2010.

2.4.3 Construction

River Vue's construction began on June 13, 2011. The major phases of construction include Abatement and Demolition, Site Work, Interiors, MEP/FP Rough-In, MEP/FP Finishes, Punch Lists and Inspections, and Completion and Occupancy. When official work began on Monday, June 13, 2011, the beginning stages of the construction phase included the demolition of all the existing systems and asbestos abatement. Once demolition and asbestos abatement was complete, the element that remained was the superstructure. With the superstructure of the building remaining, the construction of the basement and first floors parking garages began. During this construction sequence, the site work for the new parking garage ramps was completed. In addition to the site work occurring during the construction of the parking garages, the 218 apartment units are constructed starting on the second floor and moving up to the sixteenth floor. The building will be turned over to the owner in two phases. The basement through the fifth floors will be available in April 2012, and the entire building will be turned over by October 2012. Therefore, the total number of construction days is 342 days or approximately 16 months. A detailed construction plan and sequence was utilized for the project to ensure timely project completion.

<u>*2.5 Site Layout Planning Summary*</u>

2.5.1 Excavation Phase of Construction

See Appendix D for the Site Plan for Excavation Phase of Construction

For the excavation phase of construction, the project has a lot of excavation work going on, and the site is limited on space around those areas. Excavation work for the basement and first floors parking garage ramps is the largest and main area of excavation. During the excavation phase, some of the key features on the site plan include the construction fence that marks the construction site location, closed-off metered parking spaces and public sidewalks, gravel and soil stock piles, dumpsters, four temporary toilers, and the timber shoring support excavation system. Also, since it is a renovation project, Turner is using a northeast-side section of the building for their field offices.

2.5.2 Demolition Phase of Construction

See Appendix E for the Site Plan for Demolition Phase of Construction

For the demolition phase of construction, dumpsters and material lay down areas are on the site. Also, a hydraulic truck crane with a boom length of 167 ft is located on the east side of the site near the existing loading dock. However, the crane can be placed anywhere on the east and west sides of the building. During demolition, the crane is used to remove the old chillers from the basement floor, and any rooftop equipment from the roof. In addition, the interior features of the building are used for material storage, and one of the existing elevators is used for a trash chute. For the River Vue project, major transportation equipment, such as personnel and material hoists, are not needed because of the existing operable elevators inside the building.

2.5.3 MEP/Finishes Phase of Construction

See Appendix F for the Site Plan for MEP/Finishes Phase of Construction

During the MEP/Finishes phase of construction, the different key feature is the new crane location. However, the crane can be placed anywhere on the east and west sides of the building. During installing of MEP system components and finishes, the crane is used to install the new steam vault at the north end of the site, move any rooftop equipment to the roof, and place large equipment that might be installed on the upper floors. In addition, much like the demolition phase, material storage is located in and around the building; and major transportation equipment, such as personnel and material hoists, are not needed because of the existing operable elevators inside the building.

3.0 Technical Analysis #1: Photovoltaic Glass Window System Implementation

3.1 Problem Identification

The River Vue project is achieving LEED Certification for its sustainable construction techniques including pollution prevention, materials and resources reuse, low-emitting materials use, and construction waste management. However, very few sustainable design and energy production techniques were used on the project that could provide financial benefit to the owner, RVA.

3.2 Research Goals

The goals for this technical analysis are to develop a preliminary photovoltaic (PV) glass window system design and to determine the financial and energy feasibility of incorporating this new type of window system into the existing electrical system. Also, an electrical/renewable energy breadth analysis will determine the amount of renewable energy generated by the PV glass window system and how it will be connected to the electrical power system.

3.3 Research Methods

- Research PV glass advantages and disadvantages
- Research types of PV glass window systems
- Determine amount of glass in the building's façade
- Determine the electrical energy consumption of the building
- Determine amount of kWh able to be produced by the PV system
- Analyze the energy savings associated with the PV glass
- Analyze how the PV system will connect and operate with the electrical power system
- Calculate upfront costs for the PV glass window system
- Calculate life-cycle costs for the PV glass window system

3.4 Background Information

With the global demand for energy increasing and the amount of nonrenewable resources decreasing, it is essential that renewable resources are incorporated into building systems using a significant amount of energy. There are several techniques utilized to make a building's design more sustainable in the renewable energy sector including solar, wind, hydro, bio-energy, geothermal, and hydrogen. Specifically, solar is the most abundant source of energy. To collect this solar energy, solar PVs were designed. PVs are a rapidly increasing sector of the renewable-energy technologies market because they use the properties of semi-conductors to directly convert solar radiation (direct, diffuse, and reflected) into electricity.

3.4.1 Photovoltaic Glass

Over the past few years, building-integrated photovoltaic (BIPV) systems have been an increasing interest in these renewable-energy technologies because the PV elements produce electricity and become an integral part of a building and its envelope. Since River Vue has a significant amount of vertical glazing (approximately 1,500 glass windows) incorporated into its enclosure and the upper roof is housing mechanical equipment, the type of BIPV technology that could benefit the building's energy efficiency is PV glass. PV glass is an extremely intelligent method of incorporating PV technology into both new and existing buildings.

3.4.2 Advantages and Disadvantages of Photovoltaic Glass Window Systems

There are many advantages to implementing a PV glass window system into a building's design; however, there are several disadvantages as well.

Advantages:

- Uses sunlight as an energy source that is free and readily available
- Produces no emissions or noise (environmentally friendly technology)
- Flexible and scalable
- Extremely high performing (20%+)
- Adds value to the building beyond financial savings (Marketability)

Disadvantage:

- Expensive initial cost
- Requires large array area to produce a significant amount of power
- Requires abundant sunlight during afternoons and summer months
- Requires a location with good solar radiation resources

3.4.3 Product Information

See Appendix G for Pythagoras Solar's Photovoltaic Glass Unit's Technical Specifications

After extensive research, Pythagoras Solar's Photovoltaic Glass Unit (PVGU) will be used for this PV glass window system technical analysis. According to Pythagoras Solar's official website, "Pythagoras Solar is a multinational company that provides innovative BIPV products. These products combine energy efficiency, solar power generation, and transparency to enable aesthetically-pleasing, self-powered buildings" ("Company Background" et al.). Also, they are the first company to deliver the solar technology industry's first transparent high power PV glass unit.

The PVGU uses embedded optical technology, high-efficiency silicon, and advanced materials to provide the high-density PV power generation in a standard double-pane window. Specifically, according to the PVGU's technical specifications found on Pythagoras Solar's Website, the PVGU's design, shown in Figure 9, consists of a system of optics and PV cells that are adhered to the inner surface of the outer glass pane.

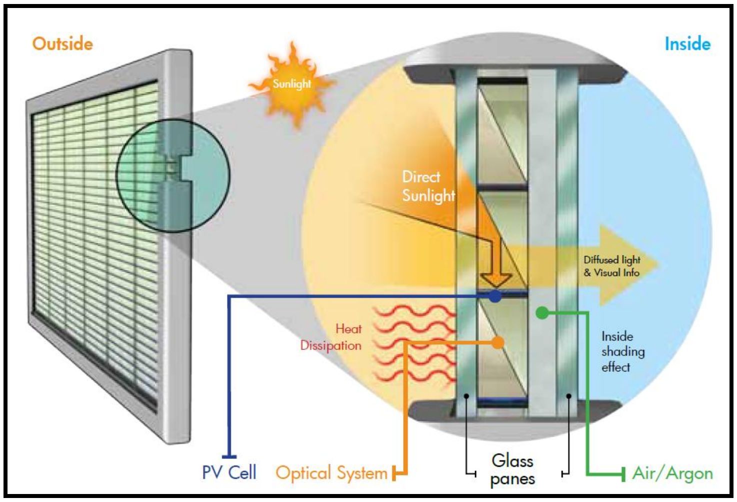

Figure 9 – Image of the PVGU from Pythagoras Solar's Website

The optical elements of the unit separate light, based on the angle at which it hits the glass, and distribute the direct sunlight onto the PV cells. The PV cells are mounted perpendicular to the glass panes. After the direct sunlight is distributed, diffused light is transmitted through the unit and into the building space. This aspect of the PVGU allows it to provide high energy generation and to act as a shading device. Even though the PVGU has a very low SHGC (0.14) and a high visual light transmission for daylight harvesting, electrical energy generation and savings are only in the scope for this analysis.

Photovoltaic Glass Unit Specifications: Pythagoras Solar's PVGUs are custom made per project; therefore, the units can be made into any size. The standard window units come with a ¼" ultra-clear outer lite and a ¼" low-e inner lite, but they can be made with any glass specified. Also, electrical wires extend from the sides of each PVGU and are connected to the wires from the other units to link the entire system. In Table 6, the PVGUs' technical specification for the River Vue project's 3 ¾' x 5 ½' windows is given.

Table 6: Photovoltaic Glass Unit Technical Specifications	
Physical Characteristics	
Length	66 in
Width	45 in
Area	2970 in^2
Total Glass Thickness	1.25 in
Total Weight	67.75 lbs
U-Value	0.30
Module Efficiency	15.13%
Electrical Characteristics	
Nominal Power (P_{mpp})	101.2 W
Voltage at Nominal Power (V_{mpp})	36.02 V
Open-Circuit Voltage (V_{oc})	43.38 V
Current at Nominal Power (I_{mpp})	2.81 A
Short-Circuit Current (I_{sc})	2.95 A
Test Operating Temperature	- 40°C - 85°C
Maximum System Voltage (V_{mpp})	600 V (DC)
Electrical Coefficients	
Nominal Operating Cell Temperature (NOCT)	53°C
Temperature Coefficient of P_{mpp}	-0.55%/°C
Temperature Coefficient of V_{oc}	-0.36%/°C
Temperature Coefficient of I_{sc}	-0.03%/°C

3.5 Preliminary Photovoltaic Glass Window System Design

3.5.1 Location, Orientation, and Shading

The River Vue building's largest sides are oriented toward the east and west, which experience major sunlight during the morning and early evening hours, respectively. The smaller sides of the building are oriented toward the north and south which experience no sunlight and major sunlight, respectively.

In addition, River Vue is surrounded by several taller and shorter buildings which hinder the design of the PV glass window system due to shading. Using Google SketchUp, a schematic model was created to analyze the solar shading effects on the building's north, south, east, and west facing sides. Even though the River Vue building's enclosure is composed of metal and marble panels, for modeling purposes, the River Vue building is represented in blue to better see and understand the shading effects. Figures 10-12 show the solar shading effects for the summer solstice, fall/spring equinox, and winter solstice at 9:00 AM and 4:00 PM.

During the summer solstice, shown in Figure 10, at 9:00 AM, the north, south, and west-facing sides of the building are shaded. The east-facing side and the upper and part of the lower rooftops are experiencing sunlight. Then, at 4:00 PM, the north, south, and east-facing sides of the building are shaded. The west-facing side and the lower and upper rooftops are experiencing sunlight.

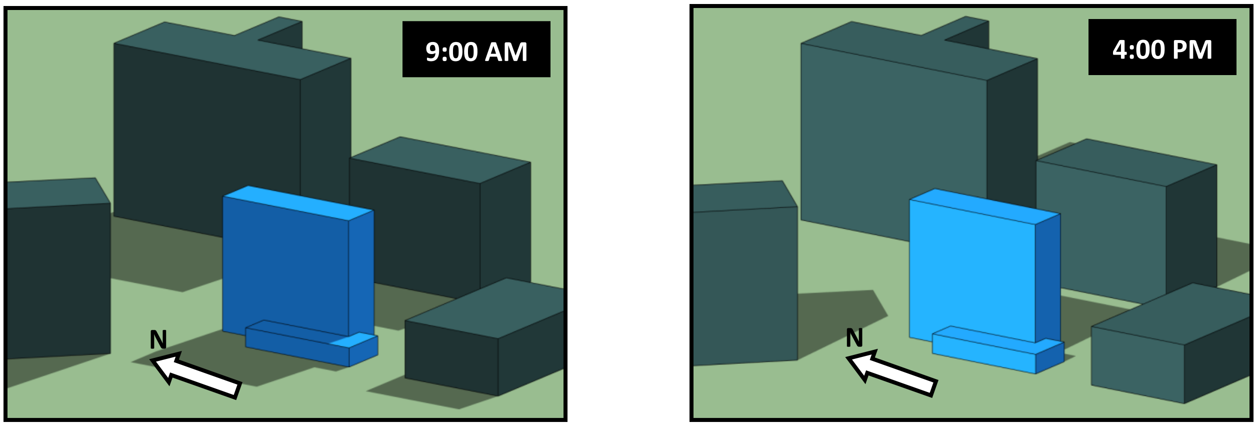

Figure 10: Summer Solstice (June 20) Shading

During the fall/spring equinox, shown in Figure 11, at 9:00 AM, the north and west-facing sides of the building and part of the lower rooftop are shaded. The south and west-facing sides of the building and the upper and part of the lower rooftops are experiencing sunlight. Then, at 4:00 PM, the north and east-facing sides of the building are shaded. The south and west-facing sides and the lower and upper rooftops are experiencing sunlight.

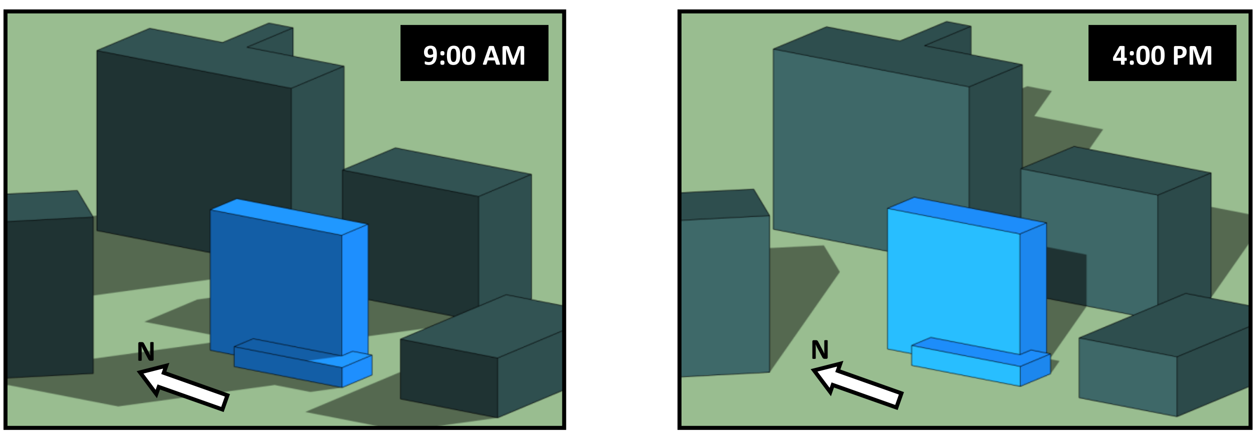

Figure 11: Fall/Spring Equinox (September 22 and March 20) Shading

During the winter solstice, shown in Figure 12, at 9:00 AM, the north and west-facing sides of the building and the lower rooftop are shaded. The east-facing side and the upper half of the south-facing side of the building are experiencing sunlight. Then, at 4:00 PM, the north and east-facing sides and the lower and upper rooftops are shaded. The south and west-facing sides of the building are experiencing sunlight.

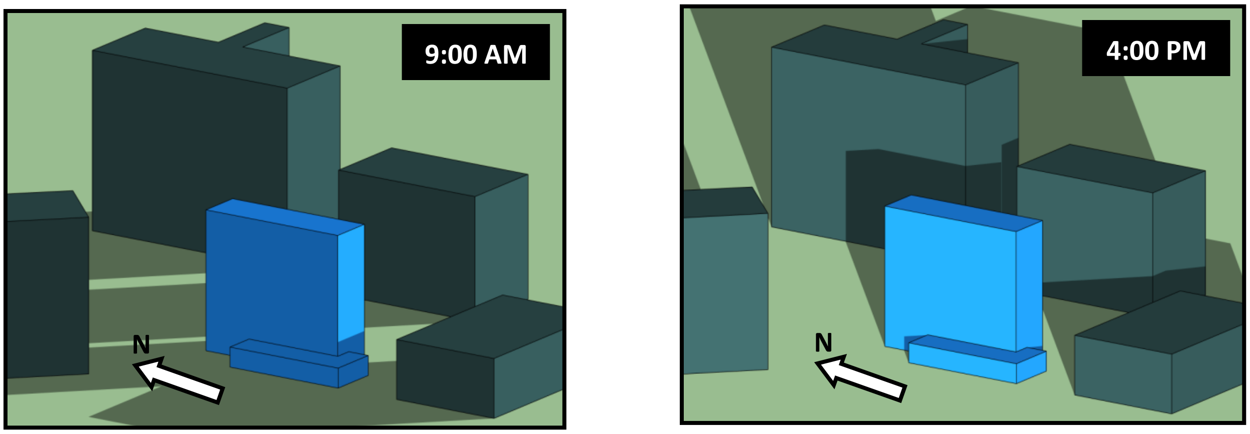

Figure 12: Winter Solstice (December 21) Shading

3.5.2 Potential Energy Reduction

To reduce a building's electrical energy consumption, a PV glass window system can be very beneficial. However, apartment buildings, such as River Vue, generate a large amount of electrical energy because they are occupied 24 hours a day and every day each year. Therefore, the PV glass window system cannot completely service the building's electrical consumption, but it can help reduce the overall electrical energy consumption and utility costs.

To determine the yearly electrical energy consumption of River Vue, the U.S. Department of Energy's Building Energy Data Book was used. It showcased a case study for The Solaire (Solaire), an apartment building in New York City, New York. Solaire and River Vue are significantly similar in size, design, and urban location. Therefore, Solaire's electrical energy data was used to determine the estimated value for the electrical energy consumption of the River Vue building. The estimated total value for the River Vue building's electrical energy consumption is 34,993,283.2843 kWh/year.

To determine the number of PVGUs required to efficiently reduce the electrical energy consumption of the whole building, the estimated total value for River Vue's electrical energy consumption was used. Table 7 shows the sizing calculation for the whole building.

Table 7: Photovoltaic Glass Window System Sizing Calculation for the Whole Building	
Kilowatt-Hours Per Year	34,993,283.2843
Kilowatt-Hours Per Month	2,916,106.9404
Kilowatt-Hours Per Day	95,872.0090
Sun Hours Per Day	3.28
Kilowatt-Hours Per Hour of Sunlight	29,229.27
Produced Power (kW) Per PVGU	0.1012
Number of PVGUs Required	**288,827**

The kWh/year value is the estimated value of 34,993,283.2843 kWh/year. To calculate the kilowatt-kWh/month and the kWh/day, the kWh/year was divided by 12 months and it was divided by 365 days, respectively. The sun hours per day value was obtained from Whole Sale Solar's Sun Hours/Day Zone Solar Insolation Map ("Sun Hours/day Zone Solar Isolation Map" et al.). The produced power per PVGU was determined using the PVGU's technical specifications provided by Pythagoras Solar. After calculating all of the necessary values, the number of PVGUs required to produce the daily consumption of the River Vue building's daily electrical energy consumption is approximately 288,827 PVGUs. After performing this calculation, this size of a system would never be possible for the River Vue building. Also, it would be very expensive, and the life-cycle costs and pay-back period would not be beneficial for the owner.

Since it is impossible to power all of the River Vue building's electrical loads, the ultimate goal of the PV glass window system was altered to produce electricity for the apartments' appliances. After examining the equipment and appliance floor plans and schedules, the types of appliances were determined. Table 8 shows a breakdown of each major appliance required for each apartment unit and the kWh they produce each day. The power values for each appliance were obtained from the General Electric Appliances and LG Appliances websites. Also, assumptions were made for the typical hours of operation for each appliance per day for this analysis.

Table 8: Energy Loads for Apartment Appliances

Component	Quantity	kW	Hrs/Day	kWh / Day
GE Energy Star 22.1 Cu. Ft. Side-by-Side Refrigerator with Dispenser	218	1.8	24	9,417.60
GE Profile 30" Free Standing Electric Range	218	10.4	2	4,534.40
GE Tall Tub Built-in Dishwasher with Smart Dispense Technology	218	1.092	1	238.06
GE Spacemaker 1.7 Cu.Ft. Over-the-Range Microwave Oven with Venting System	218	1.55	1	337.90
LG WM3987HW Ventless Washer-Dryer Combo 22lb capacity	218	1.44	2	627.84
TOTAL	**1,080**			**15,155.80**

To determine the number of PVGUs required to efficiently reduce the electrical energy consumption of the apartment units' electrical appliances, the calculated total value for the appliances' electrical energy consumption was used. Table 9 shows the sizing calculation for the apartment appliances.

Table 9: Photovoltaic Glass Window System Sizing Calculation for Apartment Appliances

Kilowatt-Hours Per Day	15,155.80
Sun Hours Per Day	3.28
Kilowatt-Hours Per Hour of Sunlight	4,620.67
Produced Power (kW) Per PVGU	0.1012
Number of PVGUs Required	**45,659**

The kWh/day value is the calculated value of 15,155.80. The sun hours per day value was obtained from Whole Sale Solar's Sun Hours/Day Zone Solar Insolation Map ("Sun Hours/day Zone Solar Isolation Map" et al.). The produced power per PVGU was determined using the PVGU's technical specifications provided by Pythagoras Solar. After calculating all of the necessary values, the number of PVGUs required to produce the daily consumption of the 218 apartment units' appliances' daily electrical energy consumption is approximately 45,659 PVGUs. Much like the result of the sizing calculation for the whole building, this size of a system would never be possible for the River Vue building. Also, it would be very expensive, and the life-cycle costs and pay-back period would not be beneficial for the owner. Therefore, this analysis will first consider the total number of PVGUs that can be incorporated into the building's existing window system. The number will be based on the number of windows on the south, east, and west-facing sides of the building because these sides experience the most sunlight throughout the day. Also, the design will be based on a shading analysis.

3.5.3 Photovoltaic Glass Window System Design and Size

River Vue has a significant amount of glazing incorporated into its façade. This aspect makes PV glass an excellent type of PV technology to implement into the design of the building's façade to reduce its electrical energy consumption. Throughout the entire building's façade, there are approximately 1,500 windows. Even though more energy would be generated with a 1,500 glass window system, the transparent PV glass units' perpendicular PV cells would obstruct the residents' view of the city's surroundings. Therefore, the PVGUs will be used in every other glass window. There are 86 glass windows on the north-facing side, 100 glass windows on the south-facing side, 224 glass windows on the east-facing side, and 328 glass windows on the west-facing side.

Since the north-facing side of the building never experiences direct sunlight, the PVGUs will only be electrically connected on the south, east, and west-facing sides. Therefore, for this analysis, the total number of PVGUs used to generate electricity is 652 PVGUs. In addition, for aesthetic reasons only, the north-facing side could use these units as well, but they would not be electrically connected. Also, glass window panels with a similar look can be used instead of the very expensive PVGUs. However, for this analysis, the north-facing side will not be included into the systems design or the cost of the overall PV glass window system.

With this type of PV glass window, electricity is generated by direct, diffuse, and reflected sunlight. Each PVGU produces 101.2 watts of electrical direct current (DC) power. The total ideal amount of kW produced by the 652 PVGU window system is 65.982 kW.

3.5.4 Inverter Sizing

See Appendix H for Fronius IG Plus PV Inverter Sizes and Specifications

To determine the appropriate inverter size for the ideal PV system size, the PV glass window system was broken down into three systems: the south-facing side system, east-facing side system, and the west-facing side system. Each system requires a different inverter size because each side has a different number of PV glass window panels. The information below shows a breakdown of the three systems and the calculations performed to determine the appropriate inverter for each system.

South-Facing Side System: (Using the Fronius IG Plus 10.0-1$_{UNI}$ Inverter)

PVGU System Power: 100 glass windows x 101.2 W = 10,120 W

Minimum Input Power: 8,500 W / 101.2 W = 84 PVGUs

Maximum Input Power: 11,500 W / 101.2 W = 114 PVGUs

Number of inverters = 1 inverter

The south-facing side system includes 100 glass windows generating an output power of 101.2 W each. Therefore, the total output power of this system is 10,120 W which is acceptable for one Fronius IG Plus 10.0-1$_{UNI}$ inverter.

East-Facing Side System: (Using the Fronius IG Plus 10.0-1$_{UNI}$ Inverter)

PVGU System Power: 224 glass windows x 101.2 W = 22,669 W

Minimum Input Power: 8,500 W

Maximum Input Power: 11,500 W

Number of inverters = 22,669 W / 11,500 W per inverter = 2 inverters

The east-facing side system includes 224 glass windows generating an output power of 101.2 W each. Therefore, the total output power of this system is 22,669 W which is acceptable for two Fronius IG Plus 10.0-1$_{UNI}$ inverters.

West-Facing Side System: (Using the Fronius IG Plus 10.0-1$_{UNI}$ Inverter)

PVGU System Power: 328 glass windows x 101.2 W = 33,194 W

Minimum Input Power: 8,500 W

Maximum Input Power: 11,500 W

Number of inverters = 33,194 W / 11,500 W per inverter = 3 inverters

The west-facing side system includes 328 glass windows generating an output power of 101.2 W each. Therefore, the total output power of this system is 33,194 W which is acceptable for three Fronius IG Plus 10.0-1$_{UNI}$ inverters.

3.6 Electrical/Renewable Energy Breadth

To determine the feasibility of the PV glass window system's implementation, the energy produced by

Pythagoras Solar's PVGUs needs to be calculated. The ideal system with no shading for the PV glass window system would include an overall DC system rating of 65,982 W, including 652 glass panels with a power production output of 101.2 W. However, since the PV windows are incorporated onto the south, east, and west-facing sides of the building, the shading from the surrounding buildings and the different times of the day need to be taken into consideration. Table 10 shows the PV glass window system's design parameters and specifications.

Table 10: Photovoltaic Glass Window System Information	
Station Identification	
City	Pittsburgh
State	Pennsylvania
Latitude	40.50°N
Longitude	80.22°W
PV System Specifications	
Array Type	Fixed Tilt
Array Tilt	90°
Array Azimuth (South, East, West)	180°, 135°, 225°
Energy Specifications	
Cost of Electricity	9.6 cents/kWh

3.6.1 South-Facing Side System Energy Production with Shading

See Appendix I for the South-Facing Side System Solar Shading Effects

To analyze how shading affects the PV glass window system on the south-facing side of the building, the Renewable Energy Laboratory's System Advisor Model software was used. After inputting the necessary characteristics for the PV glass units, Fronius IG Plus 10.0-1_{UNI} inverter, and the shading effects on the south-facing side of the River Vue building, the results were calculated. The results from the System Advisor Model are given in Table 11. The total DC energy output of the south-facing side is 11,404.81 kWh/year. After the inverter converts the total DC power to total alternating current (AC) power, the total AC energy output is 10,689.73 kWh/year. The total AC energy value for the south-facing side was determined to be only $1,026.21/year.

Table 11: South-Facing Side System Results with Shading				
Month	Solar Radiation ($kWh/m^2/day$)	DC Energy (kWh)	AC Energy (kWh)	AC Energy Value ($)
1	2.50	754.43	704.85	67.67
2	3.11	865.29	810.45	77.80
3	3.10	1,114.25	1,043.14	100.14
4	2.89	1,127.49	1,057.80	101.55
5	2.61	986.08	924.91	88.79
6	2.49	931.42	873.29	83.84
7	2.55	1,034.09	970.23	93.14
8	3.05	1,218.78	1,145.65	109.98
9	3.13	1,127.13	1,058.68	101.60
10	3.35	1,123.93	1,054.68	101.25
11	2.29	655.00	612.65	58.81
12	1.70	466.91	433.78	41.64
Year	**2.73**	**11,404.812**	**10,689.73**	**$1,026.21**

3.6.2 East-Facing Side System Energy Production with Shading

See Appendix I for the East-Facing Side System Solar Shading Effects

To analyze how shading affects the PV glass window system on the east-facing side of the building, the Renewable Energy Laboratory's System Advisor Model software was used. After inputting the necessary characteristics for the PV glass units, Fronius IG Plus 10.0-1_{UNI} inverter, and the shading effects on the east-facing side of the River Vue building, the results were calculated. The results from the System Advisor Model are given in Table 12. The total DC energy output of the east-facing side is 8,661.09 kWh/year. After the inverter converts the total DC power to total AC power, the total AC energy output is 7,949.78 kWh/year. The total AC energy value for the east-facing side was determined to be only $763.18/year.

Table 12: East-Facing Side System Results with Shading				
Month	Solar Radiation ($kWh/m^2/day$)	DC Energy (kWh)	AC Energy (kWh)	AC Energy Value ($)
1	2.03	382.29	341.92	32.82
2	2.70	52.00	478.94	45.98
3	2.85	709.96	650.78	62.47
4	2.96	902.97	834.58	80.12
5	3.09	1,058.36	979.64	94.05
6	3.07	1,036.94	959.52	92.11
7	3.22	1,062.27	982.64	94.33
8	3.16	974.20	901.06	86.50
9	3.02	694.11	636.32	61.09
10	2.81	575.45	523.60	50.27
11	1.88	401.31	360.33	34.59
12	1.39	338.21	300.47	28.84
Year	**2.68**	**8,661.09**	**7,949.78**	**$763.18**

3.6.3 West-Facing Side System Energy Production with Shading

See Appendix I for the West-Facing Side System Solar Shading Effects

To analyze how shading affects the PV glass window system on the west-facing side of the building, the Renewable Energy Laboratory's System Advisor Model software was used. After inputting the necessary characteristics for the PV glass units, Fronius IG Plus 10.0-1_{UNI} inverter, and the shading effects on the west-facing side of the River Vue building, the results were calculated. The results from the System Advisor Model are given in Table 13. The total DC energy output of the west-facing side is 11,629.98 kWh/year. After the inverter converts the total DC power to total AC power, the total AC energy output is 10,643.63 kWh/year. The total AC energy value for the west-facing side was determined to be only $1,021.79/year.

Table 13: West-Facing Side System Results with Shading				
Month	Solar Radiation ($kWh/m^2/day$)	DC Energy (kWh)	AC Energy (kWh)	AC Energy Value ($)
1	1.95	520.94	463.84	44.53
2	2.56	703.80	639.53	61.39
3	2.72	951.85	869.99	83.52
4	3.01	1,168.54	1,076.01	103.30
5	3.00	1,403.23	1,295.97	124.41
6	3.08	1,433.22	1,325.42	127.24
7	2.94	1,439.73	1,329.78	127.66
8	3.30	1,279.98	1,180.22	113.30
9	2.92	924.42	844.35	81.06
10	2.81	784.16	711.24	68.28
11	1.84	553.20	494.65	47.49
12	1.36	466.91	412.63	39.61
Year	**2.62**	**11,629.98**	**10,643.63**	**$1,021.79**

3.6.4 Photovoltaic Glass Window System Energy Production with Shading

After individually calculating the DC energy output, AC energy output, and the AC energy value for the south-facing side, east-facing side, and west-facing side systems, total PV glass window system's DC energy output, AC energy output, and the AC energy value was calculated. Table 14 shows these calculated values.

Table 14: Total Photovoltaic Glass Window System Results with Shading			
System	DC Energy (kWh)	AC Energy (kWh)	AC Energy Value ($)
South-Facing Side	11,404.81	10,689.73	$1,026.21
East-Facing Side	8,661.09	7,949.78	$763.18
West-Facing Side	11,629.98	10,643.63	$1,021.79
TOTAL	**31,695.88**	**29,283.14**	**$2,811.18**

The total DC energy output of the entire system is 31,695.88 kWh/year. After the inverter converts the total DC power to total AC power, the total AC energy output is 29,283.14 kWh/year. The total energy value for the entire system was determined to be only $2,811.18/year.

3.6.5 Electrical System Tie-In

Since the PV glass window system designed for this analysis does not produce a significant amount of electricity, the type of PV system used is a system that does not have energy storage, but it does have a grid connection. When designing a PV system that has a grid connection, it is very important to determine the point of connection. The point of connection is the location at which the PV system interconnects with the electric utility system. Section 690.64 of the National Electric Code (NEC®) establishes how and where a utility-interactive PV system may be connected to the existing utility system. The output of the PV system's inverters can be connected to the load-side or the supply-side of the service disconnect. For smaller PV systems, a load-side interconnection is typically used and the point of connection is usually at a circuit breaker in the distribution panel. For commercial and larger PV systems, the grid connection must be made on the supply side of the service disconnect to comply with the requirements of the NEC®690.64. Therefore, for this analysis, a supply-side interconnection will be used because the PV glass window system designed for the River Vue project is very large (652 PVGUs).

When using a supply-side interconnection, there are many NEC® requirements that need to be met and several electrical components that need to be installed. A supply-side interconnection requires adding another service-entrance disconnect in parallel with the existing service disconnect (Dunlop 339). Specifically, the PV glass window system's power supply must tie-in with the utility power supply from a transformer at a service-tap meter box. One power supply feeds into the main distribution panel and is distributed to the buildings electrical loads. Figure 13 shows a diagram of the supply-side interconnection for the PV glass window system.

In addition, several electrical components are required to connect the PV glass window system to the existing electrical system in the building and to convert solar energy into usable electricity for DC and AC loads. Theses electrical components include DC wire runs, DC disconnects, inverters, AC disconnects, AC wire runs, and a service-tap meter box. The DC wire runs (represented in green on the diagram) are used to connect the PV glass units to the inverters, and the inverters are used to convert the DC power from the PV glass window units to AC power. The AC wire runs (represented in blue on the diagram) are used to connect the inverters to the service-tap meter box, and the service-tap meter box is used to combine the PV glass window system supply with the electric utility's (Duquesne Light Company) power supply.

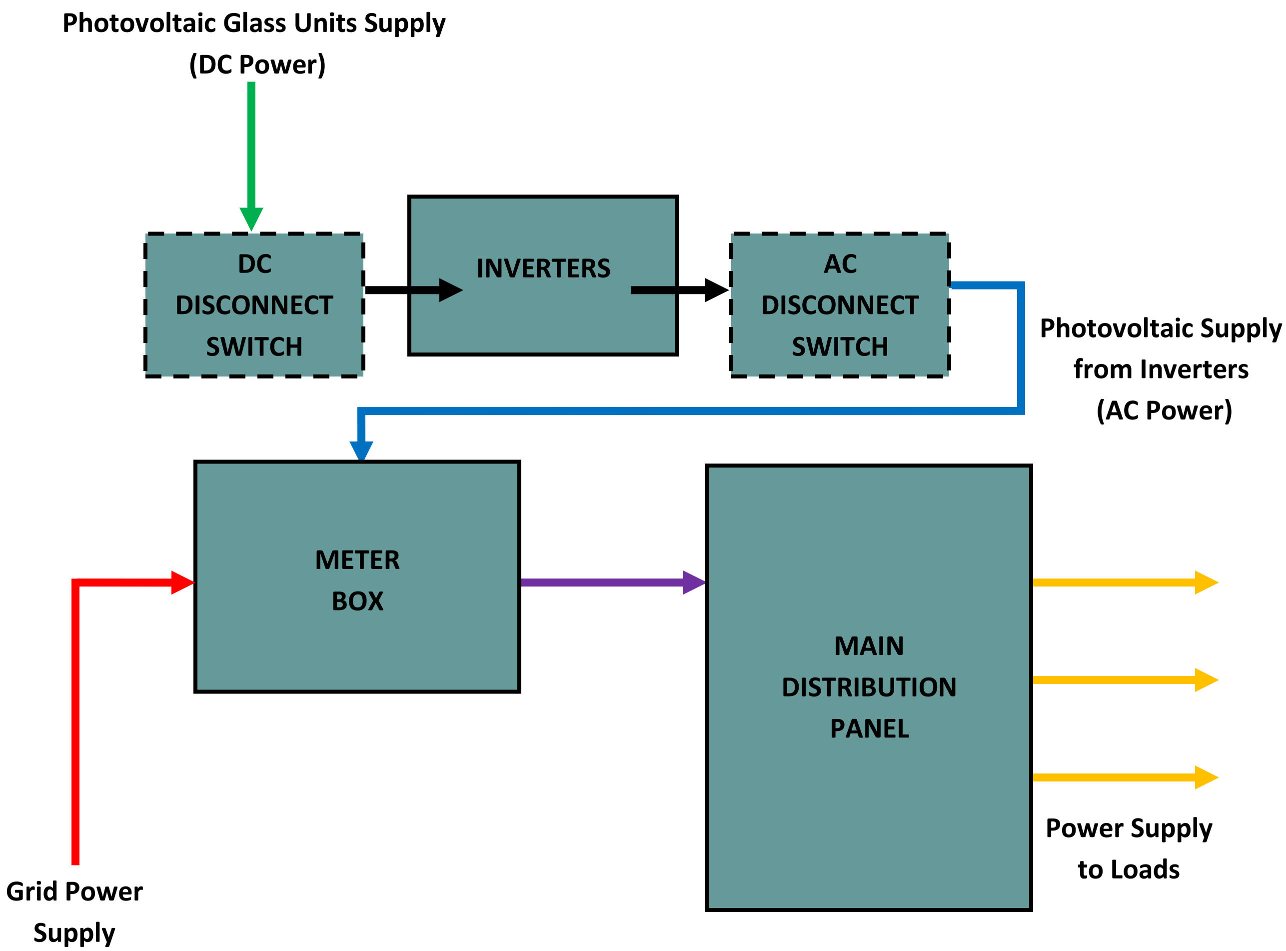

Figure 13: Diagram of Supply-Side Interconnection for the Photovoltaic Glass Window System

3.7 Feasibility Analysis

3.7.1 System Cost

The total cost of the PV glass window system and its economic feasibility determines if the system should be implemented into River Vue's design. To effectively determine the feasibility of the PV glass window system, the total cost of the system was calculated including the systems appropriate components. The following is a breakdown of the system costs:

Photovoltaic Glass Unit (PVGU):

The cost per square foot for Pythagoras Solar's PVGU was obtained from Pythagoras Solar engineer Moana Reynau, LEED®AP. Also, the cost per SF indicated below already includes the 30% Federal Investment Tax Credit and accelerated depreciation (MACRS). However, it does not include local and state incentives and rebates that are available.

Number of glass panels = 652

SF per panel = 3.75’ x 5.5’ = 20.625 SF/panel

Total SF of glass window panels = 13,447.5 SF

Cost per SF = $75/SF

Total cost of PVGUs = $1,008,562.50

Inverters:

The cost for the Fronius IG Plus 10.0-1$_{UNI}$ inverters was obtained from Akari Energy.

Cost of one Fronius IG Plus 10.0-1$_{UNI}$ inverter = $4,173

Total cost of six Fronius IG Plus 10.0-1$_{UNI}$ inverters = $25,038

Photovoltaic Glass Window System without Incentives and Rebates:

Table 15 shows the initial cost of the PV glass window system without incentives or rebates.

Table 15: Initial Cost of the Photovoltaic Glass Window System without Incentives and Rebates

Component	Total Cost
Pythagoras Solar’s PVGUs	$1,008,562.50
Inverters	$25.038.00
TOTAL	**$1,033,600.50**

3.7.2 System Cost with Rebates and Incentives

To promote sustainability, the Pennsylvanian government has instituted rebates and incentives to companies and organizations that install PV systems into their building’s design. The following list includes the rebates and incentives:

- Pennsylvania Alternative Energy Production Tax Credit: 15% after all other incentives
- Pennsylvania Sunshine Solar Rebate Program: 35% of cost up to $5,000

Table 16 shows the PV glass window system’s initial cost after the rebates and incentives have been issued for the River Vue project.

Table 16: Initial Cost of Photovoltaic Glass Window System After Incentives and Rebates

Incentive & Rebate Name	Description	Cost Reduction	Adjusted Cost
-	Initial Cost	-	$1,033,562.50
PA Sunshine Solar Rebate	35% of cost (up to $5,000)	$5,000.00	$1,028,600.50
PA Alternative Energy Production	15% after all other incentives	$154,290.10	$874,310.40
		FINAL COST	**$874,310.40**

3.7.3 Life-Cycle Cost and Payback Period

When implementing this PV glass window system into River Vue building's design, the ultimate goal is for the owner to receive the initial costs of the system back through their energy savings within an acceptable payback period. To determine energy savings and the payback period, the life-cycle savings costs of the PV glass window system needs to be calculated. According to Pythagoras Solar's PVGU Brochure, the lifespan on the PVGU is approximately 25 years. Therefore, the life-cycle savings costs will be evaluated for 25 years of the system's operation.

To calculate the life-cycle savings costs of the PV glass window system, the energy cost per year, AEC value per year, energy savings per year, total savings per year, and the yearly maintenance cost were determined. The energy cost ($/kWh) is the retail cost of the electricity, which is the rate paid by the utility company (Duquesne Light Company). For this calculation, it was assumed that the energy cost of $0.170/kWh would increase by one percent each year. The AEC Value ($/kWh) is an Alternative Energy Credit, which is earned when a qualified facility generates 1,000 kWh of electricity through estimated or actual metered production. The energy savings is the AC energy produced by the system, and it generates 29,283.14 kWh/year. The yearly maintenance cost ($/kWh) is the cost saved because PV glass window systems require very little maintenance during their lifespan. Table 17 shows a breakdown of each category and energy savings for each year of the 25-year life-cycle.

Table 17: Life-Cycle Energy Savings Cost for the Photovoltaic Glass Window System						
Year	Energy Cost ($/kWh)	AEC Value ($/kWh)	Energy Savings (kWh)	Total Savings ($)	Yearly Maintenance Cost ($/kWh)	Total Savings Cost ($)
1	0.170	0	29,283.14	4,978.13	0.03	4,099.64
2	0.172	0.4	29,283.14	16,741.17	0.03	15,862.68
3	0.173	0.4	29,283.14	16,791.45	0.03	15,912.96
4	0.175	0.4	29,283.14	16,842.23	0.03	15,963.74
5	0.177	0.4	29,283.14	16,893.52	0.03	16,015.03
6	0.179	0.4	29,283.14	16,945.32	0.03	16,066.83
7	0.180	0.4	29,283.14	16,997.65	0.03	16,119.15
8	0.182	0.4	29,283.14	17,050.49	0.03	16,172.00
9	0.184	0.4	29,283.14	17,103.86	0.03	16,225.37
10	0.186	0.4	29,283.14	17,157.77	0.03	16,279.27
11	0.188	0.4	29,283.14	17,212.21	0.03	16,333.72
12	0.190	0.4	29,283.14	17,267.20	0.03	16,388.71
13	0.192	0.4	29,283.14	17,322.74	0.03	16,444.25
14	0.193	0.4	29,283.14	17,378.84	0.03	16,500.34
15	0.195	0.4	29,283.14	17,435.49	0.03	16,557.00
16	0.197	0.4	29,283.14	17,492.71	0.03	16,614.22
17	0.199	0.4	29,283.14	17,550.51	0.03	16,672.02
18	0.201	0.4	29,283.14	17,608.88	0.03	16,730.39
19	0.203	0.4	29,283.14	17,667.84	0.03	16,789.34
20	0.205	0.4	29,283.14	17,727.38	0.03	16,848.89
21	0.207	0.4	29,283.14	17,787.53	0.03	16,909.03
22	0.210	0.4	29,283.14	17,848.27	0.03	16,969.77
23	0.212	0.4	29,283.14	17,902.62	0.03	17,031.12
24	0.214	0.4	29,283.14	17,971.58	0.03	17,093.09
25	0.216	0.4	29,283.14	18,034.16	0.03	17,155.67
					TOTAL	$399,754.22

For the 25-year life-cycle of the PV glass window system, the total life-cycle energy savings cost is $399,754.22. Since the system's initial cost is $874,310.40, the owner does not receive the initial costs of the system back through the energy savings within the 25-year payback period. Therefore, the PV system is not a recommended investment for the owner.

3.8 Schedule Impact

Since the schedule is the main factor in completing a project successfully and efficiently, a schedule impact overview is important to include in this analysis. The PV glass window design will not affect the critical schedule for the River Vue project because the glass window replacement overlaps with other tasks. Also, the PVGUs will be assembled into the window framing system offsite; therefore, installation time should not be a problem. The components of the system that will take the most amount of time to install will be the wiring and the connections to the existing utility system. However, the time for this task is still not significant enough to affect the critical schedule.

3.9 Photovoltaic Glass Window System Analysis Summary

After analyzing the implementation of a PV glass system into River Vue's design, the following information was determined:

- After extensive research, Pythagoras Solar's PVGU was used for this analysis.
- A 3 ¾' x 5 ½" PVGU generates 101.2 W and has a module efficiency of 15.13%.
- Using an every other glass window design, there are 86 glass windows on the north facing side, 100 glass windows on the south-facing side, 224 glass windows on the east-facing side, and 328 glass windows on the west-facing side.
- Since the north-facing side of the building never experiences direct sunlight, the PVGUs will only be used on the south, east, and west facing sides. Therefore, for this analysis, the total number of PVGUs used to generate electricity is 652 PVGUs.
- For this analysis, a supply-side interconnection will be used because the PV glass window system designed for the River Vue project is very large (652 PV glass window units).
- After completing a shading analysis, the total DC energy, AC energy, and AC energy value are 31,695.88 kWh, 29,283.14 kWh, and $2,811.18 respectively.
- After eligible incentives and rebates, the initial cost of the PV glass window system, including the cost of the PVGUs and six Fronius IG Plus 10.0-1_{UNI} inverters, is $874,310.40.
- For the 25-year life-cycle of the PV glass window system, the total life-cycle energy savings cost is $399,754.22.
- Since the system's initial cost is $874,310.40, the owner does not receive the initial cost of the system back through the energy savings within the PVGU's 25-year lifespan.
- This specific PV glass window system is not a recommended investment for the owner. However, the PVGUs are transparent, and the owner could decide to use an every-window design instead of an every-other-window design to generate more electricity, but the initial cost will be much higher.

4.0 Technical Analysis #2: Green Roof System Implementation

4.1 Problem Identification

As previously stated in Section 3.1 of this report, the River Vue project is achieving LEED Certification for its sustainable construction techniques. However, very few sustainable design techniques were used on the project that could provide financial benefit to the owner, RVA.

4.2 Research Goals

The goals for this technical analysis are to develop a preliminary resident-accessible green roof system design, analyze the structural impact of the load-bearing green roof system, and determine the financial feasibility of incorporating this new roof system into the existing building's design.

4.3 Research Methods

- Research green roof system advantages and disadvantages
- Research types of green roof systems
- Design resident-accessible green roof
- Analyze how the load-bearing green roof system affects the existing roof's structural system
- Calculate upfront costs for the green roof system
- Analyze how a resident rent increase affects the feasibility of the green roof system
- Analyze the schedule impact to construct the green roof system

4.4 Background Information

There are several techniques utilized to make a building's design more sustainable. For River Vue, incorporating a resident-accessible green roof system onto the Level 2 roof is one way to make the building's design more sustainable. In order to successfully complete this analysis, background research was completed.

Extensive and intensive are the two major types of green roof systems. The growing membrane's size is one factor that determines the type of system. Figure 14 shows an image of an extensive green roof system's vegetation and growing medium compared to an intensive green roof system's vegetation and growing medium.

Extensive Green Roof Systems: According to the "Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West," extensive green roof systems are very popular and often used on commercial buildings with inaccessible roofs that are only accessible to maintenance personnel (Tolderlund et al.). These shallow green roof systems have a growing medium depth of approximately 4"-6" to support very lightweight plants in the grass and sedum families, and they are ideal systems because structural changes are usually not needed to implement them (Tolderlund et al.). At fully-saturated conditions, the typical weight for extensive green roof systems range from 15 lb/ft^2 to 55 lb/ft^2. There are several advantages for implementing an extensive green roof system onto a building's roof. These advantages include low weight, low maintenance, low capital, and low irrigation depending on the climate of the building's location (Tolderlund et al.).

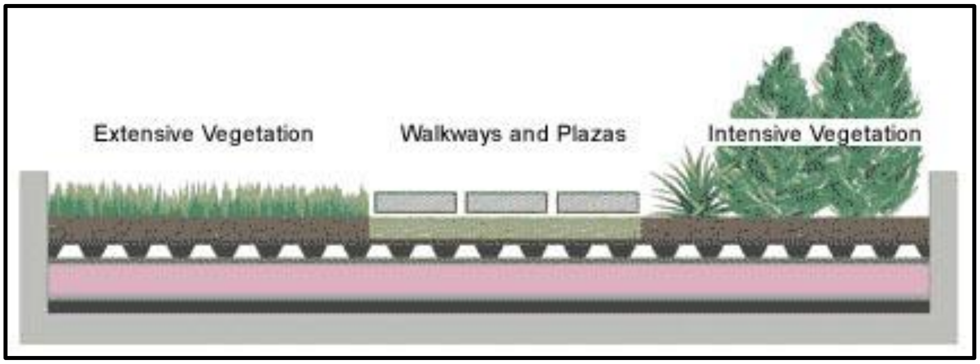

Figure 14: Image of an Extensive Green Roof vs. an Intensive Green Roof from Built-Green's Website

Intensive Green Roof Systems: According to the "Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West", intensive green roof systems are often used for green roof gardens and allow for greater plant diversity (Tolderlund et al.). These deep green roof systems have a growing medium depth of 6"-8", and they typically require structural changes to implement them for retrofit projects (Tolderlund et al.). At fully-saturated conditions, the typical weight for intensive green roof systems range from 60lb/ft^2 to 150 lb/ft^2. There are several advantages for implementing an intensive green roof system onto a building. These advantages include greater plant diversity and biodiversity, better storm water management and insulation properties, greater design opportunities, and greater chance for variety and accessibility (Tolderlund et al.).

In addition, green roof systems can be conventional or modular systems. There are several main differences between these two types of green roof systems. Conventional green roof systems contain a suitable waterproofing membrane and root barrier system, drainage layer, filter fabric, edge treatment, growing medium, and plants (Tolderlund et al.). Each of these components is installed layer by layer which increases the green roof system's installation time. Modular green roof systems contain a roof-edge treatment, moisture portal, growing medium, and plants in pre-made modular trays (Tolderlund et al.). The only components that are loose from the trays are the suitable waterproofing membrane and slip sheet/root barrier.

4.4.1 Advantages and Disadvantages of Green Roof Systems

There are many advantages to implementing a green roof system into a building's design; however, there are several disadvantages as well.

Advantages:

Private Advantages: (Building Owner Benefits)

- Energy efficiency

- Increased roofing membrane durability
- Fire retardation
- Noise reduction
- Increased marketability

Public Advantages:

- Aesthetic improvement
- New amenity and recreational space
- Storm water management
- Moderation of urban heat island effect
- Air quality improvement

Disadvantages:

- High initial cost
- Maintenance required – depends on type of green roof system
- Unattractive aesthetically in winter months

4.4.2 Product Information

After extensive research, LiveRoof®, LLC's pre-vegetative modular green roof system will be used for this analysis. According to LiveRoof®, LLC's official website, "LiveRoof® is the only modular green roof system that uses specifically designed soil and moisture portals to interconnect the entire growing medium" ("LiveRoof® System" et al.). This specific design allows for natural sharing of moisture and nutrients unlike other modular systems. To naturally function, LiveRoof® systems do not have exposed lips or edges and air gaps between modules for optimal R value, cooling value, and storm water absorption. However, these systems do have drain channels that disperse water at 7.0 GPM per linear foot ("LiveRoof® System" et al.). Figure 15 shows an image of the LiveRoof® system's modular-tray breakdown from the product brochure on LiveRoof®, LLC's official website.

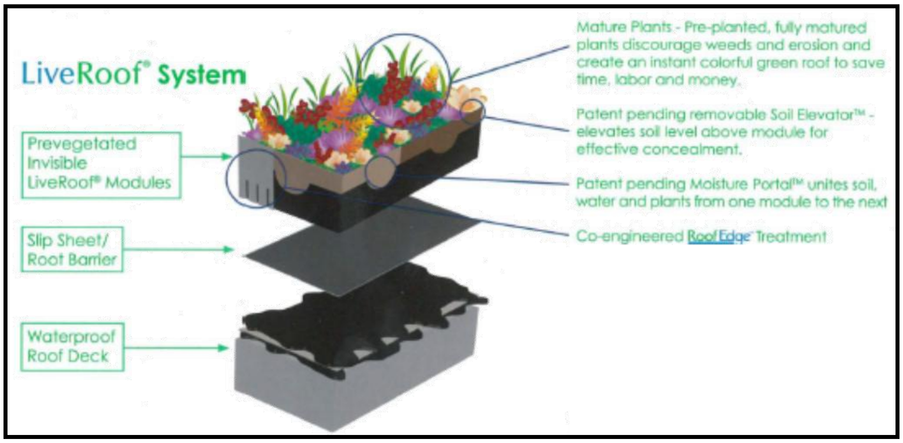

Figure 15: Image of LiveRoof® Green Roof System from LiveRoof®, LLP's Website

In addition, there are several other advantages to using a LiveRoof® modular green roof system. "During all of Earth's seasons, LiveRoof® systems are aesthetically pleasing with their meadow-like natural beauty, and they are very flexible which allow them to be custom cut to the design of any green roof" ("LiveRoof® System" et al.). Other advantages include instantly mature and beautiful vegetation, less maintenance, weed prevention, resistance to wind erosion, evaporative cooling, enhancement of LEED ratings in many categories, and time and cost savings.

When using a LiveRoof® system, there are several LiveRoof® system options. LiveRoof®, LLC offers four convenient systems: LiveRoof® Lite, Standard, Deep, and Maxx. For this analysis, the LiveRoof® Maxx System will be used because of its design and plant diversity. The LiveRoof® Maxx System has a soil depth of 8" and a saturated weight of 65 lb/ft^2 which serves as a growing medium for succulent ground covers, drought tolerant native and adapted non-native perennials, grasses, and vegetables ("LiveRoof® System" et al.). Also, this system is designed to meet municipal codes in locales with 8" soil depth requirement and optimize biodiversity.

4.5 Preliminary Green Roof System Design

4.5.1 Green Roof Design and Layout

For River Vue, the primary function of the green roof system is to incorporate a relaxing green space for residents to enjoy in an urban environment. Therefore, when designing the green roof, the aesthetics and the layout were very important considerations. Figure 16 shows a drawing of the green roof's design and layout.

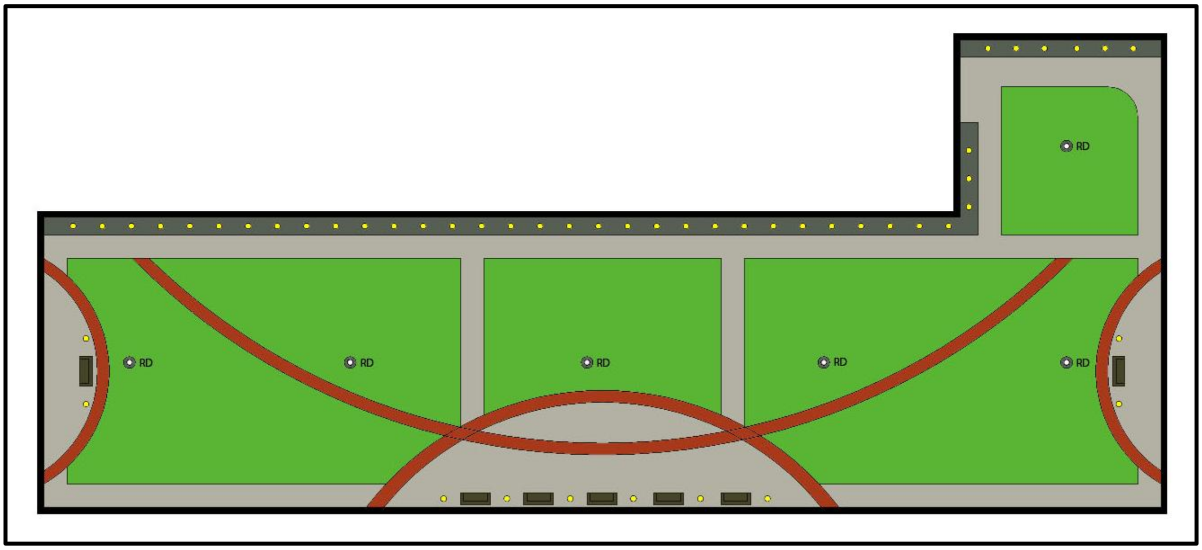

Figure 16: Drawing of the Green Roof's Design and Layout

The proposed green roof design consists of a pre-vegetated modular LiveRoof® Maxx System, concrete pavers, brick pavers, aggregate/stone gravel, floor-recessed and pole lighting, recreational benches, and access stairs and handicapped ramp. The following list indicates which color represents each component of the green roof in Figure 16:

- Green: Vegetation
- Light Gray : Concrete tile pavers
- Dark Red: Brick pavers
- Dark Gray: Aggregate/stone gravel
- Yellow: Floor-recessed lighting and pole lighting
- Brown: Benches

The overall roof area of River Vue's Level 2 roof is 10,268.76 SF. The green roof accounts for 57.64% of the overall roof area which makes this a very energy efficient, flexible, and functional design. Table 18 shows a breakdown of each green roof system component and its occupying percentage of the Level 2 roof.

Table 18: Green Roof System Square-Foot Takeoffs

Green Roof System Component	Square Footage	Percentage of Level 2 Roof
Aggregate/ Stone Gravel	536.25 SF	5.22%
Brick Pavers	718.95 SF	7.00%
Concrete Tile Pavers	3,094.90 SF	30.14%
Vegetation	5,918.66 SF	57.64%
TOTAL SF	**10,268.76 SF**	**100%**

4.5.2 Green Roof Accessibility

Accessibility of the green roof to the apartment building's residents is a critical component of its design. The top of the roof is approximately two feet below the floor line of the third floor; therefore, the roof would have to be accessible from this floor. In order for this design to work, a third-floor apartment unit has to be removed and several additions have to be installed. In order to accommodate all of the residents, access stairs and a handicapped ramp will be installed as well as railings and an exterior door.

Figure 17 depicts the layout design of the green roof and the third floor. The yellow arrow indicates the pathway through the third floor's hallway to the roof, while the blue area is the third floor apartment unit that would have to be removed.

Figure 17: Drawing of Green Roof Accessibility and Design Layout

Removing this third-floor apartment unit raises concerns with the owner on what to do with the space and how to earn back the monthly rent lost on that apartment unit. Below are three situations explaining the potential uses of the space as well as methods to gain back the money lost.

Rent Increase: Since the green roof system adds quality and marketability to River Vue's design, increasing the rent for the remaining 217 apartments would be a potential way to receive the money lost. For this analysis, this situation is the one chosen to further analyze. Section 4.7.3 of this report covers this rent analysis.

Fitness Center: Since the fitness center on the second floor is very small, a larger gym could be added in this space. The existing apartment unit's bathroom can be kept incase gym patrons or residents outside on the roof need to use it. The money put into losing the space and providing more gym equipment can be paid back by increasing the residents' rent gradually over several years.

Party Preparation Area: For residents wanting to entertain guests in a more scenic area, the extra space can be transformed into a party preparation room equipped with the existing apartment unit's bathroom and kitchen. Several pieces of furniture and tables can be kept inside incase the residents want to transition between areas. For entertainment purposes, the owner could rent the roof out to the public for special events, such as business and social parties. For both cases, money can be earned back to the owner by gradually increasing rent each year or charging a fee to rent out the room to the residents or the public.

4.6 Structural Breadth

Additional loading is one of the main factors in determining the viability of a green roof installation. If a green roof is installed on an existing building like River Vue, the design will be limited to carrying a capacity that the existing roof can accommodate. However, the owner can upgrade the structure to accommodate for the green roof system they want to incorporate into their building's sustainable design, but it could be a significant investment as well. For this structural analysis, the LiveRoof® Maxx System, with a soil depth of 8"and a saturated weight of 65 lb/ft^2, will be used. To determine how the load-bearing intensive green roof impacts River Vue's existing roof's structural system, a section shown in Figure 18, the total load exerted on the roof system, such as the metal roof deck and steel joists, needs to be calculated. Only the roof structural members were analyzed due to the sophisticated column splices and moment frame which are beyond the scope of this structural analysis.

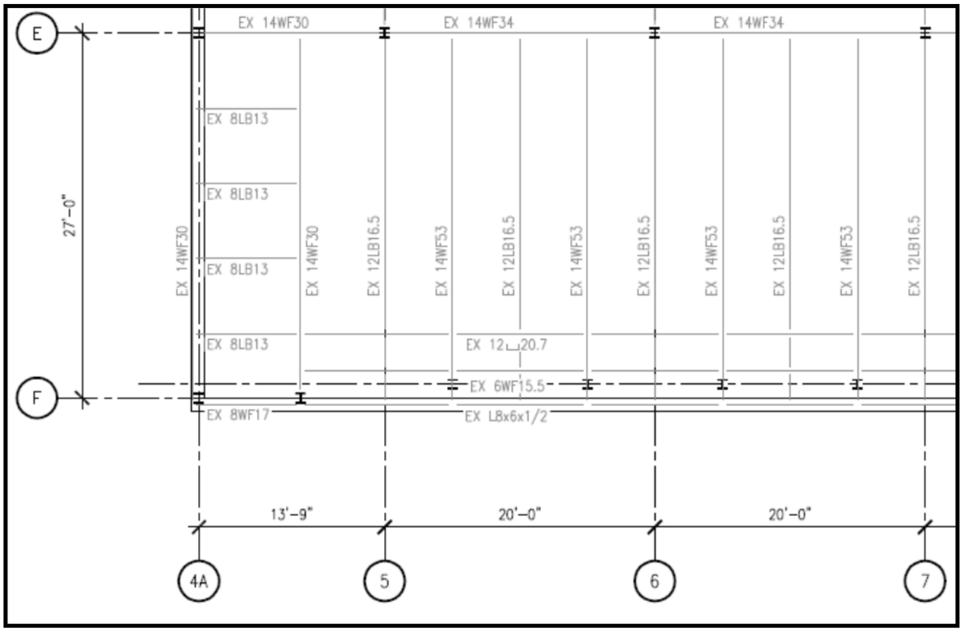

Figure 18: Image of a Section of the Existing Roof's Steel Joists Structural Plan

4.6.1 Existing Roof System Information

Before calculating the load-bearing green roof system's structural impact on the existing roof system, it is important to understand the existing roof system and its design parameters. All information and loads were obtained from the structural drawings produced by Whitley Bailey Cox and Magnani, LLC, the project's structural engineers.

Design Loads:

- **Roof Live Loads:**
  - Roof Live Load = 20 PSF
  - Flat Roof Snow Load = 21 PSF
- **Roof Dead Loads:**
  - Roofing + Insulation + Deck = 6 PSF

- MEP = 5 PSF
- Sprinklers = 3 PSF
- Ceiling = 4 PSF
- Miscellaneous = 2 PSF
- Steel Beam Framing = 10 PSF
- Total Roof Dead Load = 30 PSF

Metal Roof Deck: The existing roof deck consists of a 1 ½" – 20 GA galvanized metal roof deck.

4.6.2 LiveRoof® Maxx System Calculations

See Appendix J for ASCE Section 7.10 Table 4-1

To determine the new size and type of roof deck needed to support the green roof system's load, the total dead load and total load were calculated.

Green Roof System Assumptions:

- Live Load (L_r) = 100 PSF (obtained from Table 4-1 in Section 7.10 of the ASCE manual)
- Snow Load = 21 PSF
- Intensive Green Roof Max Weight (saturated) = 65 PSF
- The intensive green roof's weight will control instead of the concrete tile and brick pavers and the aggregate/stone gravel weights because of the green roof system's design.
- Metal Deck = 2 PSF
- Fenestration Systems = 5 PSF
- Miscellaneous Dead Load = 2 PSF
- Number of spans = 3 spans
- Maximum SDI Const. Span = 10'-3"

Dead Load Calculation:

The dead load calculation includes the weight of the intensive green roof, metal deck, fenestration systems, and miscellaneous dead loads.

Total Dead Load = 65 PSF + 2 PSF + 5 PSF + 2 PSF

Total Dead Load = 74 PSF

Total Load Calculations:

See Appendix K for International Building Code 2006 Section 1605 – Load Combinations

To calculate total load (dead load and live load) of the accessible green roof system, Equation 16-2 in Section 1605 – Load Combinations of the International Building Code 2006 was used.

Total Load = 1.2D + 1.6 (L_r or S or R) + L = (1.2 x 74 PSF) + (1.6 x 100 PSF) + 0

Total Load = 248.8 PSF = 249 PSF

Roof Deck Selection:

See Appendix L for Vulcraft's 1.5B16 Roof Deck Specifications

After calculating the total load the existing roof is experiencing due to the green roof system, the roof deck size and type was selected. Using Vulcraft's Steel Roof & Floor Deck Catalog, the roof deck needed to accommodate for the total dead load of 249 PSF is a 1.5B16 roof deck, which weighs 3.54 PSF. The "1.5" represents the roof deck's rib depth, and the "16" represents the roof deck's specified gauge. Type B is wide-ribbed roof deck that provides excellent structural load carrying capacity per pound of steel utilized. Also, its design eliminates the need for die-set ends.

Roof Deck Calculation Check:

This roof deck calculation check incorporates the actual deck weight of the selected 1.5B16 roof deck, which is 3.54 PSF, instead of the assumed metal deck weight of 2 PSF.

Dead Load = 65 PSF + 3.54 PSF + 5 PSF + 2 PSF

Total Dead Load = 75.54 PSF

Total Load = (1.2 x 75.54 PSF) + (1.6 x 100 PSF) + 0

Total Load = 250.65 PSF = 251 PSF

After checking the total load, including the selected deck's actual deck weight, the selected 1.5B16 roof deck is acceptable to accommodate the LiveRoof® Maxx green roof system.

4.6.3 Steel Joist Calculations

After determining the load-bearing green roof system's impact on the metal roof deck, it is important to analyze how it affects the steel joists supporting the existing roof system. To determine the new size and type of steel joists needed to support the green roof system's load, the total load, distributed load, maximum moment capacity, and the maximum shear capacity were calculated.

Total Load Calculation:

Total Dead Load = 75.54 PSF (From the Roof Deck Calculation section)

Total Load = 75.54 PSF + 100 PSF

Total Load = 175.54 PSF

Distributed Load on Steel Joists Calculation:

Distributed Load on Steel Joists (W) = 175.54 PSF x 5' span

Distributed Load on Steel Joists (W) = 877.7 PLF

Maximum Moment Calculation:

Maximum Moment = $WL^2/8$ = [(877.7 PLF) x (27 FT)^2]/8

Maximum Moment = 79,980.4125 PLF

Maximum Moment in KIP-IN = (79,980.4125 PLF) x (1 KIP/1000 LB) x (12 IN/1 FT)

Maximum Moment in KIP-IN = 959.77 KIP-IN

Maximum Shear Calculation:

Maximum Shear = WL/2 = [(877.7 PLF) x (5 FT)]/2

Maximum Shear = 2,194.25 LBS

Steel Joist Selection:

See Appendix M for Vulcraft's 22KCS4 Open-Web Steel Joists

After calculating the maximum moment and maximum shear that the existing roof's steel joists are experiencing due to the green roof system, a new joist size and type was selected. Using Vulcraft's Steel Joists & Joist Girders catalog, the steel joists needed to accommodate for the maximum moment capacity of 959.77 kip-in and the maximum shear capacity of 2,194.25 lbs are 22KCS4 open-web steel joists. The "22" represents the depth of the web, and "KCS" is the type of joist that is designed for simple span uniform loading.

4.6.4 Structural Breadth Summary

After analyzing the impact of the load-bearing green roof system on the existing roof's structural system, the following information was determined:

- The metal roof deck must change from a 1.5B20 roof deck to a 1.5B16 roof deck to accommodate the green roof system load.
- The steel joists must change from 14WF53 steel joists to 22KCS3 open-web steel joists to accommodate the green roof system load.
- Even though replacing the existing metal roof deck and steel joists is a significant investment, it is assumed that the owner (RVA) will upgrade the structure to accommodate the River Vue building's proposed intensive green roof. The intensive green roof adds quality and value to the building's design and marketability to the building.

4.7 Feasibility Analysis

4.7.1 System Cost

The total cost of the green roof system and its economic feasibility determines if the system should be implemented into River Vue's design. To effectively determine the feasibility of the green roof system, the total cost of the system was calculated including the systems appropriate components. The following is a breakdown of the system costs:

Green Roof System Material Cost:

For the material cost, the following is a list of the resources used to obtain the cost for each green roof system component:

- The cost per SF of the aggregate/stone gravel was obtained from Earth Source Landscape.
- The cost per SF for the brick and concrete pavers was obtained from Paver Search, Inc.
- The cost per SF for the LiveRoof® Maxx System was obtained from Corso's Perennials, an Ohio and a Pennsylvania licensed LiveRoof® system grower.
- The cost of the roof accessories was assumed based on the magnitude of accessories.
- The cost of the slip sheet/root barrier was obtained from RS Means Green Building Cost 2012.
- The cost of the metal roof deck and steel joists was an assumed cost based on the magnitude of the required metal roof deck and steel joists.

Table 19: Green Roof System Material Cost

Component	SF	Cost/SF ($/SF)	Total Cost ($)
Aggregate/Stone Gravel	536.25	2.00	1,072.50
Brick Pavers	718.95	15.00	10,784.25
Concrete Pavers	3,094.90	10.00	30,949.00
LiveRoof® Maxx System Trays	5,918.66	19.00	112,454.54
Roof Accessories	-	-	30,000
Slip Sheet/Root Barrier	10,268.76	0.70	7,188.13
Metal Roof Deck & Steel Joists	-	-	48,112.11
TOTAL			**$240.,560.53**

Green Roof System Equipment & Installation Cost:

For the equipment and installation cost, the following is a list of the resources used to obtain the cost for each green roof system component:

- The cost per SF of the aggregate/stone gravel was obtained from Earth Source Landscape.
- The cost per SF for the brick and concrete pavers was obtained from Paver Search, Inc.
- The cost per SF for the LiveRoof® Maxx System was obtained from LiveRoof®, LLP's website.
- The cost of the roof accessories was assumed based on the magnitude of accessories.
- The cost of the slip sheet/root barrier was obtained from RS Means Green Building Cost 2012.

- The cost of the metal roof deck and steel joists was an assumed cost based on the magnitude of the required metal roof deck and steel joists.

Table 20: Green Roof System Equipment and Installation Cost			
Component	**SF**	**Cost/SF ($/SF)**	**Total Cost ($)**
Aggregate/Stone Gravel	536.25	2.00	1,072.50
Brick Pavers	718.95	20.00	14,379.00
Concrete Pavers	3,094.90	10.00	30,949.00
LiveRoof® Maxx System Trays	5,918.66	3.80	22,490.91
Roof Accessories	-	-	33,000
Slip Sheet/Root Barrier	10,268.76	0.77	7,906.95
Metal Roof Deck & Steel Joists	-	-	54,479.79
TOTAL			**$164,278.14**

Green Roof System Yearly Maintenance Cost: Since the proposed green roof design is an intensive green roof system, landscape maintenance and review is required four times per year. The primary beneficial maintenance task is the manual removal of any weeds growing in the modular system's growing medium. Also, the green roof is monitored to verify long-term soil irrigation balancing, plant health, and soil composition changes. The cost per SF for the LiveRoof® Maxx System's maintenance was obtained from LiveRoof®, LLP's website. Table 21 shows a breakdown of the green roof system's maintenance cost.

Table 21: Green Roof System Maintenance Cost			
Time / Year	**SF**	**Cost/SF ($/SF)**	**Total Cost ($)**
1	5,918.66	0.30	1,775.60
2	5,918.66	0.30	1,775.60
3	5,918.66	0.30	1,775.60
4	5,918.66	0.30	1,775.60
TOTAL			**$7,102.39**

Total Green Roof System Cost without Incentives and Rebates: After extensive research and contacting the available resources, information about incentives and rebates for implementing a green roof system into River Vue's design could not be found for the Pittsburgh, PA area. Table 22 shows the initial total cost of the green roof system without incentives or rebates. Also, it does not include the green roof's yearly maintenance cost because it is not a one-time cost.

Table 22: Initial Total Cost of the Green Roof System Without Incentives and Rebates	
Component	**Total Cost**
Materials Cost	$240,560.53
Equipment & Installation Cost	$164,278.17
TOTAL	**$404,838.68**

4.7.2 Rent Increase Analysis

For this analysis, determining the energy savings generated by implementing a green roof system was not in the scope of the proposed methodology. Therefore, an educated assumption was made that the owner would receive their initial investment within the lifespan of the green roof system based only on the cost of the energy savings. Since the green roof system adds quality and marketability to River Vue's design, a rent increase always was performed. Increasing the rent for the remaining 217 apartments would be a potential way to receive the money lost from eliminating the third-floor apartment unit and the money for the green roof system's yearly maintenance cost. First, for comparison purposes, it is important to calculate the total apartment rent paid each year without implementing the proposed green roof system. According to Chris DiLorenzo from Turner, the rent price range is from $800 to $3,000 per month. To calculate the total rent paid, the rent price range was used and distributed to each of the apartment unit types based on their design and features. Table 23 shows a breakdown of each apartment unit type and the rent paid without a green roof system.

Table 23: Total Rent Paid Without Green Roof System

Apartment Type	No. of Apartments	Rent Price ($)	Rent Paid/Month ($)	Rent Paid/Year ($)
Floors 2-14:				
1 Bedroom, No Balcony	43	800	34,400	412,800
	43	900	38,700	464,400
	42	1,000	42,000	504,000
	42	1,100	46,200	554,400
2 Bedrooms, No Balcony	4	1,200	4,800	57,600
	4	1,300	5,200	62,400
	4	1,400	5,600	67,200
	4	1,500	6,000	72,000
1 Bedroom Studio, No Balcony	3	1,600	4,800	57,600
	3	1,700	5,100	61,200
	3	1,800	5,400	64,800
	3	1,900	5,700	68,400
Floor 15				
1 Bedroom, Small Balcony	3	2,000	6,000	72,000
	3	2,100	6,300	75,600
1 Bedroom, Large Balcony	1	2,200	2,200	26,400
	2	2,300	4,600	55,200
2 Bedrooms, Small Balcony	2	2,400	4,800	57,600
	2	2,500	5,000	60,000
	3	2,600	7,800	93,600
1 Bedroom Studio, Small Balcony	1	2,700	2,700	32,400
1 Bedroom Studio, Large Balcony	1	2,800	2,800	33,600
2 Bedrooms, 2 Floors, Large Balcony	1	2,900	2,900	34,800
3 Bedrooms, 2 Floors, Large Balcony	1	3,000	3,000	36,000
TOTAL	**218**		**$252,000**	**$3,024,000**

After calculating the total rent paid without implementing the proposed green roof system, the total rent paid to accommodate the green roof's yearly maintenance and the loss of the third-floor apartment unit needs to be calculated. To determine the rent increase needed, a simple calculation was performed.

Third-Floor Apartment Unit:

For this calculation, it was assumed that the third-floor apartment unit being removed was the most expensive one bedroom apartment in that rent range.

Third-Floor Apartment Unit Rent per Month= $1,100/month

Rent Increase = $1,100 / 217 apartment units = $5.07 ~ $10.00

Green Roof System Maintenance:

Green Roof Maintenance Cost per Year = $7,102.39

Rent Increase = $7,102.39 / 217 apartment units = $32.73 ~ $35.00

Total Rent Increase for Apartment Unit and Green Roof Maintenance = $10.00 + $35.00 = $45.00

Using these calculated values, the total rent paid per month and the total rent paid per year was determined. Table 24 shows the total rent paid each month and year to accommodate for the green roof system's yearly maintenance cost and the loss of the third-floor apartment unit. Increasing the rent by $45.00 results in a total rent paid per year of $3,127,980. The difference between the total rent paid per year without the green roof system and the total rent paid per year to accommodate for the maintenance and the apartment unit is $103,980. Based on the rent increase analysis alone, the green roof system is a very beneficial investment to the owner because it adds quality and marketability to the building's design, increases the building's energy efficiency, and increases the roofing membrane's durability.

Table 24: Total Rent Paid to Accommodate for Green Roof Maintenance Cost and Loss of Third Floor Apartment Unit				
Apartment Type	**No. of Apartments**	**Rent Price ($)**	**Rent Paid/Month ($)**	**Rent Paid/Year ($)**
Floors 2-14:				
1 Bedroom, No Balcony	43	845	36,335	436,020
	43	945	40,635	487,620
	42	1,045	43,890	526,680
	41	1,145	46,945	563,340
2 Bedrooms, No Balcony	4	1,245	4,980	59,760
	4	1,345	5,380	64,560
	4	1,445	5,780	69,360
	4	1,545	6,180	74,160
1 Bedroom Studio, No Balcony	3	1,645	4,935	59,220
	3	1,745	5,235	62,820
	3	1,845	5,535	66,420
	3	1,945	5,835	70,020
Floor 15				
1 Bedroom, Small Balcony	3	2,045	6,135	73,620
	3	2,145	6,435	77,220
1 Bedroom, Large Balcony	1	2,245	2,245	26,940
	2	2,345	4,690	56,280
2 Bedrooms, Small Balcony	2	2,445	4,890	58,680
	2	2,545	5,090	61,080
	3	2,645	7,935	95,220
1 Bedroom Studio, Small Balcony	1	2,745	2,745	32,940
1 Bedroom Studio, Large Balcony	1	2,845	2,845	34,140
2 Bedrooms, 2 Floors, Large Balcony	1	2,945	2,945	35,340
3 Bedrooms, 2 Floors, Large Balcony	1	3,045	3,045	36,540
TOTAL	**217**		**260,665**	**$3,127,980**

4.8 Construction and Schedule Impact

See Appendix N for the Detailed Green Roof System and Level 2 Construction Schedule

The construction process of the designed green roof system's installation is very important to understand and consider as a potential critical schedule delay. Since the schedule is the main factor in completing a project successfully and efficiently, a schedule impact analysis was performed. The green roof system's construction will affect the critical schedule for the River Vue project because the existing metal roof deck and steel joists need to be replaced. This process will take longer than the process of installing all of the green roof system's components. Therefore, it is important to analyze which construction tasks on the existing detailed project schedule will be affected by the green roof system's construction including the installation of the new metal roof deck and steel joists. Table 25 shows the construction tasks affected and their original durations.

Table 25: Construction Tasks Affected by Green Roof System Implementation			
Construction Tasks	**Duration (Days)**	**Start Date**	**End Date**
Level 2 Roofing Construction			
Demolition of existing roofing components including roofing membrane	10	7/25/2011	8/5/2011
Installation of new roofing components including new TPO roofing membrane	10	8/8/2011	8/19/2011
MEP/FP Rough-In			
Level 2 – Beneath Lower Roof Only	30	7/25/2011	9/2/2011
Interiors			
Level 2 – Beneath Lower Roof Only	60	9/5/2011	11/25/2011
MEP/FP Finishes			
Level 2 – Beneath Lower Roof Only	30	11/28/2011	1/6/2012
Punchlists and Inspections			
Level 2 – Beneath Lower Roof Only	20	2/27/2012	3/23/2012
Completion and Occupancy			
Level 2 – Beneath Lower Level Roof Only	0	4/3/2012	4/3/2012

After consulting the project's detailed schedule, it was determined that the demolition of the lower roof's roofing components and the installation of the new roofing components will be affected by the implementation of the green roof system. Also, the MEP/FP Rough-In, Interiors, MEP/FP Finishes, Punchlists and Inspections, and Completion and Occupancy tasks of the Level 2 apartment units located beneath the lower roof will be delayed as well. Since metal roof deck and steel joist changes are needed to accommodate the intensive green roof system, the schedule will change drastically because these construction tasks are on the critical path to the completion and occupancy of the Level 2 apartments by April 3, 2012. Table 26 shows the new construction tasks and durations associated with the installation of all the green roof system's components and the new durations and dates for the existing construction tasks. For this schedule impact analysis, it was assumed that the construction tasks, such as MEP/FP Rough-In, Interiors, MEP/FP Finishes, Punchlists and Inspections, and Completion and Occupancy, for the other levels of the building will not be affected or delayed by the implementation of the green roof system because they are stand-alone levels and can be completed as initially scheduled.

Table 26: New Construction Tasks and Durations Due to the Implementation of the Green Roof System			
Construction Tasks	**Duration (Days)**	**Start Date**	**End Date**
Level 2 Roofing Construction			
Demolition of existing roofing components including roofing membrane	10	7/25/2011	8/5/2011
Removal of existing metal roof deck	10	8/8/2011	8/19/2011
Removal of existing steel joists	15	8/22/2011	9/9/2011
Installation of new steel joists	15	9/12/2011	9/30/2011
Installation of new metal roof deck	10	10/3/2011	10/14/2011
Form, Rebar, and Pour lower-roof concrete	10	10/17/2011	10/28/2011
Concrete – fully cured	30	10/31/2011	12/9/2011
Installation of new roofing components including new TPO roofing membrane	10	12/12/2011	12/23/2011
Spray Fireproofing	10	12/12/2011	12/23/2011
Installation of green roof components	15	12/26/2012	1/13/2012
Installation of LiveRoof® modular green roof vegetation	2	1/16/2012	1/17/2012
MEP/FP Rough-In			
Level 2 – Beneath Lower Roof Only	60	12/26/2011	3/16/2012
Interiors			
Level 2 – Beneath Lower Roof Only	30	2/6/2012	3/16/2012
MEP/FP Finishes			
Level 2 – Beneath Lower Roof Only	30	3/19/2012	4/27/2012
Punchlists and Inspections			
Level 2 – Beneath Lower Roof Only	10	6/18/2012	6/29/2012
Completion and Occupancy			
Level 2 – Beneath Lower Level Roof Only	0	7/10/2012	7/10/2012

The demolition construction task's duration does not change from the existing detailed project schedule. To implement the green roof system onto the lower roof, the new construction tasks that need to be added to the detailed project schedule include: removal of the existing metal roof deck, removal of the existing steel joists, installation of the new steel joists, installation of the new metal roof deck, pouring of the lower roof's concrete, complete curing of the concrete, installation of new roofing components, spraying of fireproofing, installation of green roof components, and installation of LiveRoof®'s modular green roof vegetation.

It was assumed that the total construction process of the lower roof will take 117 days; therefore, the construction of the lower roof will start on July 25, 2011 and end on December 23, 2011. This duration is approximately 90 days more than the previous detailed project schedule's duration for the construction of the lower roof. However, this approximation is very reasonable because the use of a hydraulic truck crane is needed to remove the existing steel joists and install the new steel joists. Also, a concrete pump truck is needed for the construction of the lower roof's new concrete slab. For the green roof system, the installation of the green roof components and the installation of LiveRoof®'s modular green roof vegetation will take approximately 17 days; therefore, the construction of the green roof system only will start on December 26, 2011 and end on January 17, 2012.

The MEP/FP Rough-In construction task can start at the same time as the installation of the green roof system's components and LiveRoof® vegetation construction tasks. Therefore, using the same duration of 60 days from the existing detailed project schedule, the MEP/FP Rough-In of the Level 2 apartment units located beneath the lower roof will begin on December 26, 2011 and end on March 16, 2012. Then, Level 2's Interiors and MEP/FP Finishes construction tasks will be completed in a total of 70 days starting on February 6, 2012 and ending on April 27, 2012. The Punchlists and Inspections construction task will start on June 18, 2012 and end 10 days later on June 29, 2012.

Accounting for all of the construction delays due to the implementation of the designed green roof system, the Level 2 apartment units located beneath the lower roof will not be completed and occupied until July 10, 2012, which is approximately 79 days after the existing expected completion of these apartment units. The results of this schedule impact analysis show that the implementation of the proposed green roof system causes a major delay in the critical path of the detailed project construction schedule. However, it does not delay the overall project completion date, which is in October 2012.

In addition, even though the process of replacing the existing metal roof deck and steel joists will take longer than the process of installing all the green roof system's components, it is very important to understand the process of installing the modular LiveRoof® system. According to the "LiveRoof® Installation: Guide of Standardized Procedures," when installing a LiveRoof® modular green roof system, there are several tasks that need to be completed. First, the roof is tested to ensure that it is waterproof, and the roofing contractor approves the beginning of the installation. Then, the protective slip sheet (root barrier) is placed and held down with temporary weights. After the slip sheet is placed, the LiveRoof® systems components are ready to be delivered to the construction site. Advanced preparation is very important to consider before the modules arrive at the construction site because it will save time and money and ensure maximum quality (LiveRoof® Installation: Guide of Standardized Procedures" et al.). During the advanced preparation process, a plan is devised to set up for efficient installation. This plan includes determining the efficient placement of the hydraulic truck crane, unloading point and point of delivery, and conveyors, and the efficient process of work flow. Once the plants are installed, they need to be watered because each module requires approximately 1 ¼ gallons of water.

4.9 Green Roof System Analysis Summary

After analyzing the implementation of a green roof system onto River Vue's lower level roof's design, the following information was determined:

- After extensive research, the pre-vegetated modular LiveRoof® Maxx System was used for this analysis.
- For River Vue, the primary function of the green roof system is to incorporate a relaxing green space for residents to enjoy in an urban environment.
- The proposed green roof design consists of a pre-vegetated modular LiveRoof® Maxx System, concrete pavers, brick pavers, aggregate/stone gravel, floor-recessed and pole lighting, recreational benches, and access stairs and handicapped ramp.
- The overall roof area of River Vue's Level 2 roof is 10,268.76 SF. The green roof accounts for 57.64% of the overall roof area which makes this a very energy efficient, flexible, and functional design.
- To access the lower-level roof, one apartment unit on the third floor has to be eliminated, and access stairs, a handicapped ramp, railings, and an exterior door would have to be installed because the third-floor floor line is approximately two feet above the lower-roof line.
- The metal roof deck must change from a 1.5B20 roof deck to a 1.5B16 roof deck to accommodate the green roof system load.
- The steel joists must change from 14WF53 steel joists to 22KCS3 open-web steel joists to accommodate the green roof system load.
- The initial cost of the green roof system, including material and equipment and labor, is $404,838.68.
- A rent increase analysis was performed to accommodate for the green roof system's yearly maintenance costs and for the loss of the third-floor apartment unit. The total rent increase is $45.00 per apartment.
- Based on the rent increase analysis alone, the green roof system is a very beneficial investment to the owner because it adds quality and marketability to the building's design, increases the building's energy efficiency, and increases the roofing membrane's durability.
- Even though the implementation of the designed green roof system causes a delay of the lower roof's and Level 2's (beneath the lower roof) construction schedule, the green roof system is still a very valuable investment for the owner.

5.0 Technical Analysis #3: 3D Laser Scanning Technology Implementation

5.1 Problem Identification

After analyzing the unique and challenging constructability issues on the River Vue project, as-built drawing inconsistencies and coordination were two of the most significant challenges. Since the existing building was constructed in the 1950s and renovated in the 1980s, the as-built drawings are not up to date. The drawings caused some challenges on the project during the construction phase. Coordination of the MEP systems took an extensive amount of time because of as-built drawing inconsistencies and the existing steel and the tight constraints between the structure and the future building heights. For the River Vue project, Building Information Modeling (BIM) was not used in the designing, analyzing, integrating, and documenting processes. The MEP designers coordinated the MEP systems without using coordination software.

5.2 Research Goals

The goals for this technical analysis are to analyze the effects of using three-dimensional (3D) laser scanning technologies to evaluate existing building conditions and to determine the cost and schedule impact. Also, it is important to analyze how the 3D laser scanning technology contributes to a 3D model and 3D coordination.

5.3 Research Methods

- Research benefits of the 3D laser scanning technology
- Determine the project members that benefit from 3D laser scanning technology
- Analyze how 3D laser scanning technology contributes to a 3D model
- Analyze how the 3D model can benefit coordination
- Perform cost analysis on 3D laser scanning technology implementation
- Interview General Contractor and MEP designer
- Compare 3D laser scanning technology costs with change order costs
- Determine the schedule impact when implementing 3D laser scanning technology

5.4 Background Information

There are several techniques utilized to capture and evaluate existing building conditions. Specifically, 3D laser scanning is very beneficial on renovation construction projects like River Vue. To beneficially complete this analysis, it is important to understand what 3D laser scanning technology is, how it is used properly, and what benefits are associated with this type of innovative technology.

According to article "Virtual Reality and Laser Scanning Applications," "3D laser scanning is a fast, accurate, and cost-effective method of gathering three-dimensional data to use for 3D modeling and mapping" (Anderson-Wilk, Andrle, and Jaselskis et al.). In addition, the 3D laser scanning and 3D modeling process involves six primary steps including targeting the area, scanning the area to create a point cloud, coloring the points, registering the scans together, creating a virtual database, and creating the detailed 3D model (Anderson-Wilk, Andrle, and Jaselskis et al.). Laser scanning applications can be used in construction design, logistics, management, mechanical engineering, planning and surveys.

5.4.1 Benefits of 3D Laser Scanning Technology

In the construction industry, 3D laser scanning technology offers many benefits; however, there are several disadvantages as well.

Benefits:

- Captures existing condition data for accurate adaptive reuse and renovation construction planning and design
- Creates as-built construction drawings for quality assurance purposes
- Generates 2D plans from highly accurate point clouds
- Creates a 3D model of the complete building from the point clouds for daily operation planning and analysis by the building's owner
- Creates a visual reference of as-built conditions
- Links information between architects, contractors, and engineers which reduces costs
- Increases accuracy and reduces variance in engineering and construction bids
- Compares the existing conditions against the planned design to identify "clashes" prior to construction
- Reduces project errors and rework
- Ensures pre-fabricated parts will fit in their intended location prior to transportation and installation on the project
- Reduces the overall project schedule

5.4.2 Product Information

See Appendix O for Leica ScanStation C10 Product Specifications

After extensive research, Leica Geosystems Inc.'s ScanStation C10, shown in Figure 19, will be used for this 3D laser scanning technology technical analysis. According to Leica Geosystems, Inc.'s official website, "the Leica ScanStation C10 is a compact, all-in-one 3D laser scanner that includes a tilt sensor, battery, controller, data storage, auto-adjusting video camera, and laser plummet" ("Leica ScanStation C10" et al.). There are several benefits to using the ScanStation C10 including excellent system performance, unprecedented versatility, major productivity advances, and valuable cost savings. For example, at a 1 m to 50 m range, one sigma, this 3D laser scanner's accuracy of position and distance is astonishingly

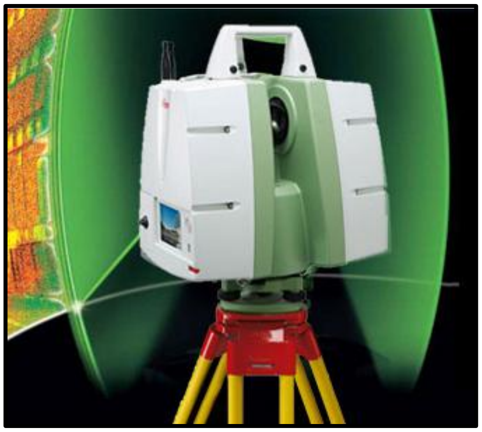

Figure 19: Image of the Leica ScanStation C10 from Leica Geosystems Inc.'s Website

6 mm and 4 mm, respectively. Also, it has the capability of all-in-one construction which includes the total station-like interface, external laptop for onsite viewing and data processing, integration of real-time streaming video with zoom, Smart X-Mirror™ design, and compatibility with standard surveying equipment ("Leica ScanStation C10" et al.).

After extensive research about the appropriate software to use to process the data produced by the 3D laser scan, Leica Geosystems Inc.'s HDS Cyclone software will be used for this analysis. According to Leica Geosystems, Inc.'s official website, "the HDS Cyclone (Cyclone) software provides point cloud users with the widest set of work process options for 3D laser scanning projects in engineering and construction" ("Leica Cyclone" et al.). In addition, for different needs, Cyclone is flexible, and it consists of individual software modules including Scan, Register, Model, Survey, Importer, Viewer Pro, Server, and Publisher. To briefly summarize the individual modules, Scan is the software interface that operates the ScanStation C10, and Register aligns point clouds captured quickly and accurately from different scanning positions ("Leica Cyclone" et al.). "The Model software enables industry professionals to use point clouds directly to process them into objects for export into CAD and other design applications" ("Leica Cyclone" et al.). From the point cloud data, the Survey software lets surveyors quickly receive relevant feature and coordination information, and Importer provides direct importing of point cloud formats. Finally, Viewer Pro is an enhanced view-and-measure-only software, and Server and Publisher lets industry members access 3D point cloud data sets and publishes point cloud date for web-sharing respectively ("Leica Cyclone" et al.).

5.4.3 As-Built Drawing Inconsistencies

During the construction phase of the River Vue project, the as-built drawings caused some constructability challenges. The not-expected building elements were found during the demolition phase. To better understand the types of issues caused by the as-built drawing inconsistencies, a detailed breakdown of each constructability challenge is described below.

Demolition for Door 109/1: The project's scope for demolition called for wall demolition that created two chases at the future location of Door 109/1. After the demolition of these walls, a 3' high concrete haunch was discovered inside of the west chase. The 6'-0" wide door would not fit into the existing opening due to this slab. To accommodate for the new floor plan, the structural engineers (Whitney Bailey Cox & Magnani, LLC) determined that the haunch slab could be removed as required. Also, they advised that parts of the haunch should be left in place to support the remaining existing wall.

Clash Between Trash Chute and Existing Steel: During the construction phase of the River Vue project, there was a constructability challenge that consisted of a coordination issue. Specifically, for the trash-chute design, numerous collisions between the chute and existing steel occurred. The collisions were located at the roof deck, penthouse slab, and just above the mail room ceiling as the chute exited the building. Also, the trash chute clashed with the steel for the new canopy including a W24x55 spanning from north to south and a W18x40 spanning from east to west.

Column in New Apartment Space: While demolishing the existing building elements on the sixteenth floor near Elevator #7, a structural column was located in the middle of a proposed apartment unit's bedroom (Apartment #1510). Figure 20 shows the column location (marked with a circle) in the middle of Apartment #1510's bedroom. After extensive time, research, and collaboration, the structural engineers decided that the column could be relocated. Redesigning the apartment layout could not be pursued because it would affect other trade operations such as MEP system components routing to the kitchen and bathroom locations and lighting spaces. If redesigning the apartment layout was pursued, it would cost more to redesign the MEP systems to accommodate for the column.

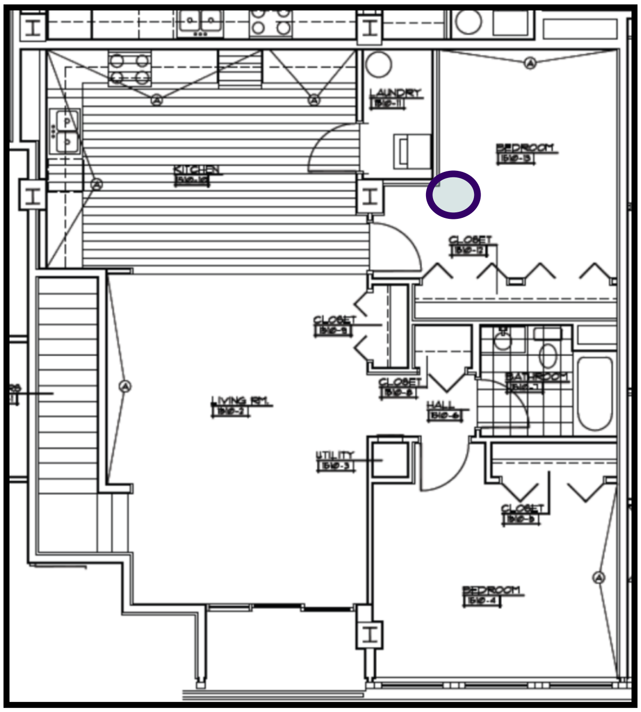

Figure 20: Original Column Location in Apartment #1510's Bedroom

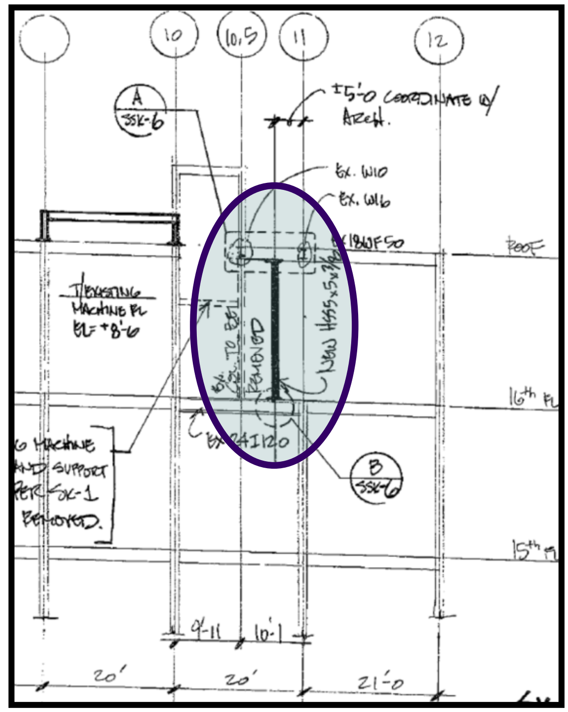

Figure 21: New Column Location

The column was a structural and load-bearing column. Therefore, it could not be moved without the structural engineers determining how to transfer the load the column was carrying from the roof in its original location to its new location. After performing the necessary calculations, the structural engineers determined that the column could be relocated between the existing W10 and W16, shown in Figure 21.

Existing Beam in New Tennant Space: During demolition, an existing W12x53 beam that spans from column 1.9 to column 3 was discovered. Located along column line B, the beam was 1'-0" above the lobby floor and 1'-7" above the first floor framing. The existing beam was used to support the wall at the former lobby. To determine if the beam could be moved, the structural engineers were contacted. They determined that the existing beam with stiffeners and bottom plate could be removed. However, the 6" I-beam that extends to the north of column line 1.9 and south of column line 3 may only be moved if it is necessary.

Existing Steel Beams at Stair 1510: On the fifteenth floor, existing steel beams were in the way of installing the new W16x36 beam that is needed to frame the stair opening for apartment unit 1510. The steel did not appear to be structural, but it needed to be removed to install the stairs. The structural engineers stated that the existing steel beams could be removed in order to install the new beam for the stair open. Figure 22, provided by Turner, shows the existing steel beams and the stair opening.

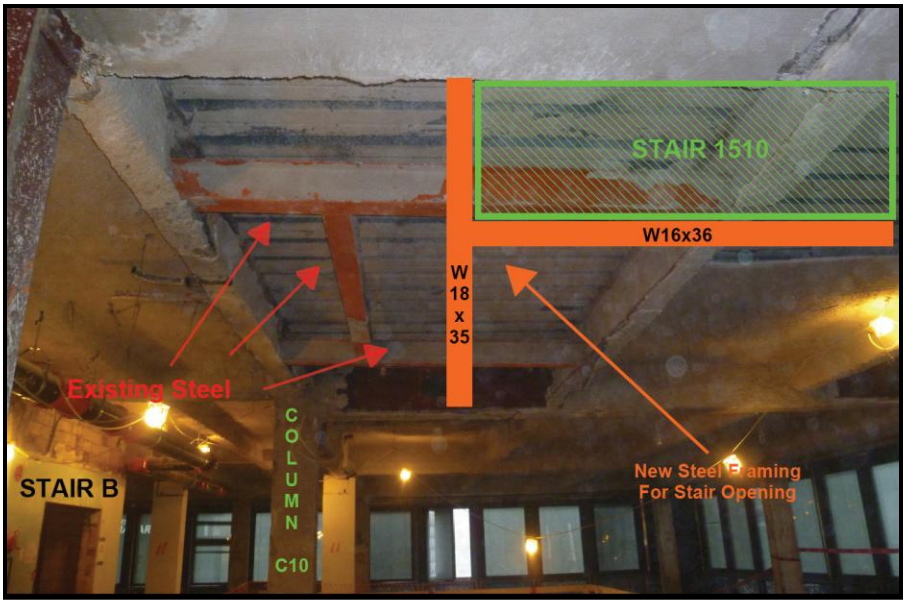

Figure 22: Image of Existing Steel Beams at Stair 1510

Overhead Beam in Unit 1519: In apartment unit 1519, above Level 16's slab, an existing 18WF55 header was located between columns B4 and B5 at a top steel elevation of 7'-10 3/8". The beam was located above the bathroom. To resolve this challenge, the EX 18WF was hung from the underside of EX 30WF108. After the hanger installation, the remainder EX 18WF was carefully cut to not damage the beam remaining and the new hanger/connection installed.

Waterproofing Details Unknown: During the construction of the new balconies, Turner determined that the support and waterproofing details of the metal panel system added constructability challenges. The challenges occurred at the location where the new inboard balconies and windows are to be installed. Specifically, during the bid period, the waterproofing details of the metal panel system were unknown because the details were not on the as-built drawings. Since the details were unknown, numerous meetings with the designers and subcontractors were held to determine and finalize the waterproofing that would be necessary. In addition, the 1980s curtain wall system was a utilized metal panel system that the balconies penetrated in between multiple panel units. The integrity of the remaining panel units needed to be confirmed.

5.5 3D Laser Technology Implementation

After determining the main constructability challenges that have occurred during the construction phase of the River Vue project, the implementation of 3D laser scanning technology is a very beneficial way to avoid these issues during the preconstruction phase of the project. The objectives for implementing 3D laser scanning are to generate accurate as-built construction drawings, generate a 3D model that benefits the design and coordination of River Vue, and quality control. To better understand why 3D laser scanning technology is so beneficial for the River Vue project, each of these objects is described in detail below.

As-Built Drawing Generation: The constructability challenges describe in Section 5.4.3 of this report added time and material costs to the River Vue project. Also, since the design process took extensive time and research, the schedule was impacted because installation of the other required building elements could not continue until those challenges were resolved. Therefore, the use of 3D laser scanning technology could be very beneficial to the construction process of River Vue. For quality control purposes, the ScanStation C10 laser scanner would capture River Vue's existing condition data (point clouds). Then, the Cyclone Model software would process the point clouds into objects for export into CAD or other design applications to accurately create two-dimensional (2D) as-built construction drawings. These 2D drawings, including plans, sections, elevations, and details, could be very beneficial to several members of the project team especially the designers. For instance, if the architects, D4S and IDG, have accurate drawings of the existing River Vue building, they can efficiently and effectively layout the new design without major issues.

3D Model Generation for Design and Coordination: The ScanStation C10 laser scanner would capture River Vue's existing condition data (point clouds). Then, using the Cyclone Model software, the point clouds would be exported into a 3D design application to create a 3D model of the complete building for design planning and analysis. Figure 23, from the 3D Laser Scanning Solution blog, shows a visual example of the work flow process just described.

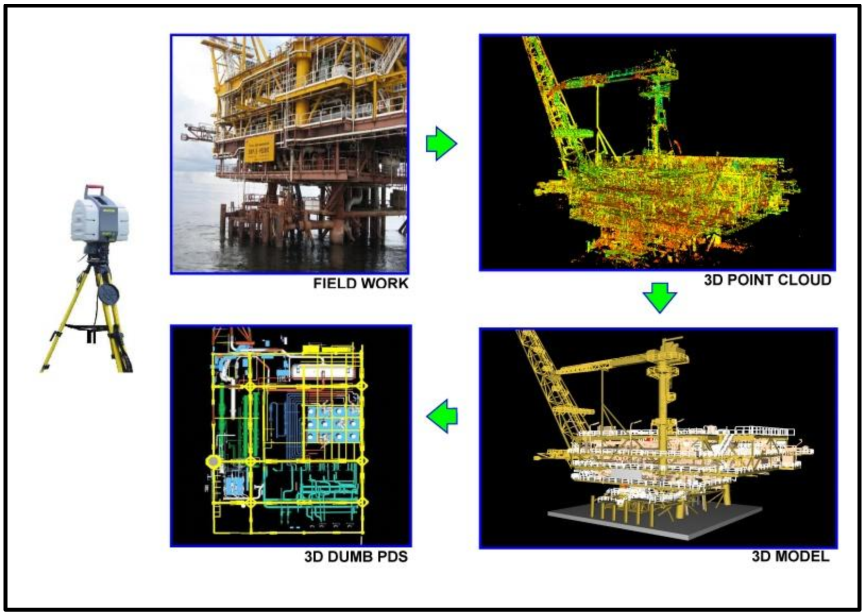

Figure 23: Image of "3D Laser Scanning Work Flow from the 3D Laser Scanning Technology Solution" Blog

The 3D model could be very beneficial to several members on the project team. For the architects, the 3D model could allow them to build virtual mock-ups of the apartment units' layout and design to visually see issues that could occur. Also, different design options and alternatives could be easily modeled and changed during the design review. For the MEP and structural designers, using Autodesk's Navisworks program, the existing conditions of River Vue could be compared to the planned building systems' design to identify clashes prior to the construction phase of the River Vue project. For the owner, RVA, 3D modeling could be a very beneficial visual representation of the River Vue building. The owner could visualize the construction and see the end product of the building before the construction phase has even started. It easily communicates the design to the owner, construction team, and end users.

In addition, once construction is complete on River Vue, the 3D model would still be very beneficial and would add a significant amount of value to the building. Specifically, the 3D model could be linked into a record model which would be used to accurately represent the physical conditions, environment, and assets of a facility. The record model would include information relating to the main architectural, structural, and MEP elements of River Vue. Also, this 3D model would aid the owner and designers in future modeling and 3D design coordination for renovations and improve documentation of building conditions.

Quality Control: After the 3D laser scanner technology is used for the preconstruction phase of the River Vue project, it could be used during the construction phase as well. As construction is progressing, the ScanStation C10 laser scanner could be used to scan the completed areas, and the Cyclone Model software would process the point clouds into objects and export them into a 3D model design software. A new model could be generated from these points and linked and compared to the existing design 3D model made during the preconstruction phase. This process guarantees that the highest level of quality is being maintained throughout the construction on River Vue.

5.6 Feasibility Analysis

5.6.1 3D Laser Scanning Technology Implementation Cost

The total cost of implementing 3D laser scanning technology includes two major costs, the cost for the laser scanning process and the BIM services. The cost of the laser scanning process was obtained from Dr. Craig Dubler, an industry professional at the Office of the Physical Plant (OPP) at the Pennsylvania State University and Architectural Engineering professor. Since BIM services cost is proportional to the level of detail needed and magnitude of the material being modeled, the BIM services cost was not obtained. Therefore, for this analysis, the only cost being evaluated is the cost of implementing the 3D laser scanning process which does not include the point cloud evaluation process cost.

The following is a breakdown of the total cost for implementing the 3D laser scanning process:

Total Gross Building Area = 295,000 SF

Cost per SF = $0.50/SF

Total cost of 3D laser scanning process = $147,500

5.6.2 Cost of Changes Orders

In determining the feasibility of implementing 3D laser scanning technology based on a cost standpoint, an important factor to evaluate is the total cost of the change orders due to as-built drawing inconsistencies. Since the actual costs of the change orders could not be provided by Turner due to privacy concerns, an educated estimate was produced to determine the total cost. The estimate is based on the magnitude of the issues and the total installation and material cost of steel provided by Turner. The magnitude of the issues is based on a scale of high magnitude (1% to 5%), medium magnitude (0.5% to 1%), and low magnitude (0.1% to 0.5%).

Table 27 shows a breakdown of the total cost of the change orders due to as-built drawing inconsistencies. These values are an approximation obtained from the standard estimating manual, RS Means Facilities Construction Cost Data 2010, and altered by the Pittsburgh, location factor. They do not represent Turner's actual values.

Table 27: Total Cost of Change Orders

Change Orders	Magnitude of Issue	Percentage of Magnitude (%)	Change Order Cost ($)
Demolition for Door 109/1	Medium	0.5	5,530.32
Clash Between Trash Chute and Existing Steel	High	3	33,181.92
Column in New Apartment Space	High	1	11,060.64
Existing Beam in New Tennant Space	Low	0.3	3,318.19
Existing Steel Beam in Stair 1510	Low	0.1	1,106.06
Overhead Beam in Unit 1519	Medium	0.6	6,636.38
Waterproofing Details Unknown	High	2	22,121.28
TOTAL			**$82,954.80**

5.6.3 Cost Comparison

To effectively determine the feasibility of implementing 3D laser scanning technology into the preconstruction phase of the River Vue project, the 3D laser scanning technology's total cost and the total cost of the change orders due to as-built drawing inconsistencies were compared. The total cost of implementing the 3D laser scanning process is $147,500, and the total cost of the change orders due to as-built drawing inconsistencies is $82,954.80 which is a $64,545.20 difference. From a cost standpoint only, the results show that implementing 3D laser scanning technology into the preconstruction phase of the project is not feasible for the owner or the project. However, laser scanning technology could offer so many benefits to the River Vue project like accurate as-built drawings, a visual reference for coordination and value, and quality control. Therefore, from a quality and value standpoint, the implementation of 3D laser scanning technology is very beneficial and feasible to the owner and project because additional quality is added to River Vue preconstruction and construction phases. Even though

3D laser scanning technology could be beneficial from a quality and value standpoint, for this analysis, implementing 3D laser scanning technology is not recommended to the owner.

5.7 Schedule Impact

Since the schedule is the main factor in completing a project successfully and efficiently, a schedule impact overview is important to include in this analysis. According to Dr. Craig Dubler, using the ScanStation C10, the 3D laser scanning process takes half of a day per floor to scan the entire floor. Also, using the Cyclone software, it takes one day per floor to process the information. Therefore, for the River Vue project, the laser scanning process will take eight full days to complete, and the information processing will take 16 days. After the point clouds from the scan are processed, they are exported into a modeling software. The amount of time it takes to generate a model from the data is proportional to the level of detail. For example, if the owner or designers require more detailed modeling, then the modeling process will take longer. However, the laser scanning technology and modeling can reduce the schedule throughout the project because delays during construction could be avoided by using this technology.

5.8 3D Laser Scanning Technology Analysis Summary

After analyzing the implementation of 3D laser technology into River Vue's construction process, the following information was determined:

- There are several benefits to implementing 3D laser scanning technology into River Vue's preconstruction and construction phases. Some of these benefits include capturing existing condition data for accurate adaptive reuse and renovation construction planning and design, creating 2D as-built construction drawings for quality assurance purposes, and creating a 3D model of complete building for visual reference.
- Leica Geosystems, Inc.'s ScanStation C10 laser scanner and Cyclone software were used for this analysis.
- During the construction phase of the River Vue project, the as-built drawing inconsistencies cause some constructability uses including the demolition for Door 109/1, clash between trash chute and existing steel, column in new apartment space, existing beam in new tenant space, existing steel beams in Stair 1510, overhead beam in Unit 1519, and unknown curtain wall water proofing details.
- The objectives for the implementation of 3D laser scanning technology are to generate accurate as-built construction drawings, generate a 3D model that benefits the design and coordination of River Vue, and quality control.
- The total cost of the laser scanning process is $147,500, and the total cost of the as-built drawing inconsistency change orders is $82,954.80 which is a $64,545.20 difference.
- Even though 3D laser scanning technology could be very beneficial during the preconstruction and construction phases of the River Vue project, from a cost standpoint, the results show that implementing 3D laser scanning technology into the preconstruction phase of the project is not

feasible for the owner or the project. Therefore, the implementation of 3D laser scanning technology is not a recommended investment to RVA.

6.0 Technical Analysis #4: Lighting Occupancy Sensor Control System Implementation

6.1 Problem Identification

During the PACE Roundtable's Energy Management Services session, industry professionals discussed many key topics about energy management, a critical industry issue, and its techniques for residential buildings like River Vue. Occupant behavior has a major impact on the building's energy consumption. However, it is a challenge to have energy efficient electrical and lighting systems that are used beneficially by the building's occupants. Most building occupants do not understand how much their behavior can harm the building's energy performance.

6.2 Research Goal

The goal for this technical analysis is to research new ideas for electrical and lighting systems that are energy efficient, but simple enough for the occupants of the building to use the system correctly without jeopardizing their comfort.

6.3 Research Methods

- Research the different types of sensor systems
- Analyze the occupant behavior in the building
- Determine the potential sensor system that could be used for River Vue
- Determine how the senor system affects the building's energy consumption
- Determine the life-cycle costs of the new sensor system
- Compare the life-cycle costs to the actual building costs

6.4 Background Information

Many of the industry professionals agreed that the major part of energy management is determining the efficient operation of the electrical and lighting systems in a building ("Energy Management Services" et al.). After the preconstruction, procurement, and construction phases, energy management still needs to be enforced when the building is occupied. Occupant behavior has a huge impact on energy management. Therefore, the controls and systems need to be simplified to the degree that the occupants will be able and willing to properly use them ("Energy Management Services" et al.). Also, if the building occupants are aware and trained about their energy consumption and how it affects the environment, they would be willing to contribute more to the lifecycle of the building ("Energy Management Services" et al.).

Specifically, simplified controls for electrical and lighting systems could be very beneficial to River Vue because it is a residential apartment building. For this analysis, the main focus is on lighting occupancy sensor control systems. In order to successfully complete this analysis, background research on this type of control system was completed.

6.4.1 Lighting Occupancy Sensor Control Systems

Lighting occupancy sensor control systems are automatic lighting control systems that recognize activity within a certain monitored area. By detecting activity in a room and automatically turning on and off the light when people enter or exit a room, lighting occupancy sensors save energy and money. Specifically, the lighting occupancy sensors can be a very cost-effective way to reduce the operating time of lighting systems and increase energy savings.

According to Sensor Switch's official website, there are several types of occupancy sensor technology including passive infrared (PIR), microphonic, ultrasonic, and dual-technology.

Passive Infrared (PIR): Passive infrared occupancy sensors detect movement and increased heat as people enter a room, and they detect the absence of movement and decreased heat as people leave a room ("Company Overview" et al.). This type of sensor is most effective in smaller, enclosed spaces where the sensor has a direct line of sight to sense motion.

Microphonic: Microphonic occupancy sensors listen to irregular sound patterns to detect motion in a room ("Company Overview" et al.). This type of sensor is most effective in rooms with obstructions and where occupants turn their backs to the sensor. Also, this sensor provides a more reliable occupancy detection performance than ultrasonic technology because it does not transmit sound waves into a room which could potentially be prone to interference ("Company Overview" et al.).

Ultrasonic: Ultrasonic occupancy sensors emit a high-frequency signal that bounces off objects, surfaces, and people in a room ("Sensor Systems" et al.). After returning to the sensor, the change in the frequency is interpreted as motion. This type of sensor is most effective in rooms with open space or with obstacles, restrooms, and rooms with hard surfaces. However, ultrasonic sensors are highly sensitive to smaller movements, and false triggering can become a problem if these sensors are not correctly designed ("Sensor Systems" et al.).

Dual-Technology: Dual-technology occupancy sensors utilize both passive infrared and microphonic technologies for maximum coverage and reliability ("Company Overview" et al.). This type of technology allows the sensor to first see motion using the passive infrared technology and then engage microphonics to hear sounds that indicate continued occupancy. To self adapt a sensor to its environment by filtering out constant background noises and detecting only noises typical of human activity, automatic gain control (AGC) technology is used. When occupancy is detected, the relay switches the connected load on, which is dictated by the sensor's operational settings. Also, this type of sensor is most effective in rooms with obstructions and where occupants turn their backs to the sensor.

6.4.2 Product Information

***See Appendix P for Sensor Switch's WSD-PDT Specifications**

After extensive research and consulting the specifications for River Vue, one of Sensor Switch's products will be used for this analysis because their products are being used in restrooms in River Vue's lobby area. According to Sensor Switch's official website, "Sensor Switch is the industry leader in developing occupancy sensor products and technology for lighting control. Their products have many features that make them the most technologically advanced in the industry including continuous coverage patterns for small motion detection, 'see and hear' technology into areas with obstructions, relay circuit protection, and sensors with the widest array offered from any manufacturer in the USA" ("Company Overview" et al.).

After reviewing the operation settings and features, the wall switch decorator sensor – passive dual technology (WSD-PDT), shown in Figure 24, was chosen and recommended. According to the WSD-PDT's datasheet found on Sensor Switch's website, the WSD-PDTs utilize both passive infrared and microphonics detection technology. The WSD-PDTs will operate under the following conditions: "automatic on" which is the default operation that allows the lights to come on when occupancy is detected and "predictive off mode" allows occupants to turn lights off by pressing the push-button without losing the purpose of an occupancy sensor because the lights will still automatically turn on when the room is re-entered again.

Figure 24 – Image of the WSD-PDT Sensor from Sensor Switch's Website

In addition, the WSD-PDTs will have a coverage pattern of small motion (e.g. hand movement) detection up to 20 ft and large motion (e.g. walking) detection up to 50 ft. The internal timer of the WSD-PDT is recommended to be set at a one minute delay instead of the default 10 minute delay to save more energy, and voice reactivation will be included. Finally, to accommodate for high humidity in the apartment units' bathrooms, the WSD-PDT sensors will feature the low/high humidity option. This option ensures that the sensor is corrosion resistance and that it can operate at negative 4°F.

6.5 Building Occupant Behavior Analysis

Since building occupant behavior has a major impact on the building's energy consumption, it is important to understand how the apartment residents might behave in River Vue. For instance, automatic human habits, such as exiting a room without turning the lights off or leaving a computer on all day, are one of the most significant aspects that contribute to an increase in a residential building's energy consumption.

According to the article "Sensors for an Energy Conscious World" on Hubbell, Inc.'s official website, apartment building residents use a significant amount of electricity each day. This electricity is used to operate appliances, climate control, electronics, lighting, water heating, and other electrical consuming devices. Figure 25 shows a percentage breakdown of a typical residential electricity usage. Even though climate control uses 25% of the total residential electricity usage, lighting uses a significant amount (23%) as well. The remainder is Electronics, Appliances, Water Heating, and Other.

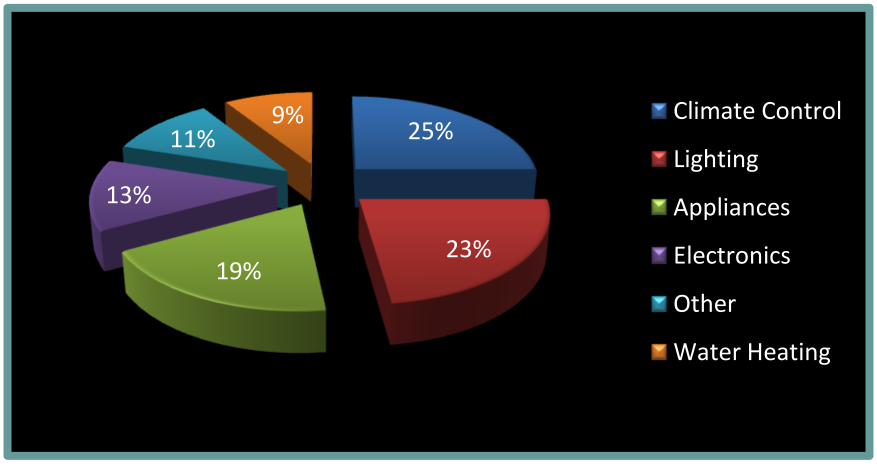

Figure 25: Typical Residential Electricity Usage Breakdown

This typical residential electricity usage information is very important in determining energy saving locations in the apartment units and potential success factors. The most effective locations to place occupancy sensors are areas that are frequently used, areas with regular use patterns, or areas where lights are inadvertently left on. These locations include apartment bathrooms, bedrooms, closets, hallways, kitchens, and laundry rooms; however, the apartment bathrooms, closets, and laundry rooms have the most energy savings based on an average occupancy and installation complexity.

6.6 Potential Energy Savings

To reduce a building's electrical energy consumption, a lighting occupancy sensor control system can be very beneficial. However, apartment buildings, such as River Vue, generate a large amount of electrical energy because they are occupied 24 hours a day and every day each year. Therefore, the lighting occupancy sensor control system cannot service every space and light fixture throughout the entire building, but it can help reduce the overall electrical energy consumption and utility costs. The yearly electrical energy consumption for River Vue, was previously calculated in Section 3.5.2 of this report. Table 28 shows the estimated total value for River Vue's electrical consumption per year, month, and day.

Table 28: Energy Loads for the Whole Building

Kilowatt-Hours Per Year	34,993,283.2843
Kilowatt-Hours Per Month	2,916,106.9404
Kilowatt-Hours Per Day	95,872.0090

The estimated value of kWh/year is 34,993,283.2843 kWh. To calculate the kWh/month and the kWh/day, the kWh/year was divided by 12 months and 365 days, respectively. Since a lighting occupancy sensor system would not be practical to use throughout the entire building, this analysis will focus on implementing the WSD-PDTs in the apartment units' bathrooms, laundry/utility rooms, and walk-in closets. Table 29 shows the calculated energy loads for the apartment unit's bathroom, laundry/utility room, and walk-in closet lighting.

Table 29: Energy Loads for Bathroom, Laundry, and Walk-In Closet Lighting							
Light Fixture	Location Used	Watts/Light Fixture	Quantity	kW	Hours/ Day	kWh/ Day	kWh/ Year
Vanity Light	Bathroom	39	239	9.321	12	111.852	40,825.98
Exhaust Fan/Light	Bathroom	75	238	17.85	12	214.2	78,183
Surface Fluorescent	Laundry/Utility Room	64	152	9.728	12	116.736	42,608.64
Decorative Glass	Walk-In Closets	26	38	0.988	12	11.856	4,327.44
	TOTAL	**204**	**667**	**37.887**		**454.644**	**165,945.06**

To calculate the energy loads for the apartment units' bathroom, laundry/utility, and walk-in closet lighting, the type of light fixture and watts used per light fixture needed to be determined. After consulting the River Vue project's drawings and specifications for this information, the watts per light fixture were calculated. Then, light fixture take-offs were completed to correctly determine the quantity for each type of light fixture. A detailed breakdown of the apartment units' light fixture take-offs notes is provided in **Appendix Q**. In each location in the apartment units, assuming an operation of 12 hours for each light fixture, the kWh/day values were figured. By multiplying the kWh/day by 365 days, the kWh/year values were determined and added together to calculate the total kWh/year for all of the light fixtures in the apartment units. The total kWh/year for all of the light fixtures is 165,945.06 kWh/year. These energy loads are only 0.474% of the total electrical energy loads for the whole building. However, reducing these energy loads by implementing a lighting occupancy sensor control system is still very beneficial to River Vue's energy efficiency and the owner.

A lighting occupancy sensor control system is a very beneficial electrical and lighting design that reduces River Vue's energy consumption. Table 30 shows the energy savings from the occupancy sensors.

Table 30: Energy Savings from Occupancy Sensors								
Location Used	Quantity	Watts/ Light Fixture	kW	Hours/ Day	kWh/ Day	Percent Savings (%)	Daily Energy Savings	Annual Energy Savings
Bathroom	239	39	9.321	12	111.852	40	44.7408	16,330.392
Bathroom	238	75	17.85	12	214.2	40	85.68	31,273.2
Laundry/ Utility Room	152	64	9.728	12	116.736	50	58.368	21,304.32
Walk-In Closets	38	26	0.988	12	11.856	60	7.1136	2,596.464
TOTAL	**667**	**204**	**37.887**		**454.644**		**195.90**	**71,504.38**

To determine the annual energy savings for implementing the lighting occupancy sensor control system, the type of light fixture, watts used per light fixture, and the quantity of each light fixture was obtained from the previous calculation. In each location in the apartment units, assuming an operation of 12 hours for each light fixture, the kWh/day values were figured. Each location in the apartment units has a certain percentage of potential energy savings because of the system. Specifically, according to Green Wise, a sustainability initiative of Hubbell Lighting, the apartment bathrooms, laundry/utility room, and walk-in closets have 40%, 50%, and 60% potential energy savings, respectively ("Energy Savings with Occupancy Sensors" et al.). To calculate the daily energy savings, the kWh/day values were multiplied by the percent savings. The total daily energy savings from the occupancy sensors is 195.90 kWh/day. The total annual energy savings is 71,504.38 kWh/year.

6.7 Feasibility Analysis

6.7.1 Lighting Occupancy Sensor Control System Initial Cost

The total cost of the lighting occupancy sensor control system and its economic feasibility determines if the system should be implemented into River Vue's electrical design. To effectively determine the feasibility of the lighting occupancy sensor control system, the total cost of the system was calculated including the systems appropriate components. The following is a breakdown of the system's cost:

Lighting Occupancy Sensors:

The cost per WSD-PDT for Sensor Switch's WSD-PDT was obtained from Global Industrial.

Number of WSD-PDT sensors = 670

Cost per WSD-PDT sensor = $93.95/sensor

Total cost of WSD-PDT sensors = $62,946.50

Shipping:

The cost per WSD-PDT sensor for Sensor Switch's WSD-PDT occupancy sensor was obtained from Global Industrial.

Number of WSD-PDT = 670

Shipping cost per WSD=PDT sensor = $15.21/sensor

Total shipping cost for WSD-PDT sensors = $10,190.70

Lighting Occupancy Sensor Control System without Incentives and Rebates:

Table 31 shows the initial cost of the lighting occupancy sensor control system without incentives or rebates.

Table 31: Initial Cost of Lighting Occupancy Sensor Control System without Incentives and Rebates	
Component	**Total Cost**
WSD-PDT Occupancy Sensors	$62,946.50
Shipping	$10,190.70
TOTAL	**$73,137.2**

6.7.2 System Cost with Rebates and Incentives

To promote energy efficient electrical and lighting systems, electrical utility companies are instituting rebates and incentives to companies and organizations that install energy efficient products into their building's electrical and lighting design. The following list includes the rebates and incentives eligible in the Pittsburgh, Pennsylvania area:

- Duquesne Light Company offers a $16.50 rebate per sensor. The requirements for this rebate include a wall-box occupancy sensor that must control less than 500 W.

The River Vue project is eligible for this rebate because its lighting occupancy sensor control system meets the requirements, and it is already connected to Duquesne Light Company's vault.

Lighting Occupancy Sensor Control System with Incentives and Rebates:

Number of WSD-PDT sensors = 670

Rebate value per WSD-PDT sensor = $16.50/sensor

Total rebate value for WSD-PDT sensors = $11,055

Table 32 shows the lighting occupancy sensor control system's initial cost after the incentives and rebates have been issued for the River Vue project.

Table 32: Initial Cost of Lighting Occupancy Sensor Control System After Incentives and Rebates			
Incentive & Rebate Name	**Description**	**Cost Reduction**	**Adjusted Cost**
-	Initial Cost	-	$62,946.50
Duquesne Light Company Rebate	$16.50 rebate per sensor	$11,055	$51,891.50
-	Shipping	-	$10,190.70
		FINAL COST	**$62,082.20**

6.7.3 Life-Cycle Cost and Payback Period

When implementing this lighting occupancy sensor control system into River Vue's electrical design, the ultimate goal is for the owner to receive the initial costs of the system back through the system's energy savings within an acceptable payback period. To determine the energy savings and the payback period, the life-cycle savings costs of the lighting occupancy sensor control system needs to be calculated. According to Sensor Switch's website, the lifespan of the WSD-PDT is approximately 15 years.

Therefore, the life-cycle savings costs will be evaluated for 15 years of the system's operation.

First, for comparison purposes, it is important to calculate the life-cycle cost of the light fixture energy loads without the use of occupancy sensors. To calculate the life-cycle cost of the light fixture energy loads, the energy cost per year and energy load per year were determined. The energy cost ($/kWh) is the retail cost of the electricity, which is the rate paid by the utility company (Duquesne Light Company). For this calculation, it was assumed that the energy cost of $0.170/kWh would increase by one percent each year. The energy load, 165,945.06 kWh per year, is the energy produced by the light fixtures each year. Table 33 shows a breakdown of each category and energy loads for each year of the 15-year life-cycle.

Table 33: Life-Cycle Cost of Light Fixture Energy Loads without Occupancy Sensors

Year	Energy Cost ($/kWh)	Energy Load (kWh)	Total Cost ($)
1	0.170	165,945.06	28,210.66
2	0.172	165,945.06	28,542.55
3	0.173	165,945.06	28,708.50
4	0.175	165,945.06	29,040.39
5	0.177	165,945.06	29,372.28
6	0.179	165,945.06	29,704.17
7	0.180	165,945.06	29,870.11
8	0.182	165,945.06	30,202.00
9	0.184	165,945.06	30,533.89
10	0.186	165,945.06	30,865.78
11	0.188	165,945.06	31,197.67
12	0.190	165,945.06	31,529.56
13	0.192	165,945.06	31,861.45
14	0.193	165,945.06	32,027.40
15	0.195	165,945.06	32,359.29
		TOTAL	**$454,025.68**

After calculating the total life-cycle for the light fixtures without occupancy sensors, it is important to calculate the total life-cycle savings from implementing a lighting occupancy sensor control system. To calculate the life-cycle savings cost of the lighting occupancy sensor control system, the energy cost per year and energy savings per year were determined. The energy cost ($/kWh) is the retail cost of the electricity, which is the rate paid by the utility company (Duquesne Light Company). For this calculation, it was assumed that the energy cost of $0.170/kWh would increase by one percent each year. The energy savings, 71,504.38 kWh per year, is the energy reduced by implementing the lighting occupancy sensor control system. Table 34 shows a breakdown of each category and energy savings for each year of the 15-year life-cycle.

Table 34: Life-Cycle Savings Cost of Lighting Occupancy Sensor Control System			
Year	Energy Cost ($/kWh)	Energy Savings (kWh)	Total Savings ($)
1	0.170	71,504.38	12,155.74
2	0.172	71,504.38	12,298.75
3	0.173	71,504.38	12,370.26
4	0.175	71,504.38	12,513.27
5	0.177	71,504.38	12,656.27
6	0.179	71,504.38	12,799.28
7	0.180	71,504.38	12,870.79
8	0.182	71,504.38	13,013.80
9	0.184	71,504.38	13,156.81
10	0.186	71,504.38	13,299.81
11	0.188	71,504.38	13,442.82
12	0.190	71,504.38	13,585.83
13	0.192	71,504.38	13,728.84
14	0.193	71,504.38	13,800.34
15	0.195	71,504.38	13,943.35
		TOTAL	$195,635.97

For the 15-year life-cycle of the lighting occupancy sensor control system, the total life-cycle energy savings cost is $195,635.97. Since the system's initial cost is $62,082.20, the owner does receive the initial costs of the system back through the energy savings within the 15-year payback period. The purple line in Table 34 indicates the payback period for the lighting occupancy sensor control system. The payback period is approximately 5 ½ years (between 5 and 6 years). After deducting the initial cost's value from the total savings value for 15 years, throughout the lifespan of the system, the owner could potentially save $133,553.77 in electrical energy. Therefore, the lighting occupancy sensor control system is a recommended investment for the owner.

6.8 Lighting Occupancy Sensor Control System Analysis Summary

After analyzing the implementation of a lighting occupancy sensor control system into River Vue's electrical design, the following information was determined:

- Lighting uses 23% of total residential electricity usage.
- Automatic human habits, such as exiting a room without turning the lights off or leaving a computer on all day, are one of the most significant aspects that contribute to an increase in a residential building's energy consumption.
- After extensive research, Sensor Switch's WSD-PDT was used for this analysis. The WSD-PDTs utilize both passive infrared and microphonics detection technology. They operate under the following conditions: "automatic on" which is the default operation that allows the lights to come on when occupancy is detected and "predictive off mode" allows occupants to turn lights off by pressing the push-button without losing the purpose of an occupancy sensor because the lights will still automatically turn on when the room is re-entered again.

- The total daily energy savings from the occupancy sensors is 195.90 kWh/day. The total annual energy savings is 71,504.38 kWh/year.
- After eligible incentives and rebates, the initial cost of the lighting occupancy sensor control system, including the cost of the WSD-PDTs and shipping, is $62,082.20.
- For the 15-year life-cycle of the lighting occupancy sensor control system, the total life-cycle energy savings cost is $195,635.97.
- Since the system's initial cost is $62,082.20, the owner does receive the initial cost of the system back through the energy savings within 5.5 years of the occupancy sensors' 15-year lifespan. Therefore, the owner saves an extra $133,553.77.
- This specific lighting occupancy sensor control system is a recommended investment for the owner.

7.0 Recommendations and Conclusions

Throughout the fall 2011 and spring 2012 semesters, River Vue Apartments was significantly evaluated to determine the areas of the building's design and construction that could have been more efficient. This final report consists of the research and analysis of four construction management depth technical analyses. The technical analysis areas include:

- Photovoltaic Glass Window System Implementation
- Green Roof System Implementation
- 3D Laser Scanning Technology Implementation
- Lighting Occupancy Sensor Control System

The theme for this architectural engineering senior thesis capstone project is to incorporate value engineering techniques, such as energy conservation and overall building quality, into River Vue's design and construction that are a financial benefit to River Vue Associates, LP.

The first analysis, Photovoltaic Glass Window System Implementation, was evaluated because River Vue is LEED certified; however, it does not include sustainable design or energy production techniques. Therefore, the goals of this technical analysis were to develop a PV glass window system design and to determine the financial and energy feasibility. Also, an electrical/renewable energy breadth analysis determined the amount of renewable energy generated by the PV glass window system and how it would be connected to the electrical power system. After extensive research, Pythagoras Solar's PVGU was used for the analysis. Using an every other glass window design, the total number of PVGUs, 652, would be connected to the existing electrical system by a supply-side interconnection. For the 25-year life-cycle of the PV glass window system, the total life-cycle energy savings cost is $399,754.22. Since the system's initial cost is $874,310.40, the owner does not receive the initial cost of the system back through the energy savings within the PVGU's 25-year lifespan. This specific PV glass window system is not a recommended investment for the owner. However, the PVGUs are transparent, and the owner could decide to use an every-window design instead to generate more electricity, but the initial cost will be much higher.

The second analysis, Green Roof System Implementation, was evaluated because River Vue Apartments is LEED certified; however, it does not include sustainable design or energy production techniques. Therefore, the goals for this technical analysis were to develop a resident-accessible green roof system design, analyze the structural impact of the load-bearing green roof, and determine the financial feasibility. After extensive research, the pre-vegetated modular LiveRoof® Maxx System was used for this analysis. To access the lower-level roof, one apartment unit on the third floor has to be eliminated, and access stairs, a handicapped ramp, railings, and an exterior door have to be installed because the third-floor floor line is approximately two feet above the lower-roof line. The metal roof deck must change from a 1.5B20 roof deck to a 1.5B16 roof deck, and the steel joists must change from 14WF53 steel joists to 22KCS3 open-web steel joists to accommodate for the green roof system's load. From a construction schedule standpoint, the completion and occupancy of the Level 2 apartment units located beneath the lower roof will be delayed by 79 days. However, this delay does not affect the building's overall completion date. The initial cost of the green roof system, is $404,838.68, and it was assumed that the owner would receive the initial cost of the system back through energy savings. A rent increase analysis, incorporating a $45.00 increase, was performed to accommodate for the green roof system's yearly maintenance costs and for the loss of the third-floor apartment unit. Based on the rent increase analysis alone, the green roof system is a very beneficial investment to the owner because it adds quality and marketability to the building's design and increases the building's energy efficiency and the roofing membrane's durability.

The third analysis, 3D Laser Scanning Implementation, was evaluated because River Vue Apartments had several constructability challenges including as-built drawing inconsistencies and coordination issues. The goals for this technical analysis were to analyze the effects of using 3D laser scanning technologies to evaluate existing building conditions and to determine the cost and schedule impact. There are several benefits to implementing 3D laser scanning technology into River Vue's preconstruction and construction phases including creating 2D as-built construction drawings for quality assurance purposes, and creating a 3D model of the complete building for visual reference. The objectives for the implementation of 3D laser scanning technology are to generate accurate as-built construction drawings, generate a 3D model that benefits the design and coordination of River Vue, and quality control. The total cost of the laser scanning process is $147,500, and the total cost of the as-built drawing inconsistency change orders is $82,954.80, which is a $64,545.20 difference. Even though 3D laser scanning technology could be very beneficial during the preconstruction and construction phases of the River Vue project, from a cost standpoint, the results show that implementing 3D laser scanning technology is not feasible for the owner. Therefore, the implementation of 3D laser scanning technology is not a recommended investment for RVA.

The fourth analysis and final analysis, Lighting Occupancy Sensor Control System Implementation, was evaluated because industry professionals discussed many key topics about energy management, a critical industry issue, and its techniques for residential buildings like River Vue at the PACE Roundtable event. The goal for this technical analysis was to research new ideas for electrical and lighting systems that are energy efficient, but user friendly. After extensive research, Sensor Switch's WSD-PDT was used for this analysis. The WSD-PDTs utilize both passive infrared and microphonics detection technology. They operate under the following conditions: "automatic on" and "predictive off mode." The total annual energy savings is 71,504.38 kWh/year. After eligible incentives and rebates, the initial cost of the lighting occupancy sensor control system, including the cost of the WSD-PDTs and shipping, is $62,082.20. For the 15-year life-cycle of the lighting occupancy sensor control system, the total life-cycle energy savings cost is $195,635.97. Since the system's initial cost is $62,082.20, the owner does receive the initial cost of the system back through the energy savings within 5.5 years of the occupancy sensors' 15-year lifespan. Therefore, the owner saves an extra $133,553.77. This specific lighting occupancy sensor control system is a recommended investment for the owner.

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Appendix A: Existing Conditions Site Plan

RIVER VUE APARTMENTS RENOVATION

EXISTING CONDITIONS SITE PLAN

BRIANNE KYLE
CONSTRUCTION MANAGEMENT

APRIL 4, 2012

LEGEND

SYMBOLS:

CONSTRUCTION GATE — GATE

REMOVABLE PANELS

CONSTRUCTION FENCE

DUQUESNE LIGHT CIOMPANY VAULT (DLCO) — DLCO VAULT

EXISTING ELEVATOR 7 TO BE USED FOR A TRASH CHUTE

VEHICULAR TRAFFIC

FIRE HYDRANT

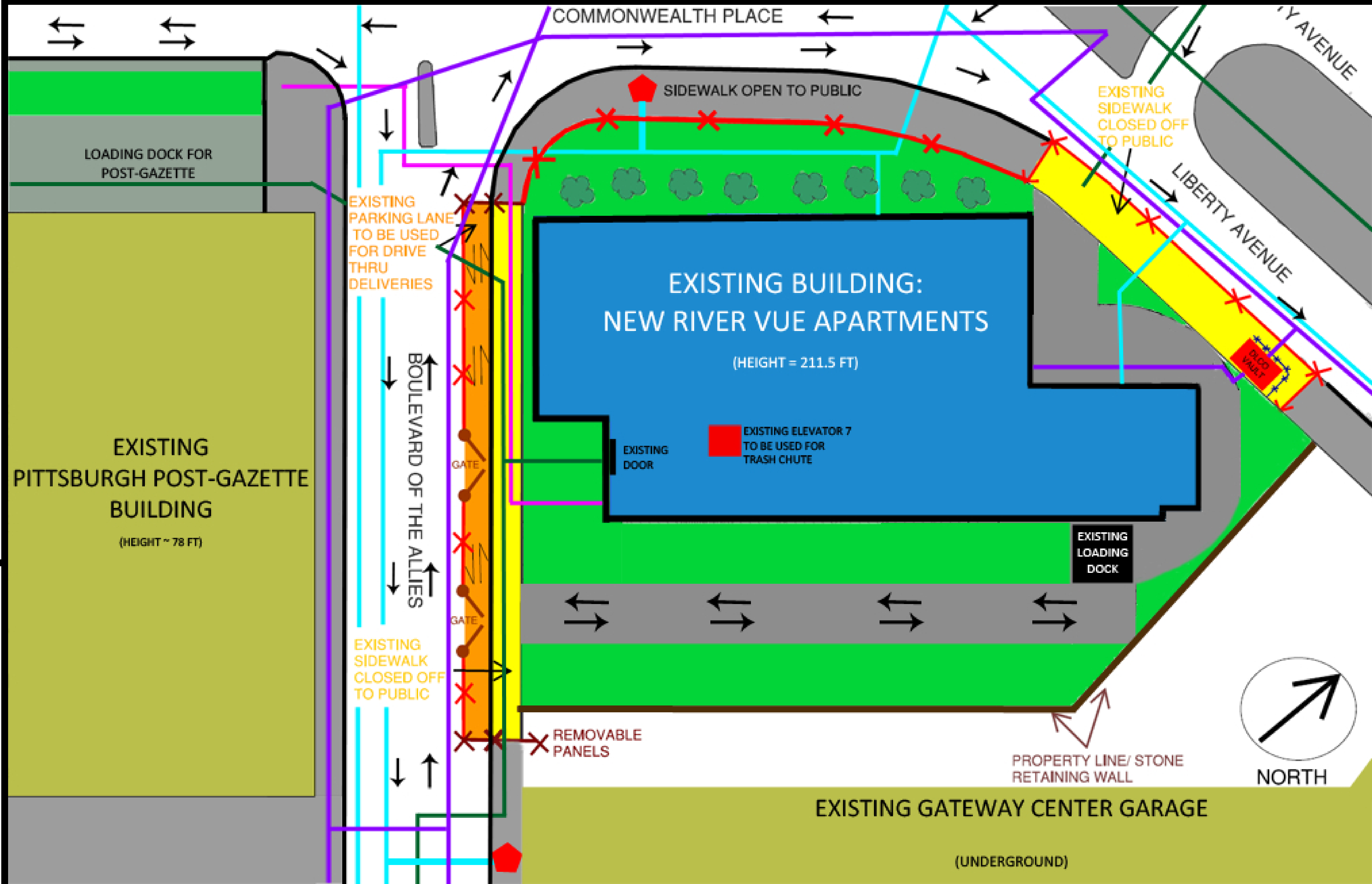
EXISTING UTILITIES:

ELECTRIC

GAS

SANITARY

WATER



Appendix B: General Conditions Estimate and Take-off Notes

General Conditions Estimate Breakdown

Table B1: Project and Staff Personnel Costs

Category	Item	Units	Quantity	Total Incl. O & P	Total Cost
Field Personnel	Business Unit General Manager	Week	31.5	$3,5000.00	$110,250.00
Field Personnel	Operations Manager	Week	31.5	$3,225.00	$101,587.50
Field Personnel	Project Executive	Week	31.5	$2,650.00	$83,475.00
Field Personnel	Project Superintendent	Week	83	$3,075.00	$255,225.00
Field Personnel	Project Engineer	Week	73	$2,150.00	$156,950.00
Field Personnel	Site Work Assistant Superintendent	Week	12	$2,575.00	$30,900.00
Field Personnel	MEP/FP Assistant Superintendent	Week	36	$2,575.00	$92,700.00
Field Personnel	2nd Shift Assistant Superintendent	Week	83	$2,575.00	$213,725.00
Field Personnel	Engineering Assistant	Week	73	$1,425.00	$104,025.00
Field Personnel	Site Laborers	Week	63	$2,000.00	$126,000.00
				SUBTOTAL	$1,274,837.50
				Location Factor	0.996
				TOTAL	**$1,269,738.15**

Table B2: Construction Facilities and Equipment Costs

Category	Item	Units	Quantity	Total Incl. O & P	Total Cost
Office & Storage Sheds	(2) Storage Boxes, 20'x8'	Month	15.75	$125.00	$1,968.75
Field Office Expense	Office Equipment Rental	Month	15.75	$171.00	$2,693.25
Field Office Expense	Office Supplies	Month	15.75	$93.50	$1,472.63
Field Office Expense	Mobile Phones	Month	15.75	$500.00	$7,875.00
Field Office Expense	Lights & HVAC in Office	Month	15.75	$165.00	$2,598.75
Temporary Fencing	Chain Link, 11ga, 6' high	Month	15.75	$600.00	$9,450.00
Temporary Project Signs	High Intensity Reflectorized	LS	1	$2,000.00	$2,000.00
Tools/Equipment	Smalls Tools & All Equipment	Month	15.75	$1,500.00	$23,625.00
Clean-Up Equipment	All Clean-up Equipment	Week	58	$20.00	$1,160.00
Dumpsters	(7) Site Dumpsters	Month	15.75	$1,200.00	$18,900.00
Portable Toilets	(3) Portable Site Toilets	Month	15.75	$900.00	$14,175.00
Safety Equipment	Hard Hats, Safety Glasses, etc	Month	15.75	$100.00	$1,575.00
Fire Extinguishers	Site Fire Extinguishers	Month	15.75	$90.00	$1,417.50
				SUBTOTAL	$88,910.88
				Location Factor	0.996
				Sales Tax	6%
				TOTAL	**$93,868.55**

Table B3: Temporary Utilities Costs					
Category	Item	Units	Quantity	Total Incl. O & P	Total Cost
Temporary Utilities	Field Network Set-up	LS	1	$3,500.00	$3,500.00
Temporary Utilities	Field Telephone Set-up	LS	1	$1,250.00	$1,250.00
Temporary Utilities	Land Line Telephone Bill	Month	15.75	$88.00	$1,386.00
Temporary Utilities	Temp. Power & Lighting Install	LS	1	$13,500.00	$13,500.00
Temporary Utilities	Temporary Power	Month	15.75	$10,000.00	$157,500.00
Temporary Utilities	Temp. Water/Sanitary Hook-up	LS	1	$1,500.00	$1,500.00
Temporary Utilities	Temp. Construction Water Bill	Month	15.75	$68.00	$1,071.00
				SUBTOTAL	$179,707.00
				Location Factor	0.996
				Sales Tax	6%
				TOTAL	**$189,727.46**

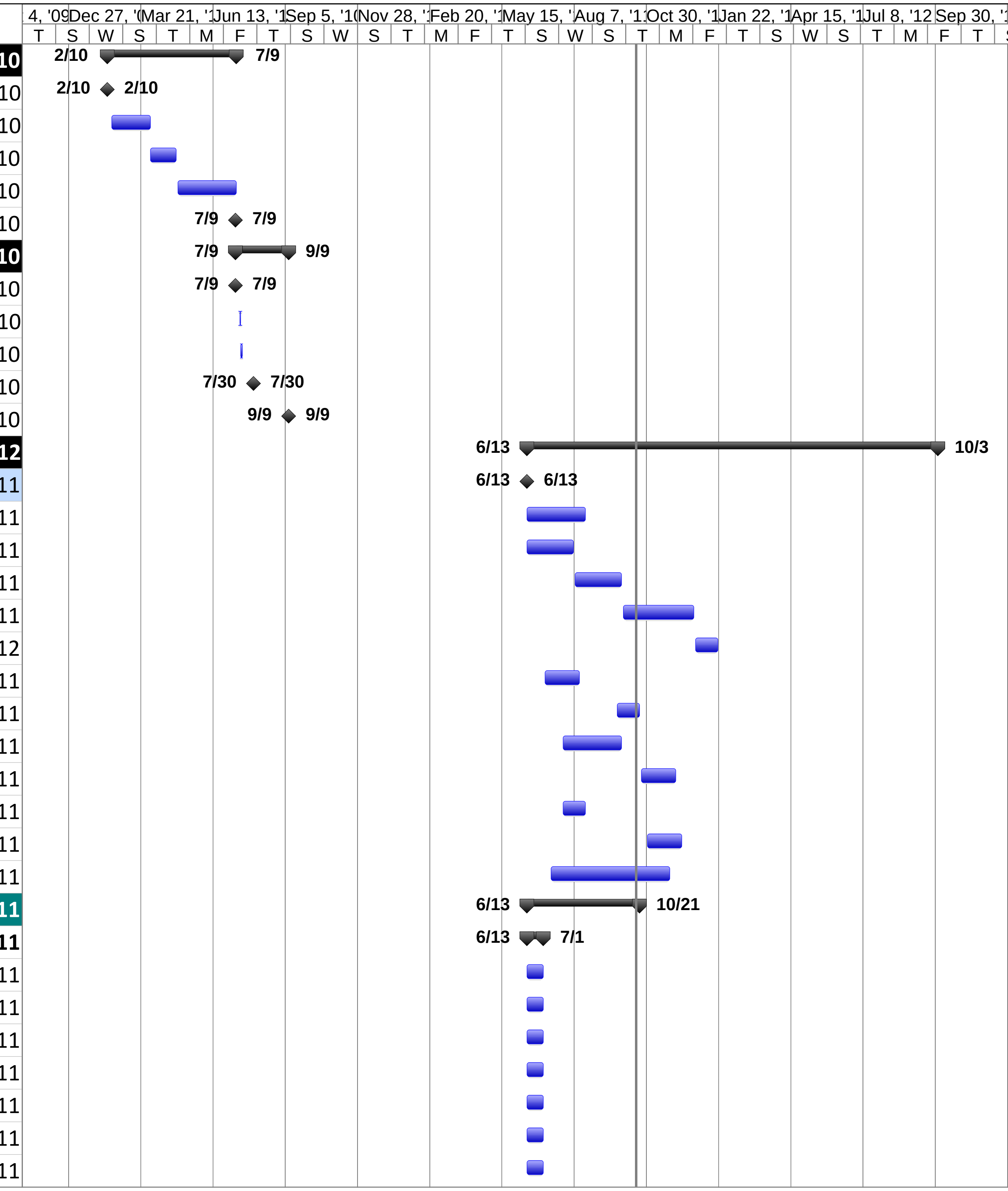
Table B4: Miscellaneous Costs					
Category	Item	Units	Quantity	Total Incl. O & P	Total Cost
Insurance	Builders Risk, Standard	Job	$28,248,910.00	0.24%	$67,797.38
Photographs	Progress Photographs	Month	15.75	$350.00	$5,512.50
Permits	Rule of Thumb, Most Cities	Job	$28,248,910.00	2%	$564,978.20
Cleaning Up	After Job Completion	Job	$28,248,910.00	0.30%	$84,746.73
Commissioning	Performance, Training, etc.	Project	$28,248,910.00	1%	$282,489.10
				SUBTOTAL	$937,726.53
				Location Factor	0.996
				TOTAL	**$933,975.62**

Table B5: Contingency Costs					
Category	Item	Units	Quantity	Total Incl. O & P	Total Cost
Contingency	Construction	Project	$28,248,910.00	8%	$2,258,912.80
				SUBTOTAL	$2,258,912.80
				Location Factor	0.996
				TOTAL	**$2,250,873.15**

Appendix C: Detailed Project Schedule

Detailed Project Schedule
River Vue Apartments | Pittsburgh, PA

ID	Task Name	Duration	Start	Finish
1	**PRECONSTRUCTION**	**108 days**	**Wed 2/10/10**	**Fri 7/9/10**
2	Contract Awarded via Letter of Intent	0 days	Wed 2/10/10	Wed 2/10/10
3	Schematic Design	33 days	Mon 2/15/10	Wed 3/31/10
4	Design Development	22 days	Thu 4/1/10	Fri 4/30/10
5	Construction Documents	50 days	Mon 5/3/10	Fri 7/9/10
6	Client Approval	0 days	Fri 7/9/10	Fri 7/9/10
7	**PROCUREMENT**	**44 days**	**Fri 7/9/10**	**Thu 9/9/10**
8	General Construction Scope Out to Bid	0 days	Fri 7/9/10	Fri 7/9/10
9	Mandatory Pre-Bid Meeting	1 day	Wed 7/14/10	Wed 7/14/10
10	Optional Pre-Bid walk-Thru	2 days	Thu 7/15/10	Fri 7/16/10
11	General Ocnstruction Bid Due Date	0 days	Fri 7/30/10	Fri 7/30/10
12	Contract Awarded via Letter of Intent	0 days	Thu 9/9/10	Thu 9/9/10
13	**CONSTRUCTION**	**342 days**	**Mon 6/13/11**	**Wed 10/3/12**
14	Mobilization	0 days	Mon 6/13/11	Mon 6/13/11
15	Garage Ramp	50 days	Mon 6/13/11	Fri 8/19/11
16	Duquesne Light vault	40 days	Mon 6/13/11	Fri 8/5/11
17	Site Utilities	40 days	Mon 8/8/11	Fri 9/30/11
18	Sitework	60 days	Mon 10/3/11	Fri 12/23/11
19	Landscaping	20 days	Mon 12/26/11	Fri 1/20/12
20	Structural Steel Basement Level and Level 1	30 days	Mon 7/4/11	Fri 8/12/11
21	Concrete Topping Slab Basement Level and Level 1	20 days	Mon 9/26/11	Fri 10/21/11
22	Structural Steel and Concrete Infills Elevator Lobbies	50 days	Mon 7/25/11	Fri 9/30/11
23	Structural Steel and Concrete Infills Levels 15 and 16	30 days	Mon 10/24/11	Fri 12/2/11
24	Level 2 Roofing	20 days	Mon 7/25/11	Fri 8/19/11
25	Level 17 Roofing	30 days	Mon 10/31/11	Fri 12/9/11
26	Glass and Glazing	100 days	Mon 7/11/11	Fri 11/25/11
27	**ABATEMENT AND DEMOLITION**	**95 days**	**Mon 6/13/11**	**Fri 10/21/11**
28	**Basment Level and Level 1 (Typical)**	**15 days**	**Mon 6/13/11**	**Fri 7/1/11**
29	Removal of Existing Walls	15 days	Mon 6/13/11	Fri 7/1/11
30	Removal of Existing Flooring Material and Prepare Floor for New Finish Material	15 days	Mon 6/13/11	Fri 7/1/11
31	Removal of Existing Doors, Frames, and Hardware	15 days	Mon 6/13/11	Fri 7/1/11
32	Removal of Ceiling Tile, Ceiling Tile Tracks, GWB Ceiling, and Other Ceiling Elements	15 days	Mon 6/13/11	Fri 7/1/11
33	Removal of Existing Casework	15 days	Mon 6/13/11	Fri 7/1/11
34	Removal of Existing Glass System	15 days	Mon 6/13/11	Fri 7/1/11
35	Removal of Existing Elevators and Stairs	15 days	Mon 6/13/11	Fri 7/1/11

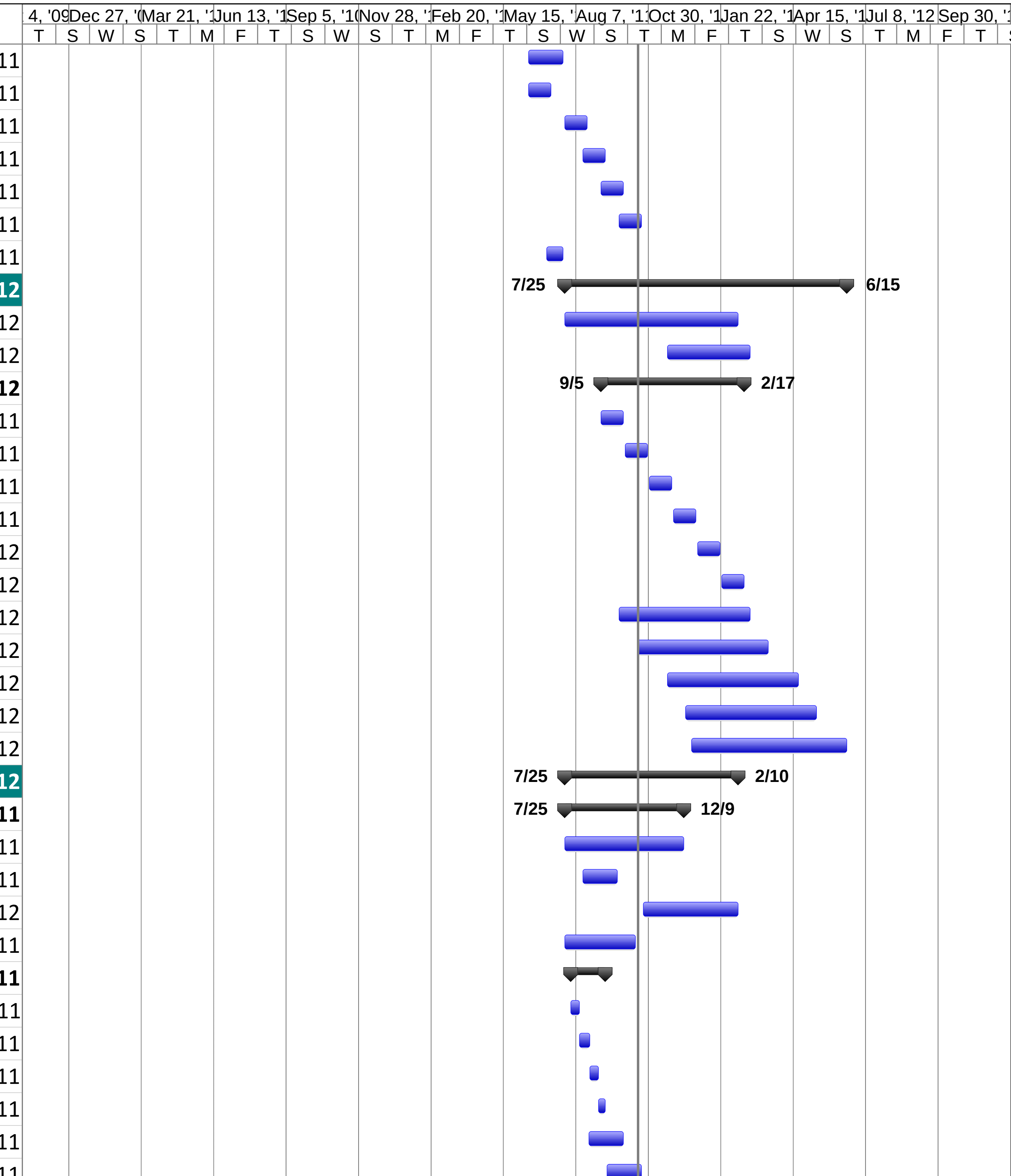


Detailed Project Schedule
River Vue Apartments
Date: 4/4/2012

Task | Rolled Up Task | Split | Inactive Task | Duration-only | Finish-only
Critical Task | Rolled Up Critical Task | External Tasks | Inactive Milestone | Manual Summary Rollup | Progress
Milestone | Rolled Up Milestone | Project Summary | Inactive Summary | Manual Summary | Deadline
Summary | Rolled Up Progress | Group By Summary | Manual Task | Start-only

Detailed Project Schedule
River Vue Apartments | Pittsburgh, PA

ID	Task Name	Duration	Start	Finish
36	Levels 2, 3, 4, and 5 (Typical)	30 days	Mon 6/13/11	Fri 7/22/11
37	Levels 6 and 7 (Typical)	20 days	Mon 6/13/11	Fri 7/8/11
38	Levels 8 and 9 (Typical)	20 days	Mon 7/25/11	Fri 8/19/11
39	Level 10 and 11 (Typical)	20 days	Mon 8/15/11	Fri 9/9/11
40	Levels 12 and 13 (Typical)	20 days	Mon 9/5/11	Fri 9/30/11
41	Levels 14, 15, and 16 (Typical)	20 days	Mon 9/26/11	Fri 10/21/11
42	Penthouse	15 days	Mon 7/4/11	Fri 7/22/11
43	**INTERIORS**	**235 days**	**Mon 7/25/11**	**Fri 6/15/12**
44	Elevator Lobbies and Stair Towers	145 days	Mon 7/25/11	Fri 2/10/12
45	Basement Level and Level 1 (Typical)	70 days	Mon 11/21/11	Fri 2/24/12
46	**Levels 2, 3, 4, and 5 (Typical)**	**120 days**	**Mon 9/5/11**	**Fri 2/17/12**
47	Interior Studs and Door Frames	20 days	Mon 9/5/11	Fri 9/30/11
48	Ceilings and Drywall Installation	20 days	Mon 10/3/11	Fri 10/28/11
49	Prime and Paint Walls	20 days	Mon 10/31/11	Fri 11/25/11
50	Finish System Trim and Casework	20 days	Mon 11/28/11	Fri 12/23/11
51	Flooring Installation	20 days	Mon 12/26/11	Fri 1/20/12
52	Doors and Hardware	20 days	Mon 1/23/12	Fri 2/17/12
53	Levels 6 and 7 (Typical)	110 days	Mon 9/26/11	Fri 2/24/12
54	Levels 8 and 9 (Typical)	110 days	Mon 10/17/11	Fri 3/16/12
55	Levels 10 and 11 (Typical)	110 days	Mon 11/21/11	Fri 4/20/12
56	Levels 12 and 13 (Typical)	110 days	Mon 12/12/11	Fri 5/11/12
57	Levels 14, 15, and 16 (Typical)	130 days	Mon 12/19/11	Fri 6/15/12
58	**MEP/FP ROUGH-IN**	**145 days**	**Mon 7/25/11**	**Fri 2/10/12**
59	**Elevator Lobbies and Stair Towes Rough-In**	**100 days**	**Mon 7/25/11**	**Fri 12/9/11**
60	Route MEP Chases in Elevator Shafts	100 days	Mon 7/25/11	Fri 12/9/11
61	Basement Level and Level 1 Underground	30 days	Mon 8/15/11	Fri 9/23/11
62	Basement Level and Level 1 Rough-In (Typical)	80 days	Mon 10/24/11	Fri 2/10/12
63	Levels 2, 3, 4, and 5 Rough-In (Typical)	60 days	Mon 7/25/11	Fri 10/14/11
64	**Levels 6 and 7 Rough-In (Typical)**	**30 days**	**Mon 8/1/11**	**Fri 9/9/11**
65	Mechanical Rough-In	8 days	Mon 8/1/11	Wed 8/10/11
66	Electrical Rough-In	8 days	Thu 8/11/11	Mon 8/22/11
67	Plumbing Rough-In	8 days	Tue 8/23/11	Thu 9/1/11
68	Fire Protecttion Rough-In	6 days	Fri 9/2/11	Fri 9/9/11
69	Levels 8 and 9 Rough-In (Typical)	30 days	Mon 8/22/11	Fri 9/30/11
70	Levels 10 and 11 Rough-In (Typical)	30 days	Mon 9/12/11	Fri 10/21/11

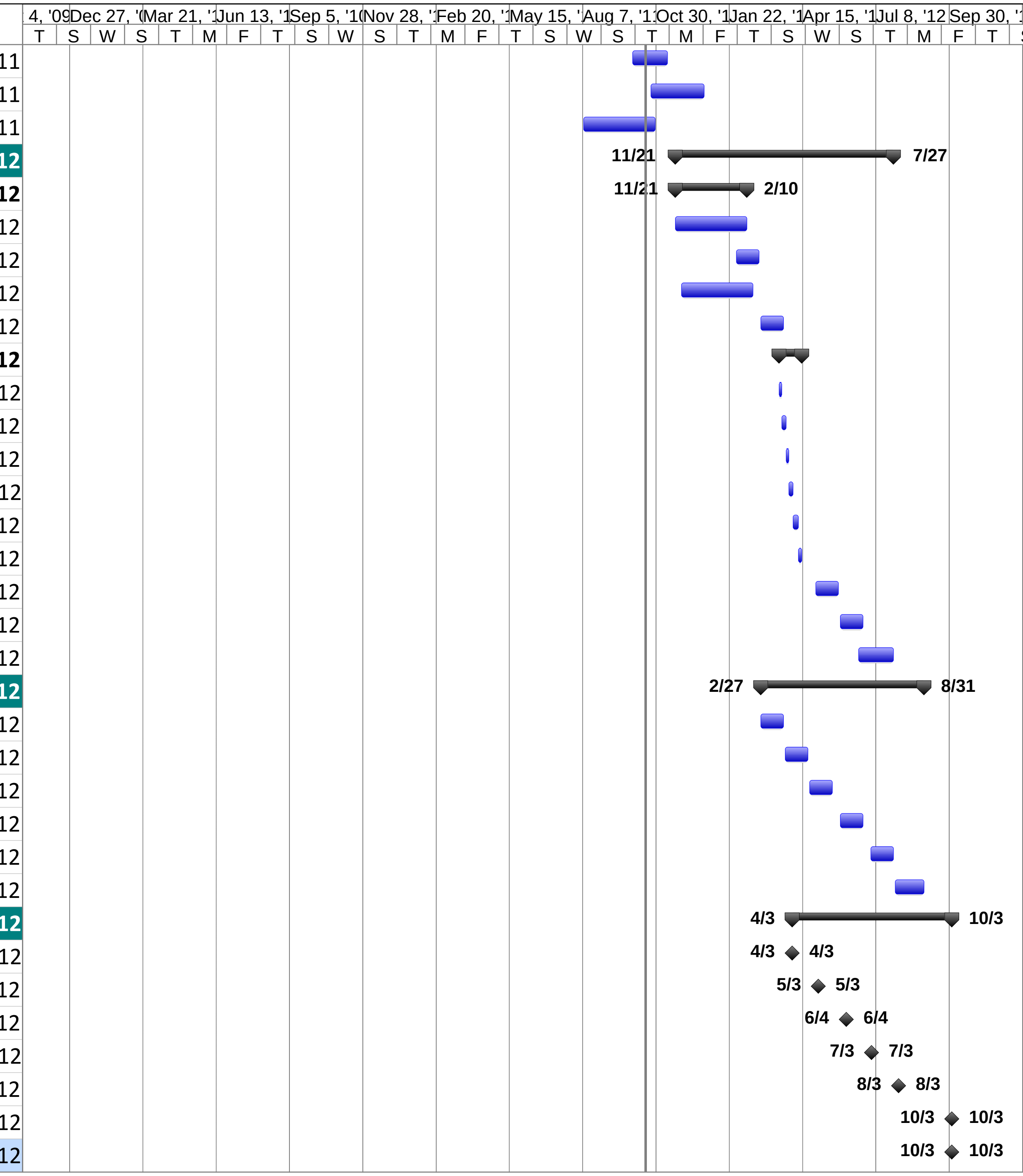


Detailed Project Schedule
River Vue Apartments
Date: 4/4/2012

Task | Critical Task | Milestone | Summary | Rolled Up Task | Rolled Up Critical Task | Rolled Up Milestone | Rolled Up Progress | Split | External Tasks | Project Summary | Group By Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Progress | Deadline

Detailed Project Schedule
River Vue Apartments | Pittsburgh, PA

ID	Task Name	Duration	Start	Finish
71	Levels 12 and 13 Rough-In (Typical)	30 days	Mon 10/3/11	Fri 11/11/11
72	Levels 14, 15, and 16 Rough-In (Typical)	45 days	Mon 10/24/11	Fri 12/23/11
73	Penthouse and Roof	60 days	Mon 8/8/11	Fri 10/28/11
74	**MEP/FP FINISHES**	**180 days**	**Mon 11/21/11**	**Fri 7/27/12**
75	**Elevator Lobbies and Stair Towers**	**60 days**	**Mon 11/21/11**	**Fri 2/10/12**
76	Install MEP Chases in Elevator Shafts	60 days	Mon 11/21/11	Fri 2/10/12
77	Basement Level and Level 1 (Typical)	20 days	Mon 1/30/12	Fri 2/24/12
78	Levels 2, 3, 4, and 5 (Typical)	60 days	Mon 11/28/11	Fri 2/17/12
79	Levels 6 and 7 (Typical)	20 days	Mon 2/27/12	Fri 3/23/12
80	**Levels 8 and 9 (Typical)**	**20 days**	**Mon 3/19/12**	**Fri 4/13/12**
81	Ductwork and VAV	3 days	Mon 3/19/12	Wed 3/21/12
82	Mechanical Piping and Insulation	3 days	Thu 3/22/12	Mon 3/26/12
83	Sprinkler Main and Branch Pipe	3 days	Tue 3/27/12	Thu 3/29/12
84	Fire Alarm Devices	3 days	Fri 3/30/12	Tue 4/3/12
85	Light Fixtures	4 days	Wed 4/4/12	Mon 4/9/12
86	Plumbing Fixtures	4 days	Tue 4/10/12	Fri 4/13/12
87	Levels 10 and 11 (Typical)	20 days	Mon 4/30/12	Fri 5/25/12
88	Levels 12 and 13 (Typical)	20 days	Mon 5/28/12	Fri 6/22/12
89	Levels 14, 15, and 16 (Typical)	30 days	Mon 6/18/12	Fri 7/27/12
90	**PUNCHLISTS AND INSPECTIONS**	**135 days**	**Mon 2/27/12**	**Fri 8/31/12**
91	Basement Level and Levels 1, 2, 3, 4, and 5	20 days	Mon 2/27/12	Fri 3/23/12
92	Levels 6 and 7	20 days	Mon 3/26/12	Fri 4/20/12
93	Levels 8 and 9	20 days	Mon 4/23/12	Fri 5/18/12
94	Levels 10 and 11	20 days	Mon 5/28/12	Fri 6/22/12
95	Levels 12 and 13	20 days	Mon 7/2/12	Fri 7/27/12
96	Levels 14, 15, and 16	25 days	Mon 7/30/12	Fri 8/31/12
97	**COMPLETION AND OCCUPANCY**	**131 days**	**Tue 4/3/12**	**Wed 10/3/12**
98	Basment Level and Levels 1, 2, 3, 4, and 5	0 days	Tue 4/3/12	Tue 4/3/12
99	Levels 6 and 7	0 days	Thu 5/3/12	Thu 5/3/12
100	Levels 8 and 9	0 days	Mon 6/4/12	Mon 6/4/12
101	Levels 10 and 11	0 days	Tue 7/3/12	Tue 7/3/12
102	Levels 12 and 13	0 days	Fri 8/3/12	Fri 8/3/12
103	Levels 14, 15, and 16	0 days	Wed 10/3/12	Wed 10/3/12
104	Final Completion	0 days	Wed 10/3/12	Wed 10/3/12



Detailed Project Schedule
River Vue Apartments
Date: 4/4/2012

Task	Rolled Up Task	Split	Inactive Task	Duration-only	Finish-only
Critical Task	Rolled Up Critical Task	External Tasks	Inactive Milestone	Manual Summary Rollup	Progress
Milestone	Rolled Up Milestone	Project Summary	Inactive Summary	Manual Summary	Deadline
Summary	Rolled Up Progress	Group By Summary	Manual Task	Start-only	

Appendix D: Site Plan for Excavation Phase of Construction

RIVER VUE APARTMENTS RENOVATION

SITE PLAN FOR EXCAVATION PHASE OF CONSTRUCTION

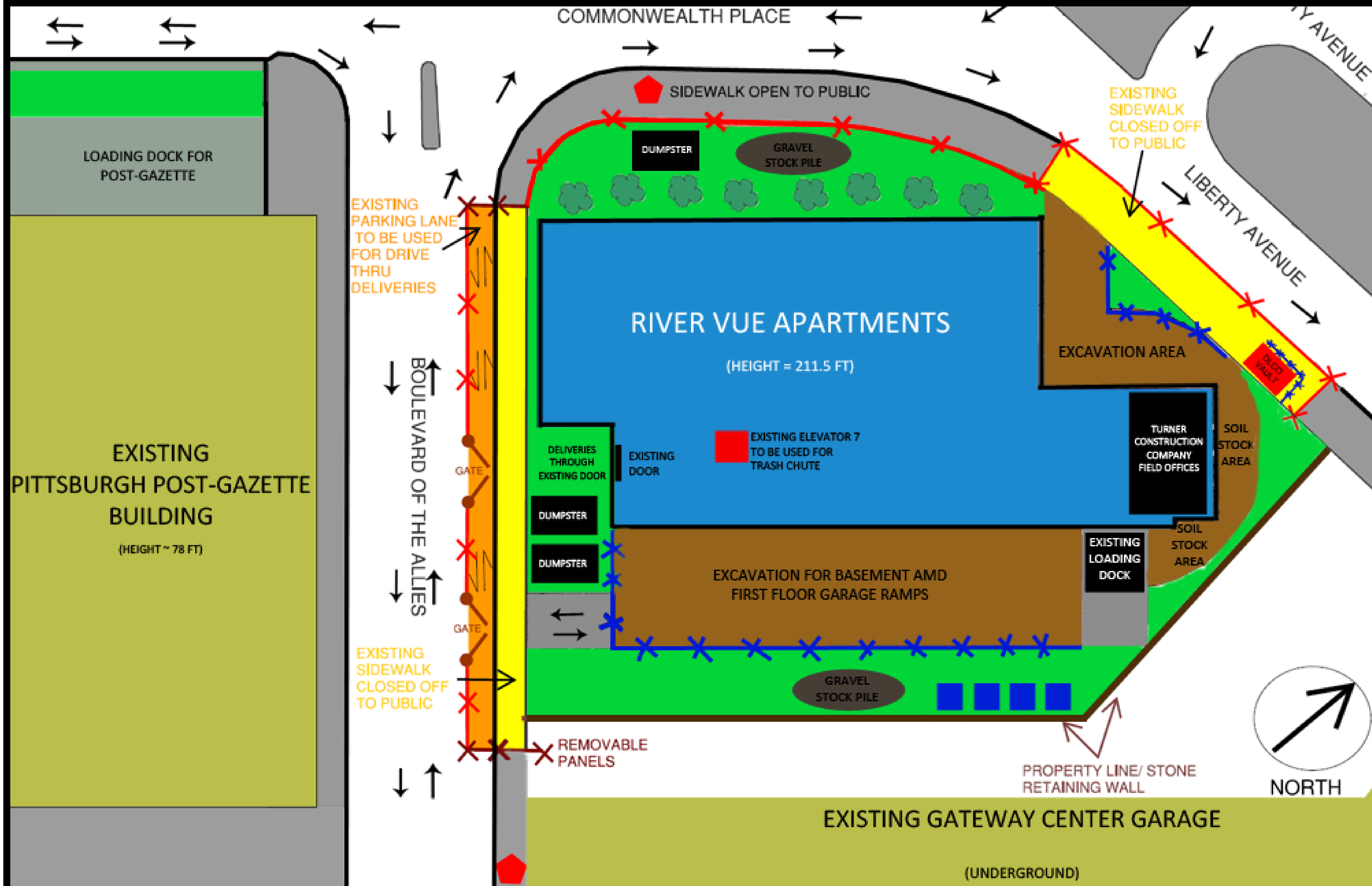
BRIANNE KYLE
CONSTRUCTION MANAGEMENT

APRIL 4, 2012

LEGEND

SYMBOLS:

- CONSTRUCTION GATE — GATE
- REMOVABLE PANELS
- CONSTRUCTION FENCE
- DUQUESNE LIGHT COMPANY VAULT (DLCO) — DLCO VAULT
- EXISTING ELEVATOR 7 TO BE USED FOR TRASH CHUTE
- TEMPORARY TOILETS
- FIRE HYDRANT
- SHORING
- VEHICULAR TRAFFIC



Appendix E: Site Plan for Demolition Phase of Construction

RIVER VUE APARTMENTS RENOVATION

SITE PLAN FOR DEMOLITION PHASE OF CONSTRUCTION

BRIANNE KYLE
CONSTRUCTION MANAGEMENT

APRIL 4, 2012

LEGEND

SYMBOLS:

- CONSTRUCTION GATE — GATE
- REMOVABLE PANELS
- CONSTRUCTION FENCE
- DUQUESNE LIGHT COMPANY VAULT (DLCO) — DLCO VAULT
- EXISTING ELEVATOR 7 TO BE USED FOR TRASH CHUTE
- TEMPORARY TOILETS
- FIRE HYDRANT
- TRUCK CRANE
- VEHICULAR TRAFFIC

Appendix F: Site Plan for MEP/Finishes Phase of Construction

RIVER VUE APARTMENTS RENOVATION

SITE PLAN FOR MEP/FINISHES PHASE OF CONSTRUCTION

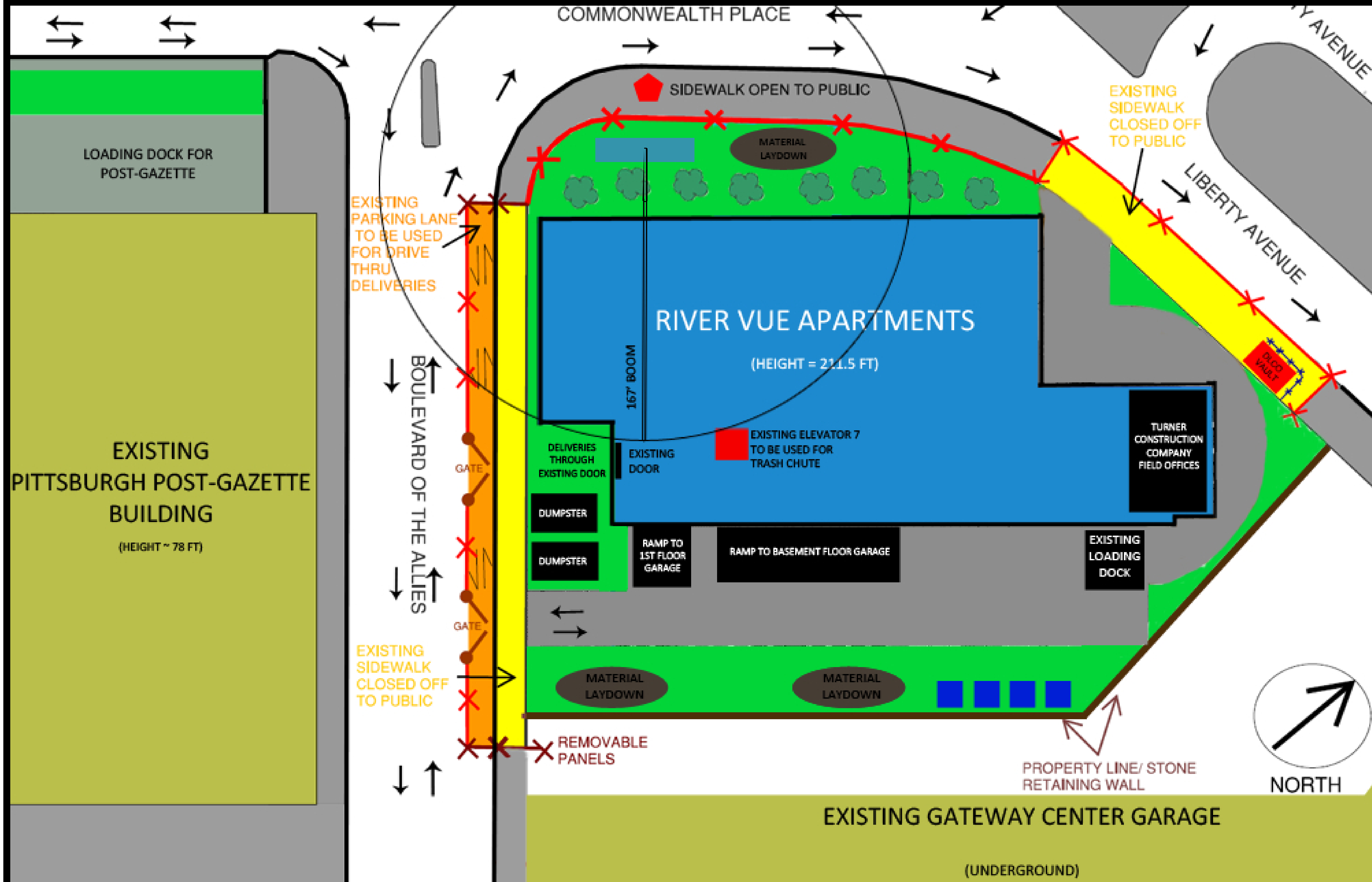
BRIANNE KYLE
CONSTRUCTION MANAGEMENT

APRIL 4, 2012

LEGEND

SYMBOLS:

- CONSTRUCTION GATE — GATE
- REMOVABLE PANELS
- CONSTRUCTION FENCE
- DUQUESNE LIGHT COMPANY VAULT (DLCO) — DLCO VAULT
- EXISTING ELEVATOR 7 TO BE USED FOR TRASH CHUTE
- TEMPORARY TOILETS
- FIRE HYDRANT
- TRUCK CRANE
- VEHICULAR TRAFFIC



Appendix G: Pythagoras Solar's PVGU Technical Specifications

Brianne PVGU Window Specification

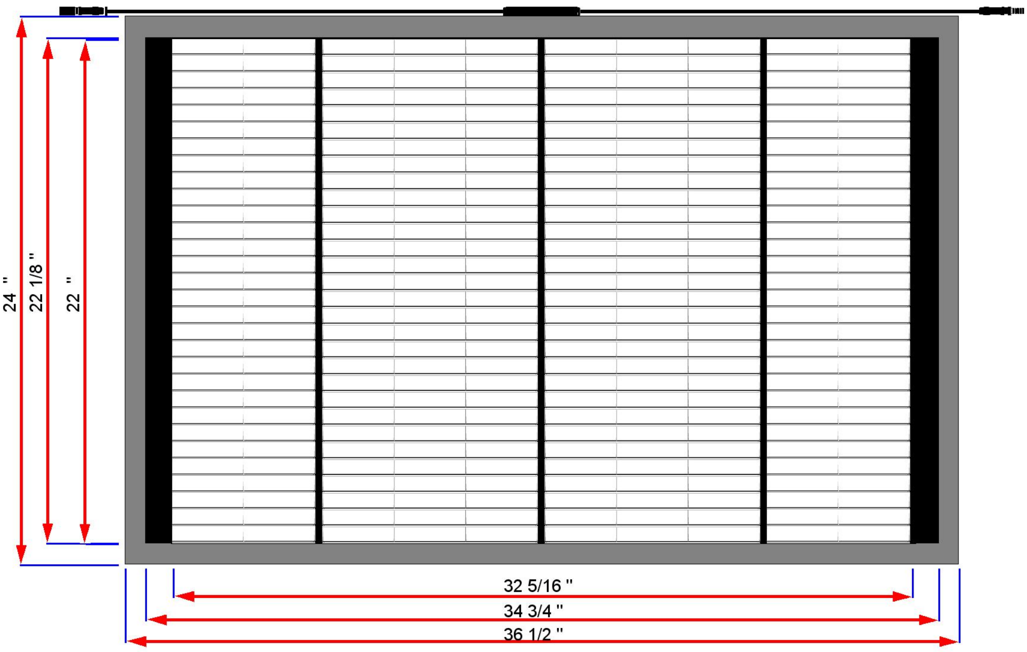
Unit Mechanical Specifications	
Height	24 " (610 mm)
Width	36 1/2" (927 mm)
Thickness	1 1/4" (32 mm)
Weight	50.6lbs (23.0 Kg)

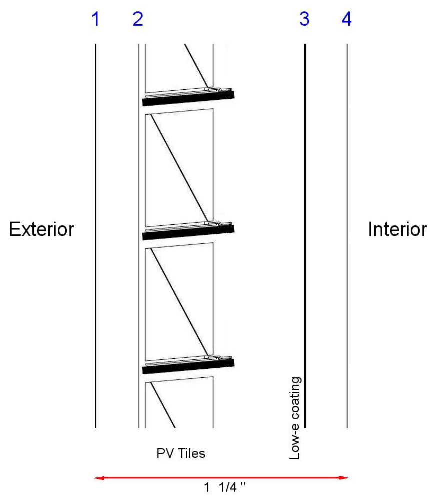
Unit Electrical Specifications	
Power mpp	56.2 W
Module Efficiency*	11.3%
V mpp	26.9 V
Voc	32.4 V
I mpp	2.1 A
Isc	2.2 A
Tested Operating Temperature	-40°C - 85°C
Maximum System Voltage	600 V DC
Maximum Series Fuse Rating	15 amps
Power Tolerance	±5%

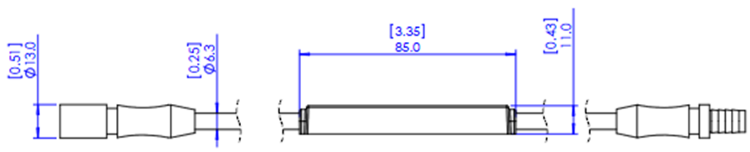
Unit Glazing Specifications	
Outer Glass	1/4"(6mm) ultra-clear
Inner Glass	1/4"(6mm) low-e coated
U-value	0.3
SHGC	0.14 (for angles > 25 above normal)
VT	0.49 (for angles < 25 above normal)
UVT	0.28 (for angles < 25 above normal)

Electrical Coefficients	
Nominal Operating Cell Temperature (NOCT)	53°C
Temperature Coefficient of Power mpp	-0.55%/°C
Temperature Coefficient of Voc	-0.36%/°C
Temperature Coefficient of Isc	-0.03%/°C

*Module efficiency is calculated over the exposed glazing area (i.e. not including the window frame bite). For the unit the exposed glazing area is 562mm x 882mm.







Junction Box & MC3 Connector Dimensions: mm [inches]

Report Time: March 17, 2012, 1:32 am

Appendix H: Fronius IG Plus PV Inverter Sizes and Specifications

INPUT DATA Fronius IG Plus	3.0-1 UNI	3.8-1 UNI	5.0-1 UNI	6.0-1 UNI	7.5-1 UNI	10.0-1 UNI	11.4-1 UNI	11.4-3 Delta	12.0-3 WYE277
Recommended PV-Power (Wp)	2500-3450	3200-4400	4250-5750	5100-6900	6350-8600	8500-11500	9700-13100	9700-13100	10200-13800
MPPT-Voltage Range	230 ... 500 V								
DC Startup Voltage	245 V								
Max. Input Voltage (at 1000 W/m² 14°F (-10°C) in open circuit operation)	600 V								
Nominal Input Current	8.3 A	10.5 A	13.8 A	16.6 A	20.7 A	27.6 A	31.4 A	31.4 A	33.1 A
Max. usable Input Current	14.0 A	17.8 A	23.4 A	28.1 A	35.1 A	46.7 A	53.3 A	53.3 A	56.1 A
Admissible conductor size (DC)	No. 14 - 6 AWG								
Number of DC Input Terminals	6								
Max. Current per DC Input Terminal	20 A; Bus bar available for higher input currents								

OUTPUT DATA Fronius IG Plus	3.0-1 UNI	3.8-1 UNI	5.0-1 UNI	6.0-1 UNI	7.5-1 UNI	10.0-1 UNI	11.4-1 UNI	11.4-3 Delta	12.0-3 WYE277
Nominal output power ($P_{AC\ nom}$)	3000 W	3800 W	5000 W	6000 W	7500 W	9995 W	11400 W	11400 W	12000 W
Max. continuous output power 104°F (40°C) 208 V / 240 V / 277 V	3000 W	3800 W	5000 W	6000 W	7500 W	9995 W	11400 W	11400 W	12000 W
Nominal AC output voltage	208 V / 240 V / 277 V							208 V / 240 V	277 V
Operating AC voltage range (default) 208 V	183 - 229 V (-12 / +10 %)								
240 V	211 - 264 V (-12 / +10 %)								
277 V	244 - 305 V (-12 / +10 %)								
Max. continuous output current 208 V	14.4 A	18.3 A	24.0 A	28.8 A	36.1 A	48.1 A	54.8 A	31.6 A*	n.a.
240 V	12.5 A	15.8 A	20.8 A	25.0 A	31.3 A	41.7 A	47.5 A	27.4 A*	n.a.
277 V	10.8 A	13.7 A	18.1 A	21.7 A	27.1 A	36.1 A	41.2 A	n.a.	14.4 A*
Admissible conductor size (AC)	No. 14 - 4 AWG								
Max. continuous utility back feed current	0 A								
Nominal output frequency	60 Hz								
Operating frequency range	59.3 - 60.5 Hz								
Total harmonic distortion	< 3 %								
Power factor	1								

GENERAL DATA Fronius IG Plus	3.0-1 UNI	3.8-1 UNI	5.0-1 UNI	6.0-1 UNI	7.5-1 UNI	10.0-1 UNI	11.4-1 UNI	11.4-3 Delta	12.0-3 WYE277
Max. Efficiency	96.2 %								
CEC Efficiency 208 V	95.0 %	95.0 %	95.5 %	95.5 %	95.0 %	95.0 %	95.5 %	95.0 %	n.a.
240 V	95.5 %	95.5 %	95.5 %	96.0 %	95.5 %	95.5 %	96.0 %	95.5 %	n.a.
277 V	95.5 %	95.5 %	96.0 %	96.0 %	96.0 %	96.0 %	96.0 %	n.a.	96.0 %
Consumption in standby (night)	< 1 W								
Consumption during operation	8 W		15 W			22 W			
Cooling	Controlled forced ventilation, variable fan speed								
Enclosure Type	NEMA 3R								
Unit Dimensions (W x H x D)	17.1 x 24.8 x 9.6 in.		17.1 x 36.4 x 9.6 in.			17.1 x 48.1 x 9.6 in.			
Power Stack Weight	31 lbs. (14 kg)		57 lbs. (26 kg)			82 lbs. (37 kg)			
Wiring Compartment Weight	24 lbs. (11 kg)		26 lbs. (12 kg)			26 lbs. (12 kg)			
Admissible ambient operating temperature	-4 ... 122°F (-20 ... +50°C)								
Compliance	UL 1741-2005, IEEE 1547-2003, IEEE 1547.1, ANSI/IEEE C62.41, FCC Part 15 A& B, NEC Article 690, C22. 2 No. 107.1-01 (Sept. 2001)								

PROTECTION DEVICES Fronius IG Plus	3.0-1 UNI	3.8-1 UNI	5.0-1 UNI	6.0-1 UNI	7.5-1 UNI	10.0-1 UNI	11.4-1 UNI	11.4-3 Delta	12.0-3 WYE277
Ground fault protection	Internal GFDI (Ground Fault Detector/Interrupter); in accordance with UL 1741-2005 and NEC Art. 690								
DC reverse polarity protection	Internal diode								
Islanding protection	Internal; in accordance with UL 1741-2005, IEEE 1547-2003 and NEC								
Over temperature	Output power derating / active cooling								

* per Phase

Fronius USA LLC Solar Electronic Division
10421 Citation Drive, Suite 1100, Brighton, Michigan, 48116
E-Mail: pv-us@fronius.com
www.fronius-usa.com

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Appendix I: Photovoltaic Glass Window System Solar Shading Effects

South-Facing Side Shading

Beam Shading Factor — 0=Full Shading, 1=No Shading — 0 — Apply to selected cells

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11p
Jan	0	0	0	0	0	0	0	0	0.84	0.71	0.76	0.82	0.84	0.88	0.94	0.96	0.94	0.92	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	0.94	0.84	0.92	0.92	0.92	0.95	0.97	0.96	0.92	0.92	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0	1	1	1	1	1	0.99	0.98	0.96	0.94	0.92	0	0	0	0	0	0
Apr	0	0	0	0	0	0	0	0	1	1	1	1	1	0.99	0.98	0.96	0.94	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	1	1	1	1	0.99	0.98	0.96	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0.99	0.98	0	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0.99	0.98	0.96	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0.99	0.98	0.96	0.94	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0	1	1	1	1	1	0.99	0.98	0.96	0.94	0.92	0	0	0	0	0	0
Oct	0	0	0	0	0	0	0	1	0.84	0.88	0.92	0.95	0.95	0.96	0.95	0.94	0.92	0.9	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0	0.79	0.76	0.78	0.8	0.82	0.88	0.9	0.92	0.92	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0.72	0.76	0.76	0.76	0.78	0.84	0.9	0.94	0.92	0	0	0	0	0	0	0

East-Facing Side Shading

Beam Shading Factor — 0=Full Shading, 1=No Shading — 0 — Apply to selected cells

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11p
Jan	0	0	0	0	0	0	0	0	0.75	0.98	0.99	0.98	0	0	0	0	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	0.65	0.86	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0.24	0.7	0.95	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Apr	0	0	0	0	0	0	0.26	0.5	0.82	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0.35	0.65	0.9	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0.48	0.75	0.95	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0.5	0.8	0.92	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0.24	0.5	0.75	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0.24	0.7	0.95	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Oct	0	0	0	0	0	0	0	0.24	0.7	0.99	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0	0.75	0.96	0.98	0.98	0	0	0	0	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0.8	0.94	0.96	0.98	0	0	0	0	0	0	0	0	0	0	0	0

West-Facing Side Shading

Beam Shading Factor — 0=Full Shading, 1=No Shading — 0 — Apply to selected cells

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11p
Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.95	0.92	0.9	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.99	0.98	0.92	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
Apr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0.98	0	0	0	0
Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0.96	0	0	0	0
Jul	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0
Aug	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0
Sep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
Oct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.99	0.98	0.92	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.98	0.95	0.92	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.95	0.92	0.9	0	0	0	0	0	0	0

Appendix J: ASCE Section 7.10 Table 4-1

Table 4-1 Minimum Uniformly Distributed Live Loads, L_o, and Minimum Concentrated Live Loads

Table 4-1 (*Continued*)

Occupancy or Use	Uniform psf (kN/m^2)	Conc. lb (kN)
Office buildings		
File and computer rooms shall be designed for heavier loads based on anticipated occupancy		
Lobbies and first-floor corridors	100 (4.79)	2,000 (8.90)
Offices	50 (2.40)	2,000 (8.90)
Corridors above first floor	80 (3.83)	2,000 (8.90)
Penal institutions		
Cell blocks	40 (1.92)	
Corridors	100 (4.79)	
Recreational uses		
Bowling alleys, poolrooms, and similar uses	75 (3.59)[a]	
Dance halls and ballrooms	100 (4.79)[a]	
Gymnasiums	100 (4.79)[a]	
Reviewing stands, grandstands, and bleachers	100 (4.79)[a,k]	
Stadiums and arenas with fixed seats (fastened to the floor)	60 (2.87)[a,k]	
Residential		
One- and two-family dwellings		
Uninhabitable attics without storage	10 (0.48)[l]	
Uninhabitable attics with storage	20 (0.96)[m]	
Habitable attics and sleeping areas	30 (1.44)	
All other areas except stairs	40 (1.92)	
All other residential occupancies		
Private rooms and corridors serving them	40 (1.92)	
Public rooms[a] and corridors serving them	100 (4.79)	
Roofs		
Ordinary flat, pitched, and curved roofs	20 (0.96)[n]	
Roofs used for roof gardens	100 (4.79)	
Roofs used for assembly purposes	Same as occupancy served	
Roofs used for other occupancies	[o]	[o]
Awnings and canopies		
Fabric construction supported by a skeleton structure	5 (0.24) nonreducible	300 (1.33) applied to skeleton structure
Screen enclosure support frame	5 (0.24) nonreducible and applied to the roof frame members only, not the screen	200 (0.89) applied to supporting roof frame members only
All other construction	20 (0.96)	
Primary roof members, exposed to a work floor		
Single panel point of lower chord of roof trusses or any point along primary structural members supporting roofs over manufacturing, storage warehouses, and repair garages		2,000 (8.9)
All other primary roof members		300 (1.33)
All roof surfaces subject to maintenance workers		300 (1.33)
Schools		
Classrooms	40 (1.92)	1,000 (4.45)
Corridors above first floor	80 (3.83)	1,000 (4.45)
First-floor corridors	100 (4.79)	1,000 (4.45)
Scuttles, skylight ribs, and accessible ceilings		200 (0.89)
Sidewalks, vehicular driveways, and yards subject to trucking	250 (11.97)[a,p]	8,000 (35.60)[q]
Stairs and exit ways	100 (4.79)	300[r]
One- and two-family dwellings only	40 (1.92)	300[r]

Appendix K: International Building Code 2006 Section 1605

SECTION 1605
LOAD COMBINATIONS

1605.1 General.
Buildings and other structures and portions thereof shall be designed to resist the load combinations specified in Section 1605.2 or 1605.3 and Chapters 18 through 23, and the special seismic load combinations of Section 1605.4 where required by Section 12.3.3.3 or 12.10.2.1 of ASCE 7. Applicable loads shall be considered, including both earthquake and wind, in accordance with the specified load combinations. Each load combination shall also be investigated with one or more of the variable loads set to zero.

1605.2 Load combinations using strength design or load and resistance factor design.

1605.2.1 Basic load combinations.
Where strength design or load and resistance factor design is used, structures and portions thereof shall resist the most critical effects from the following combinations of factored loads:

$1.4(D + F)$ **(Equation 16-1)**

$1.2(D + F + T) + 1.6(L + H) + 0.5(L_r \text{ or } S \text{ or } R)$ **(Equation 16-2)**

$1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (f_{1L} \text{ or } 0.8W)$ **(Equation 16-3)**

$1.2D + 1.6W + f_{1L} + 0.5(L_r \text{ or } S \text{ or } R)$ **(Equation 16-4)**

$1.2D + 1.0E + f_{1L} + f_{2S}$ **(Equation 16-5)**

$0.9D + 1.6W + 1.6H$ **(Equation 16-6)**

$0.9D + 1.0E + 1.6H$ **(Equation 16-7)**

f_1 = 1 for floors in places of public assembly, for live loads in excess of 100 pounds per square foot (4.79 kN/m^2), and for parking garage live load, and

= 0.5 for other live loads.

f_2 = 0.7 for roof configurations (such as saw tooth) that do not shed snow off the structure, and

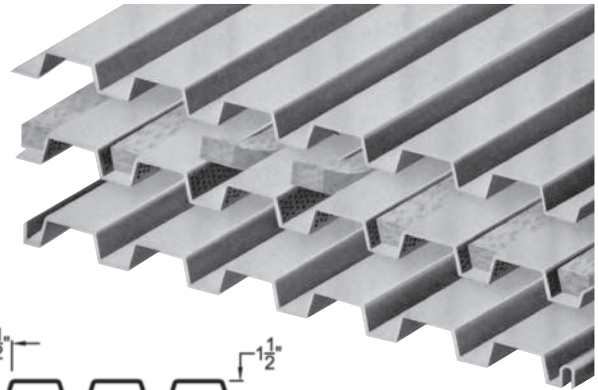
= 0.2 for other roof configurations.

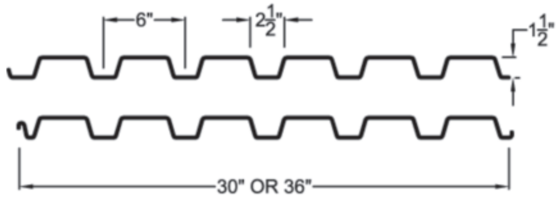
Exception: Where other factored load combinations are specifically required by the

Appendix L: Vulcraft's 1.5B16 Roof Deck Specifications

1.5 B, BI, BA, BIA

Maximum Sheet Length 42'-0
Extra charge for lengths under 6'-0
ICC ER-3415
FM Global Approved[2]





Interlocking side lap is not drawn to show actual detail.

SECTION PROPERTIES

Deck type	Design thickness in.	W psf	Section Properties I_p				V_a lbs/ft	F_y ksi
			I_p in^4/ft	S_p in^3/ft	I_n in^4/ft	S_n in^3/ft		
B24	0.0239	1.46	0.107	0.120	0.135	0.131	2634	60
B22	0.0295	1.78	0.155	0.186	0.183	0.192	1818	33
B20	0.0358	2.14	0.201	0.234	0.222	0.247	2193	33
B19	0.0418	2.49	0.246	0.277	0.260	0.289	2546	33
B18	0.0474	2.82	0.289	0.318	0.295	0.327	2870	33
B16	0.0598	3.54	0.373	0.408	0.373	0.411	3578	33

ACOUSTICAL INFORMATION

Deck Type	Absorption Coefficient 125	250	500	1000	2000	4000	Noise Reduction Coefficient[1]
1.5BA, 1.5BIA	.11	.18	.66	1.02	0.61	0.33	0.60

[1] Source: Riverbank Acoustical Laboratories.
Test was conducted with 1.50 pcf fiberglass batts and 2 inch polyisocyanurate foam insulation for the SDI.

Type B (wide rib) deck provides excellent structural load carrying capacity per pound of steel utilized, and its nestable design eliminates the need for die-set ends.

1" or more rigid insulation is required for Type B deck.

Acoustical deck (Type BA, BIA) is particularly suitable in structures such as auditoriums, schools, and theatres where sound control is desirable. Acoustic perforations are located in the vertical webs where the load carrying properties are negligibly affected (less than 5%).

Inert, non-organic glass fiber sound absorbing batts are placed in the rib openings to absorb up to 60% of the sound striking the deck.

Batts are field installed and may require separation.

VERTICAL LOADS FOR TYPE 1.5B

No. of Spans	Deck Type	Max. SDI Const. Span	Allowable Total (PSF) / Load Causing Deflection of L/240 or 1 inch (PSF) — Span (ft.-in.) ctr to ctr of supports: 5-0	5-6	6-0	6-6	7-0	7-6	8-0	8-6	9-0	9-6	10-0
1	B24	4'-8	115 / 56	95 / 42	80 / 32	68 / 26	59 / 20	51 / 17	45 / 14	40 / 11	35 / 10	32 / 8	29 / 7
	B22	5'-7	98 / 81	81 / 61	68 / 47	58 / 37	50 / 30	44 / 24	38 / 20	34 / 17	30 / 14	27 / 12	25 / 10
	B20	6'-5	123 / 105	102 / 79	86 / 61	73 / 48	63 / 38	55 / 31	48 / 26	43 / 21	38 / 18	34 / 15	31 / 13
	B19	7'-1	146 / 129	121 / 97	101 / 75	86 / 59	74 / 47	65 / 38	57 / 31	51 / 26	45 / 22	40 / 19	36 / 16
	B18	7'-8	168 / 152	138 / 114	116 / 88	99 / 69	85 / 55	74 / 45	65 / 37	58 / 31	52 / 26	46 / 22	42 / 19
	B16	8'-8	215 / 196	178 / 147	149 / 113	127 / 89	110 / 71	96 / 58	84 / 48	74 / 40	66 / 34	60 / 29	54 / 24
2	B24	5'-10	124 / 153	103 / 115	86 / 88	74 / 70	64 / 56	56 / 45	49 / 37	43 / 31	39 / 26	35 / 22	31 / 19
	B22	6'-11	100 / 213	83 / 160	70 / 124	59 / 97	51 / 78	45 / 63	39 / 52	35 / 43	31 / 37	28 / 31	25 / 27
	B20	7'-9	128 / 267	106 / 201	89 / 155	76 / 122	66 / 97	57 / 79	51 / 65	45 / 54	40 / 46	36 / 39	32 / 33
	B19	8'-5	150 / 320	124 / 240	104 / 185	89 / 145	77 / 116	67 / 95	59 / 78	52 / 65	47 / 55	42 / 47	38 / 40
	B18	9'-1	169 / 369	140 / 277	118 / 213	101 / 168	87 / 134	76 / 109	67 / 90	59 / 75	53 / 63	48 / 54	43 / 46
	B16	10'-3	213 / 471	176 / 354	149 / 273	127 / 214	110 / 172	95 / 140	84 / 115	74 / 96	66 / 81	60 / 69	54 / 59
3	B24	5'-10	154 / 120	128 / 90	108 / 69	92 / 55	79 / 44	69 / 35	61 / 29	54 / 24	48 / 21	43 / 17	39 / 15
	B22	6'-11	124 / 167	103 / 126	87 / 97	74 / 76	64 / 61	56 / 50	49 / 41	43 / 34	39 / 29	35 / 24	31 / 21
	B20	7'-9	159 / 209	132 / 157	111 / 121	95 / 95	82 / 76	72 / 62	63 / 51	56 / 43	50 / 36	45 / 31	40 / 26
	B19	8'-5	186 / 250	154 / 188	130 / 145	111 / 114	96 / 91	84 / 74	74 / 61	65 / 51	58 / 43	52 / 37	47 / 31
	B18	9'-1	210 / 289	174 / 217	147 / 167	126 / 132	108 / 105	95 / 86	83 / 71	74 / 59	66 / 50	59 / 42	54 / 36
	B16	10'-3	264 / 369	219 / 277	185 / 214	158 / 168	136 / 135	119 / 109	105 / 90	93 / 75	83 / 63	74 / 54	67 / 46

Notes: 1. Minimum exterior bearing length required is 1.50 inches. Minimum interior bearing length required is 3.00 inches. If these minimum lengths are not provided, web crippling must be checked.
2. FM Global approved numbers and spans available on page 21.

Appendix M: Vulcraft's 22KCS4 Open-Web Steel Joist Specifications

ASD

STANDARD LOAD TABLE FOR KCS OPEN WEB STEEL JOISTS Based on a 50 ksi Maximum Yield Strength						
JOIST DESIGNATION	**DEPTH (inches)**	**MOMENT CAPACITY* (inch-kips)**	**SHEAR CAPACITY* (lbs)**	**APPROX. WEIGHT** (lbs/ft)**	**GROSS MOMENT OF INERTIA (in.^{4})**	**BRIDGING TABLE SECTION NUMBER**
10KCS1	10	172	2000	6.0	29	1
10KCS2	10	225	2500	7.5	37	1
10KCS3	10	296	3000	10.0	47	1
12KCS1	12	209	2400	6.0	43	3
12KCS2	12	274	3000	8.0	55	5
12KCS3	12	362	3500	10.0	71	5
14KCS1	14	247	2900	6.5	59	4
14KCS2	14	324	3400	8.0	77	6
14KCS3	14	428	3900	10.0	99	6
16KCS2	16	349	4000	8.5	99	6
16KCS3	16	470	4800	10.5	128	9
16KCS4	16	720	5300	14.5	192	9
16KCS5	16	934	5800	18.0	245	9
18KCS2	18	395	4700	9.0	127	6
18KCS3	18	532	5200	11.0	164	9
18KCS4	18	817	5700	15.0	247	10
18KCS5	18	1062	6200	18.5	316	10
20KCS2	20	442	5200	9.5	159	6
20KCS3	20	595	6000	11.5	205	9
20KCS4	20	914	7900	16.5	308	10
20KCS5	20	1191	8400	20.0	396	10
22KCS2	22	488	5900	10.0	194	6
22KCS3	22	658	6600	12.5	251	9
22KCS4	22	1012	7900	16.5	377	11
22KCS5	22	1319	8600	20.5	485	11
24KCS2	24	534	6300	10.0	232	6
24KCS3	24	720	7200	12.5	301	9
24KCS4	24	1108	8400	16.5	453	12
24KCS5	24	1448	8900	20.5	584	12
26KCS2	26	580	6600	10.0	274	6
26KCS3	26	783	7800	12.5	355	9
26KCS4	26	1206	8500	16.5	536	12
26KCS5	26	1576	9200	20.5	691	12
28KCS2	28	626	6900	10.5	320	6
28KCS3	28	846	8000	12.5	414	9
28KCS4	28	1303	8500	16.5	626	12
28KCS5	28	1704	9200	20.5	808	12
30KCS3	30	908	8000	13.0	478	9
30KCS4	30	1400	8500	16.5	722	12
30KCS5	30	1833	9200	21.0	934	12

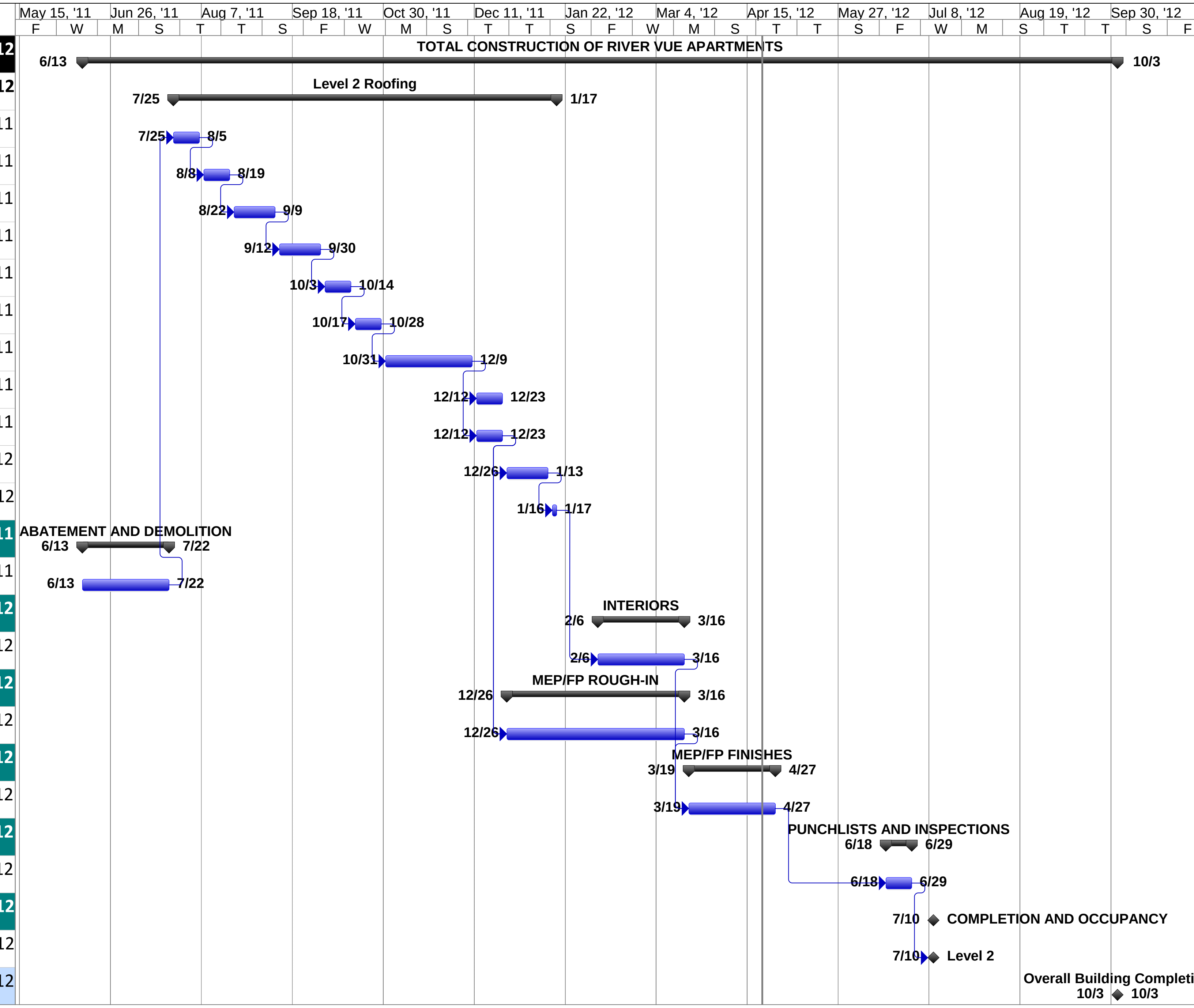
*MAXIMUM UNIFORMLY DISTRIBUTED LOAD CAPACITY IS 550 PLF AND SINGLE CONCENTRATED LOAD CANNOT EXCEED SHEAR CAPACITY

**DOES NOT INCLUDE ACCESSORIES

Appendix N: Detailed Green Roof System and Level 2 Construction Schedule

Detailed Green Roof System and Level 2 Construction Schedule
River Vue Apartments | Pittsburgh, PA

ID	Task Name	Duration	Start	Finish
1	**TOTAL CONSTRUCTION OF RIVER VUE APARTMENTS**	**342 days**	**Mon 6/13/11**	**Wed 10/3/12**
2	**Level 2 Roofing**	**127 days**	**Mon 7/25/11**	**Tue 1/17/12**
3	Demolition of existing roof components	10 days	Mon 7/25/11	Fri 8/5/11
4	Removal of existing metal roof deck	10 days	Mon 8/8/11	Fri 8/19/11
5	Removal of existing steel joists	15 days	Mon 8/22/11	Fri 9/9/11
6	Installation of new steel joists	15 days	Mon 9/12/11	Fri 9/30/11
7	Installation of new metal roof deck	10 days	Mon 10/3/11	Fri 10/14/11
8	Form, rebar, and pour lower roof concrete	10 days	Mon 10/17/11	Fri 10/28/11
9	Concrete - fully cured	30 days	Mon 10/31/11	Fri 12/9/11
10	Installation of new roofing components	10 days	Mon 12/12/11	Fri 12/23/11
11	Spray fireproofing	10 days	Mon 12/12/11	Fri 12/23/11
12	Installation of green roof components	15 days	Mon 12/26/11	Fri 1/13/12
13	Installation of LifeRoof modular green roof vegetation	2 days	Mon 1/16/12	Tue 1/17/12
14	**ABATEMENT AND DEMOLITION**	**30 days**	**Mon 6/13/11**	**Fri 7/22/11**
15	Level 2	30 days	Mon 6/13/11	Fri 7/22/11
16	**INTERIORS**	**30 days**	**Mon 2/6/12**	**Fri 3/16/12**
17	Level 2	30 days	Mon 2/6/12	Fri 3/16/12
18	**MEP/FP ROUGH-IN**	**60 days**	**Mon 12/26/11**	**Fri 3/16/12**
19	Level 2	60 days	Mon 12/26/11	Fri 3/16/12
20	**MEP/FP FINISHES**	**30 days**	**Mon 3/19/12**	**Fri 4/27/12**
21	Level 2	30 days	Mon 3/19/12	Fri 4/27/12
22	**PUNCHLISTS AND INSPECTIONS**	**10 days**	**Mon 6/18/12**	**Fri 6/29/12**
23	Level 2	10 days	Mon 6/18/12	Fri 6/29/12
24	**COMPLETION AND OCCUPANCY**	**0 days**	**Tue 7/10/12**	**Tue 7/10/12**
25	Level 2	0 days	Tue 7/10/12	Tue 7/10/12
26	Overall Building Completion	0 days	Wed 10/3/12	Wed 10/3/12



Project: Detailed Green Roof System and Level 2 Construction Schedule
River Vue Apartments
Date: 4/4/2012

Task	Rolled Up Task	Split	Inactive Task	Duration-only	Finish-only
Critical Task	Rolled Up Critical Task	External Tasks	Inactive Milestone	Manual Summary Rollup	Progress
Milestone	Rolled Up Milestone	Project Summary	Inactive Summary	Manual Summary	Deadline
Summary	Rolled Up Progress	Group By Summary	Manual Task	Start-only	

Appendix O: Leica ScanStation C10 Product Specifications

Leica ScanStation C10
Product Specifications

General

Instrument type	Compact, pulsed, dual-axis compensated, very high speed laser scanner, with survey-grade accuracy, range, and field-of-view; integrated camera and laser plummet
User interface	Onboard control, notebook, tablet PC or remote controller
Data storage	Integrated solid-state drive (SSD), external PC or external USB device
Camera	Auto-adjusting, integrated high-resolution digital camera with zoom video

System Performance

Accuracy of single measurement	
Position*	6 mm
Distance*	4 mm
Angle (horizontal/vertical)	60 µrad / 60 µrad (12″ / 12″)
Modeled surface precision/noise**	2 mm
Target acquisition***	2 mm std. deviation
Dual-axis compensator	Selectable on/off, resolution 1″, dynamic range +/- 5′, accuracy 1.5″

Laser Scanning System

Type	Pulsed; proprietary microchip
Color	Green, wavelength = 532 nm visible
Laser Class	3R (IEC 60825-1)
Range	300 m @ 90%; 134 m @ 18% albedo (minimum range 0.1 m)
Scan rate	Up to 50,000 points/sec, maximum instantaneous rate
Scan resolution	
Spot size	From 0 – 50 m: 4.5 mm (FWHH-based); 7 mm (Gaussian-based)
Point spacing	Fully selectable horizontal and vertical; <1 mm minimum spacing, through full range; single point dwell capacity
Field-of-View	
Horizontal	360° (maximum)
Vertical	270° (maximum)
Aiming/Sighting	Parallax-free, integrated zoom video
Scanning Optics	Vertically rotating mirror on horizontally rotating base; Smart X-Mirror™ automatically spins or oscillates for minimum scan time
Data storage capacity	80 GB onboard solid-state drive (SSD) or external USB device
Communications	Dynamic Internet Protocol (IP) Address, Ethernet or wireless LAN (WLAN) with external adapter
Integrated color digital camera with zoom video	Single 17° x 17° image: 1920 x 1920 pixels (4 megapixels) Full 360° x 270° dome: 260 images; streaming video with zoom; auto-adjusts to ambient lighting
Onboard display	Touchscreen control with stylus, full color graphic display, QVGA (320 x 240 pixels)
Level indicator	External bubble, electronic bubble in onboard control and Cyclone software
Data transfer	Ethernet, WLAN or USB 2.0 device
Laser plummet	Laser class: 2 (IEC 60825-1) Centering accuracy: 1.5 mm @ 1.5 m Laser dot diameter: 2.5 mm @ 1.5 m Selectable ON/OFF

Electrical

Power supply	15 V DC, 90 – 260 V AC
Power Consumption	< 50 W avg.
Battery Type	Internal: Li-Ion; External: Li-Ion
Power Ports	Internal: 2, External: 1 (simultaneous use, hot swappable)
Duration	Internal: >3.5 h (2 batteries), External: >6 h (room temp)

Environmental

Operating temp.	0° C to 40° C / 32° F to 104° F
Storage temp.	-25° C to +65° C / -13° F to 149° F
Lighting	Fully operational between bright sunlight and complete darkness
Humidity	Non-condensing
Dust/humidity	IP54 (IEC 60529)

Physical

Scanner	
Dimensions (D x W x H)	238 mm x 358 mm x 395 mm / 9.4″ x 14.1″ x 15.6″
Weight	13 kg / 28.7 lbs, nominal (w/o batteries)
Battery (internal)	
Dimensions (D x W x H)	40 mm x 72 mm x 77 mm / 1.6″ x 2.8″ x 3.0″
Weight	0.4 kg / 0.9 lbs
Battery (external)	
Dimensions (D x W x H)	95 mm x 248 mm x 60 mm / 3.7″ x 9.8″ x 2.4″
Weight	1.9 kg / 4.2 lbs
AC Power Supply	
Dimensions (D x W x H)	85 mm x 170 mm x 41 mm / 3.4″ x 6.7″ x 1.6″
Weight	0.9 kg / 1.9 lbs

Standard Accessories Included

Scanner transport case
Tribrach (Leica Professional Series)
4x Internal batteries
Battery charger/AC power cable, Car adapter, Daisy chain cable
Data cable
Height meter and distance holder for height meter
Cleaning kit
Cyclone™ SCAN software
1year CCP Basic support agreement

Additional Accessories

HDS scan targets and target accessories
Service agreement for Leica ScanStation C10
Extended warranty for Leica ScanStation C10
External battery with charging station, AC power supply and power cable
Professional charger for internal batteries
AC power supply for scanner
Tripod, tripod star, rolling base, external wireless LAN adapter (third-party)

Notebook PC for scanning with Cyclone software ∆

Component	**required (minimum)**
Processor	1.7 GHz Pentium M or higher
RAM	1 GB (2 GB for Windows Vista)
Network card	Ethernet
Display	SVGA or OpenGL accelerated graphics card (with latest drivers)
Operating system	Windows XP Professional (SP2 or higher) (32 or 64) Windows Vista (32 or 64), Windows 7 (32 or 64)

Control Options

Full color touch screen for onboard scan control
Leica Cyclone SCAN software for laptop PC (see Leica Cyclone SCAN data sheet for full list of features)
Remote controller (Leica CS10/15 or any other remote desktop capable device)

Ordering Information

Contact Leica Geosystems or authorized representatives

All specifications are subject to change without notice.
All ± accuracy specifications are one sigma unless otherwise noted.
* At 1 m – 50 m range, one sigma
** Subject to modeling methodology for modeled surface
*** Algorithmic fit to planar HDS targets
∆ Minimum requirements for modeling operations are different. Refer to Cyclone data sheet specifications

Scanner: Laser class 3R in accordance with IEC 60825-1 resp. EN 60825-1
Laser plummet: Laser class 2 in accordance with IEC 60825-1 resp. EN 60825-1

Illustrations, descriptions and technical specifications are not binding and may change.
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Leica Geosystems AG
Heerbrugg, Switzerland

www.leica-geosystems.com/hds

- when it has to be **right**

Leica Geosystems

Appendix P: Sensor Switch's WSD-PDT Specifications sensorswitch®

WSD PDT

WALL SWITCH DECORATOR SENSOR
LINE VOLTAGE • PASSIVE DUAL TECHNOLOGY (PDT)

SPECIFICATIONS

FEATURES

Patented Dual Technology with PIR / Microphonics™ Detection
Self-Contained Relay - No Power Pack Needed
Interchangeable Hot & Load Wires - Impossible to Wire Backwards
No Neutral Required / No Minimum Load
Small Motion Detection to 20 ft (6.10 m)
Self-Grounding Mounting Strap
Compatible w/ Electronic & Magnetic Ballasts, CFLs, & Incandescents
Push-Button Programmable w/o Removing the Switch Plate
Adjustable Time Delay
LampMaximizer® Minimum On Time (disabled by default)
Non-Volatile Settings Memory
Green LED Indicator

PHYSICAL SPECS

SIZE (not including mounting strap)
2.74”H x 1.68”W x 1.63”D
(6.96cm x 4.27cm x 4.14cm)
WEIGHT 5 oz
MOUNTING Single Gang Switch Box
MOUNTING HEIGHT 30-48 in (76.2-121.9 cm)
COLORS White, Ivory, Gray, Lt. Almond, Black

ELECTRICAL SPECS

MAXIMUM LOAD
800 W @ 120 VAC
1200 W @ 277 VAC
1500 W @ 347 VAC
MINIMUM LOAD None
MOTOR LOAD 1/4 HP
FREQUENCY 50/60 Hz
(timers are 1.2x for 50 Hz)

ENVIRONMENTAL SPECS

OPERATING TEMP
14° to 160° F (-10° to 71° C)
STORAGE TEMP
-14° to 160° F (-26° to 71° C)
RELATIVE HUMIDITY
20 to 90% non-condensing
SILICONE FREE
ROHS COMPLIANT

OVERVIEW

The **WSD PDT** Series is a Wall Switch Decorator style Passive Dual Technology (PDT) occupancy sensor. The combination of Passive Infrared and patented Microphonics™ detection allows this sensor to literally see & hear occupants. It is ideal for restrooms with stalls, private offices where occupant turns their back to the sensor, or rooms with obstructions.

SENSOR OPERATION

Sensors with Passive Dual Technology (PDT) first see motion using Passive Infrared (PIR) detection and then engage Microphonics™ to hear sounds that indicate continued occupancy. This patented technology uses automatic gain control (AGC) to dynamically self adapt a sensor to its environment by filtering out constant background noise and detecting only noises typical of human activity. When occupancy is detected, the relay switches the connected load on as dictated by the sensor’s operational settings.

An internal timer keeps the lights on during brief periods of inactivity and turns the lights off when it expires. The default time delay is 10 minutes. This timer is programmable from 30 seconds to 20 minutes, and is reset every time occupancy is re-detected. Patent pending LampMaximzer technology is also present in this sensor, providing an additional minimum on time (disabled by default) to be used if desired. Finally, as an added safety measure, a 10 second grace period allows the lights to be voice reactivated after initially shutting off. This state-of-the-art design requires no field calibration or sensitivity adjustments.

ON MODES

AUTOMATIC ON (default) - Lights come on when occupancy is detected.
MANUAL ON - Requires the occupant manually turn on lights via the push-button.
REDUCED TURN ON - Sensor is initially set to only detect large motions, effectively ignoring PIR signals reflected off of surfaces, while still sensing occupants when they enter the room. Once lights are on, the sensor returns to maximum sensitivity.

SWITCH MODES

PREDICTIVE OFF MODE (default) - This mode allows occupants to turn lights off via the switch without losing the convenience of having the lights automatically turn on when they re-enter the room. Pressing the switch turns the lights off and temporarily disables the occupancy detection in the sensor. After a short exit time delay, the occupancy detection reactivates and monitors for an additional grace period. If no occupancy is detected, the zone will remain in Automatic On operation. If occupancy is detected, the zone will go to a Permanent Off mode, requiring the switch to be pressed again in order to turn the lights on and restore the sensor to Automatic On operation.
PERMANENT OFF - Pressing the switch turns the lights and the sensor off. Lights will not come on until switch is pressed again.
SWITCH DISABLE - Prevents user from manually turning off the lights via the push-button. Button can still be utilized for programming.

OPTIONS

VANDAL-RESISTANT LENS (V)
- Ideal for high abuse or public areas
- Decreases detection range by 50%

INHIBIT PHOTOCELL (P)
- Auto set-point calibration
- Photocell prevents lights from turning on if adequate daylight is available, but does not turn lights off

347 VAC (347)
- Allows sensor to be powered from and switch 347 VAC
- Wall plate provided (Ivory & White only)

COLOR
- White, Ivory, Gray, Lt. Almond, Black
- Wall plate provided
- Must be specified when ordered

LOW TEMP/HIGH HUMIDITY (LT)
- Sensor is corrosion resistant
- Operates down to -4° F(-20°C)

c UL US LISTED

TITLE 24
ASSEMBLED in U.S.A.
5 YEAR WARRANTY

ORDERING INFO

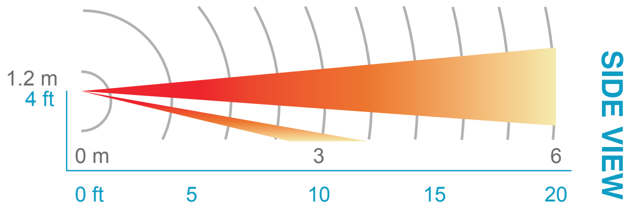
WSD PDT [LENS] [PHOTOCELL] [VOLTAGE] [COLOR] [TEMP/HUMIDITY]

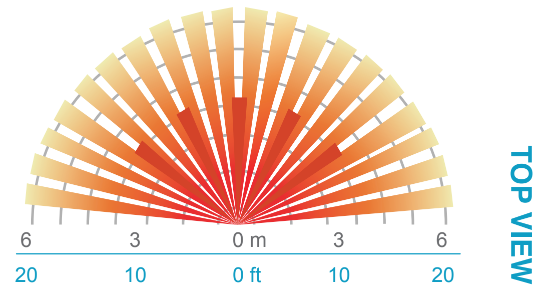
LENS	PHOTOCELL	VOLTAGE	COLOR	TEMP/HUMIDITY
Blank = Standard	Blank = None	Blank = 120/277 VAC	WH = White	Blank = Standard
V = Vandal Resistant	P = Photocell	347 = 347 VAC	IV = Ivory	LT = Low Temp
			GY = Gray	
			AL = Lt. Almond	
			BK = Black	

COVERAGE PATTERN

WALL SWITCH DECORATOR LENS W/ MICROPHONICS™

- Small motion (e.g. hand movements) detection up to 20 ft (6.10 m)
- Large motion (e.g. walking) detection up to 50 ft (15.24 m)
- Wall-to-Wall coverage
- Microphonics™ provides overlapping detection of human activity over the complete PIR coverage area
- Advanced filtering is utilized to prevent non-occupant noises from keeping the lights on





WIRING (DO NOT WIRE HOT)

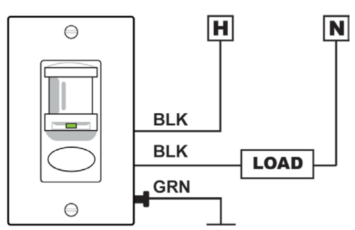
STANDARD WIRING

BLACK* - Line Input
BLACK* - Load Output
} *BLACK wires can be reversed
GREEN SCREW - Ground (required connection)

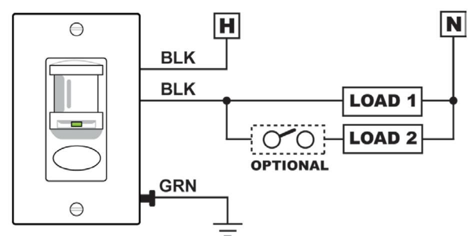
347 VAC OPTION (347)

Black wires are replaced w/ Red wires

STANDARD CONFIGURATION



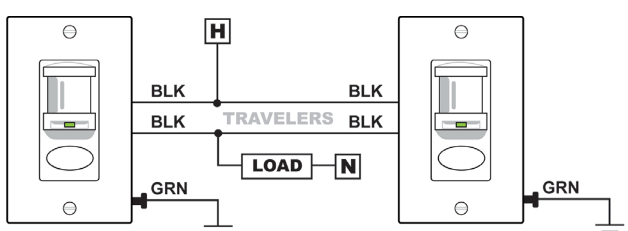
BI-LEVEL CONFIGURATION

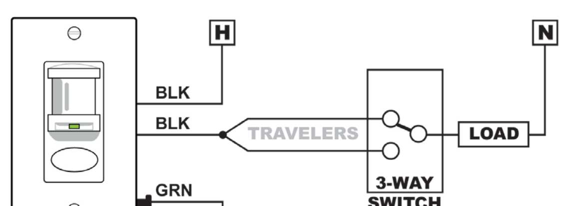


Note: Connection to Ground required for sensor to function

3-WAY WIRING CONFIGURATIONS

Travelers are used to wire sensors (or sensor and 3-way switch) in parallel.





*Wiring in this configuration makes 3-Way Switch non-functional

Note: Connection to Ground required for sensor to function

PROGRAMMING

Refer to included instruction card IC2.002 for default settings and directions on programming the sensor via the push-button.

WARNING

Fire Hazard Caution: Maximum Lamps 1500 Watts, Type 347 VAC.
Attention: Risque d'incendie : Pauissance Maximales Des Lampes 1500 Watts, Type 347 VAC.
Warning: The units are intended to be installed by a qualified person with properly rated branch circuit protectors as per applicable local and national regulations (CEC, NEC).

sensorswitch®
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WARRANTY: Sensor Switch, Inc. warrants these products to be free of defects in materials and workmanship for a period of 60 months. Sensor Switch, Inc., upon prompt notice of such defect, will, at its option, provide a Returned Material Authorization number and repair or replace returned product.
LIMITATIONS AND EXCLUSIONS: This Warranty is in full lieu of all other representation and expressed and implied warranties (including the implied warranties of merchantability and fitness for use) and under no circumstances shall Sensor Switch, Inc. be liable for any incidental or consequential property damages or losses.

TS-WSD-005A

Appendix Q: Apartment Units' Light Fixture Take-Off Notes

Table P1: Light Fixture Information								
Description	Mark	Lamp Data			Total Watts	Type of Mounting	Location Used	Notes
		Quantity	Lamp Type	C.C.T				
Vanity Light	B	3	13 W CFL Full Spiral	2700 K	39 W	Wall Mounted	Bathroom	Energy Star Certified
Exhaust Fan/ Light	J	1	75 W AIG	2700 K	75 W	Ceiling Mounted	Bathroom	Energy Star Certified
Surface Fluorescent	C	2	32 W T8	2700 K	64 W	Ceiling Mounted	Utility Room	Energy Star Certified
Decorative Surface Mount	I	2	13 W DTT	2700 K	26 W	Ceiling Mounted	Walk-In Closet	Energy Star Certified

Table P2: Occupancy Sensor Take-offs			
Apartment Number	Number of Occupancy Sensors	Light Fixture Type	Light Fixture Quantity
Second Floor			
201			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
202			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
203			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C
204			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
205			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1C

206			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
207			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1C
208			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
209			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1C
210			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
211			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
212			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
Laundry	1	Surface Fluorescent	1C
213			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
214			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
215			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
216			

Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
217			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
218			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
Third – Fourteenth Floors			
301, 401, 501, 601, 701, 801, 901, 1001, 1101, 1201, 1301, 1401			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Closet	1	Decorative Surface Mount	12I
302, 402, 502, 602, 702, 802, 902, 1002, 1102, 1202, 1302, 1402			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
303, 403, 503, 603, 703, 803, 903, 1003, 1103, 1203, 1303, 1403			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Laundry	1	Surface Fluorescent	12C
304, 404, 504, 604, 704, 804, 904, 1004, 1104, 1204, 1304, 1404			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Laundry	1	Surface Fluorescent	12C
305, 405, 505, 605, 706, 805, 905, 1005, 1105, 1205,			

1305, 1405			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Laundry	1	Surface Fluorescent	12C
306, 406, 506, 606, 706, 806, 906, 1006, 1106, 1206, 1306, 1406			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Laundry	1	Surface Fluorescent	12C
307, 407, 507, 607, 707, 807, 907, 1007, 1107, 1207, 1307, 1407			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Laundry	1	Surface Fluorescent	12C
308, 408, 508, 608, 708, 808, 908, 1008, 1108, 1208, 1308, 1408			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Laundry	1	Surface Fluorescent	12C
309, 409, 509, 609, 709, 809, 909, 1009, 1109, 1209, 1309, 1409			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Laundry	1	Surface Fluorescent	12C
310, 410, 510, 610, 710, 810, 910, 1010, 1110, 1210, 1310, 1410			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
311, 411, 511, 611, 711, 811,			

911, 1011, 1111, 1211, 1311, 1411			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
312, 412, 512, 612, 712, 812, 912, 1012, 1112, 1212, 1312, 1412			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Laundry	1	Surface Fluorescent	12C
313, 13, 513, 613, 713, 813, 913, 1013, 1113, 1213, 1313, 1413			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Laundry	1	Surface Fluorescent	12C
314, 414, 514, 614, 714, 814, 914, 1014, 1114, 1214, 1314, 1414			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Laundry	1	Surface Fluorescent	12C
315, 415, 515, 615, 715, 815, 915, 1015, 1115, 1215, 1315, 1415			
Bathroom	2	Vanity Light & Exhaust Fan/Light	12B & 12J
Laundry	1	Surface Fluorescent	12C
Fifteenth Floor			
1501			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
1502			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
1503			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J

Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Bathroom	2	Vanity Light & Exhaust Fan/Light	2B & 1J
Closet	1	Decorative Surface Mount	1I
Closet	1	Decorative Surface Mount	1I
Laundry	1	Surface Fluorescent	1C
1504			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C
1505			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C
1506			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
Laundry	1	Surface Fluorescent	1C
1507			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C
1508			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C
1509			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
Closet	1	Decorative Surface Mount	2I
Laundry	1	Surface Fluorescent	1C
1510			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C
1511			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C

1512			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
Closet	1	Decorative Surface Mount	1I
Laundry	1	Surface Fluorescent	1C
1513			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C
1514			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C
1515			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C
1516			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C
1517			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
Closet	1	Decorative Surface Mount	1I
Laundry	1	Surface Fluorescent	1C
1518			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Closet	1	Decorative Surface Mount	1I
Closet	1	Decorative Surface Mount	1I
Laundry	1	Surface Fluorescent	1C
1519			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C

1520			
Bathroom	2	Vanity Light & Exhaust Fan/Light	1B & 1J
Laundry	1	Surface Fluorescent	1C
Total Occupancy Sensors = 670			