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DEPARTMENT OF ARCHITECTURAL ENGINEERING

ANALYSIS OF COMMERCIAL CONSTRUCTION METHODS FOR A MULTI-FAMILY RESIDENTIAL BUILDING WITH PERSONALITY CHARACTERISTICS OF CONSTRUCTION TEAMS

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ABSTRACT

This report presents four analyses of the design and construction process for the construction of the Plaza Building, an apartment building in the Southeast United States. The project included a 3-story underground parking garage and approximately 300,000 square feet of residential space, split into a 5-story section and an 8-story section which were fully connected. The first three analyses are technical and analyze the potential effectiveness of proposed alternate measures to improve the cost, schedule, or quality of the building. The last analysis is a theoretical research analysis.

Analysis #1 investigates the potential impact of redesigning the 5-story wood framing portion of the Plaza with the structural metal stud and joist system in place in the 8-story portion of the building. The analysis included a structural breadth to redesign a typical wood stud panel wall with the metal stud system. Analysis #2 investigates the redesign of the original fiber cement panel façade with a terra cotta rainscreen system. This analysis included a mechanical breadth to evaluate the thermal properties of the two envelope systems, which was used to estimate the cost impacts of downsizing the mechanical system and decreasing energy costs. A payback analysis was performed for the facades. Analysis #3 investigated the potential cost and effectiveness of implementing a third-party constructability review process on the Plaza. All three technical analyses were recommended to be implemented. Analysis #4 investigated the project delivery system and team personality composition of the Plaza compared to an IPD project, using the Myers-Briggs Type Indicator.

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ACKNOWLEDGEMENTS

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Chapter 1

Project Overview

1.1 Project Description

The Plaza Building is a 219 unit, 622 bed apartment building in the Southeastern United States. There is approximately 300,000 square feet of residential space within the building, with approximately 200,000 square feet of underground parking garage. The project is located in a small city. The project site is bordered on two sides by railroad tracks, on the third by an alley with sensitive underground utilities, and on the fourth by the city's main road, which has heavy vehicular and pedestrian traffic. These site boundaries can be seen in Figure 1 below.

Figure 1: Aerial View Showing Surrounding Conditions

Niles Bolton Associates and Hardin Construction were chosen to be the designer and contractor, respectively, based on their long-term relationship with the undisclosed developer/owner. While Hardin did negotiate a GMP for their CM-at-risk contract with the owner, DPR Construction acquired Hardin immediately before construction began, in June 2013, with a targeted project completion of August 2014. This was an aggressive schedule for a building so large, however, the team did hit their targeted substantial completion date. Final cost data is being withheld for this project, although $50 million can be used as a rough approximation of construction cost. That yields about $100/SF, which is a relatively economical estimate.

Structurally, the building is broken into three separate portions: a 3-story underground parking structure with post-tensioned concrete slabs and concrete columns (200,000 sf), a 5-story wood framed building on the north and west of the project (150,000 sf), and an 8-story tower with exterior load-bearing structural cold-formed stud (150,000 sf). The 5 and 8-story sections are connected by an expansion joint, and there is no other functional difference between the two. Spread footings were used as a foundation. The MEP systems were relatively simple. For the mechanical system, each apartment has a separate Rooftop Unit, with a dedicated refrigerant line running to an in-unit air handler. Two main switchboards of 3000A and 4000A were used to supply the 208/120V electrical system. The envelope/facade system for the building consists of brick with small sections of storefront glazing along the north leg of the wood-framed portion, and cement fiber panels over the remainder.

1.2 Existing Conditions

The Plaza was planned for a site that had already been approved for mixed-use buildings of a multi-family residential nature. A Board of Architectural Review (BAR) must approve all plans for new buildings in the city before construction can begin, to ensure adherence to the historical character of the city. Most BAR requirements pertain to the building façade and are not commonly an issue, although this will be discussed further in Chapter 3. The building site is extremely tight as it is bordered on the north by a high traffic road, on the east and south by railroad tracks, and on the west by an alley with dated infrastructure underneath. The spatial limitations and support of excavation thus became the biggest issues during construction, as there were no unusual soil or subsurface conditions. Stormwater management was required to prevent excessive runoff and contamination, especially near the railroad, but this was addressed with an extensive silt fence system on the south. The site limitations required that the construction office and parking be located offsite, across the street to the north (yet still within walking distance).

1.3 Client Information

The owner of the project is an undisclosed national developer, which constructs and manages similar buildings across the nation (please note that certain pieces of information such as project location and cost data have been removed from this report at the request of the owner). Development of the Plaza idea was part of the owner's regular growth pattern into new local markets. This particular city is well suited to a project from this developer, as there is a large population of the specific audience/market that this owner generally targets. The client's biggest driver for the Plaza's design and construction was schedule, as there was a very firm move-in date for their new lessees that could not be delayed. Cost was also a major concern for the project, which will be discussed in greater detail in Section 1.7. Quality and safety were certainly owner concerns as well, though managed mostly by the contractor on a day-to-day basis. These two variables were compounded by the extremely visible and central location of the project, which generally increased the level of public scrutiny of the project.

1.4 Project Delivery

At the outset, the owner chose to form an LLC for the Plaza venture to limit their risk. As mentioned above, the owner constructs similar facilities across the nation fairly frequently, although their greatest concentration of projects is near their location in the deep south of the US. The architecture firm Niles Bolton Associates (NBA) and Hardin Construction have been repeat service providers for the owner in the deep south region, and were both asked to work on the Plaza without competition or bidding. Hardin was asked to function as a CM-at-risk for the project and negotiate a GMP on 95% construction documents, which occurred around the beginning of May 2013. The three major MEP subcontractors were immediately procured by Hardin in the deep south region. However, between this occurring and the Notice to Proceed, Hardin was acquired by DPR Construction, which therefore inherited Hardin's contract for the

Plaza. This led to a slight schedule delay while the acquisition was pending, in addition to a complete changeover of the staff for the project, which switched to mostly DPR employees. DPR then procured the rest of the subcontractors locally with lump-sum contracts. An organizational chart of the parties can be seen in Figure 2 below.

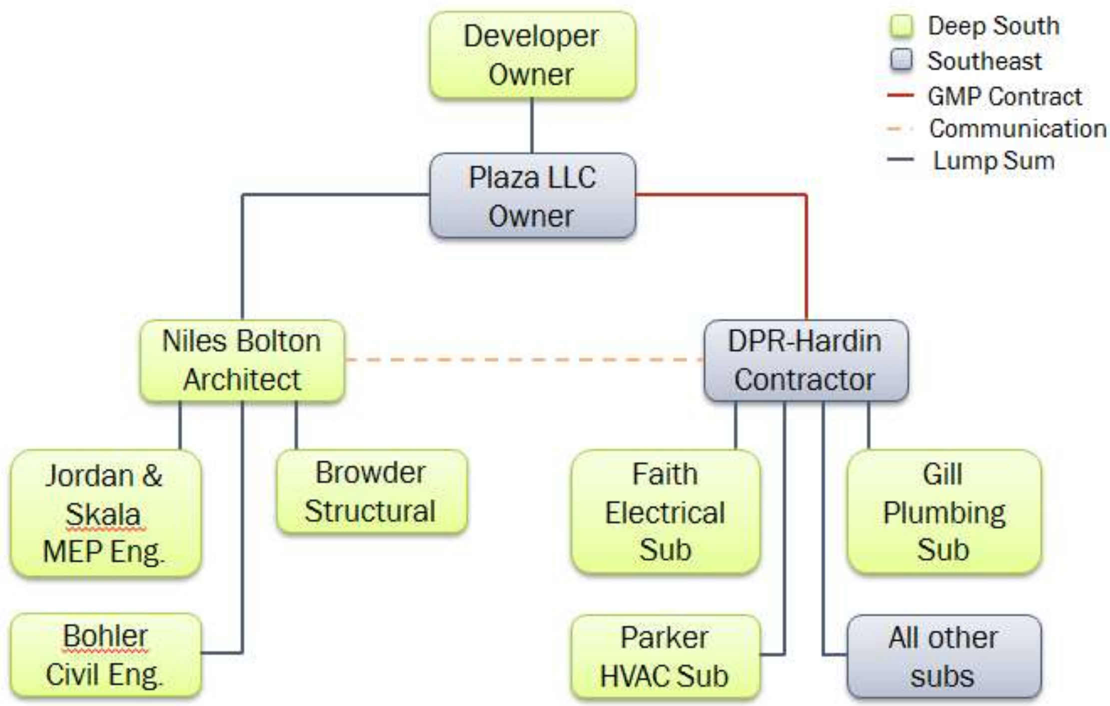


Figure 2: Firm Organizational Chart

1.4.1 Project Team

The staffing plan for this project had fairly standard roles, although the team had an unusually high rate of turnover. A project organizational chart is included below, with dates of involvement in the project to demonstrate the effects of turnover. Although the organizational chart does not include arrows due to the complexity of the timing, it is safe to assume that each "level" of the chart is generally responsible to those above it. The chart also differentiates previous Hardin and DPR employees; while previous Hardin employees negotiated the GMP, the Plaza project team was composed almost entirely of DPR employees.

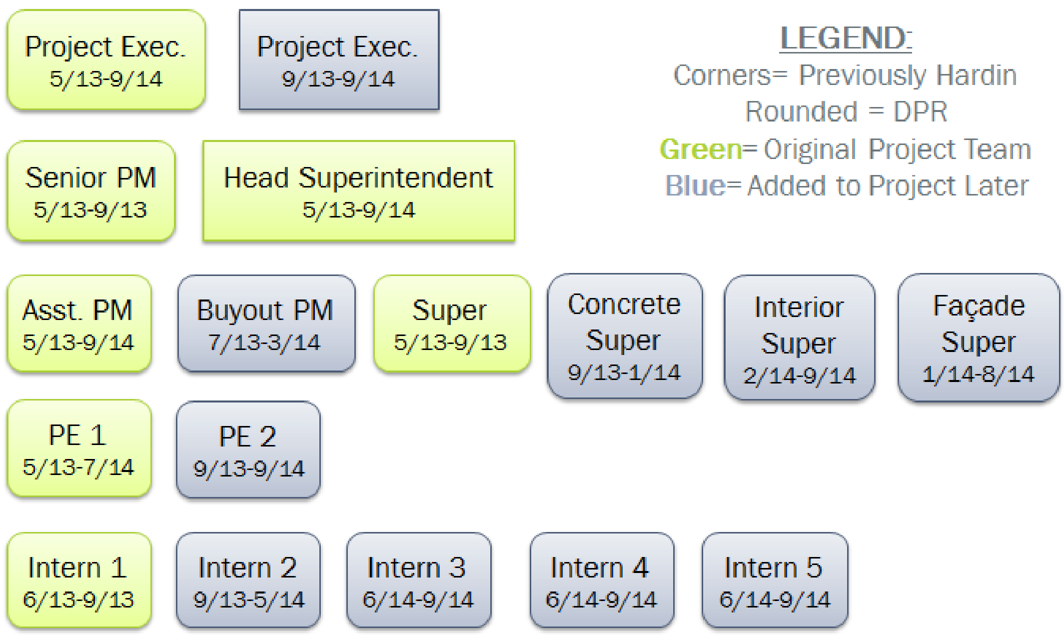


Figure 3: Project Organizational Chart

1.5 Building Systems

1.5.1 Structural System

The main structural systems for the building can be broken into two categories: sub-podium and above-podium structure. The podium is the slab that marks the top of the garage portion and the bottom of the residential portion of the Plaza.

Due to the extremely tight site geography and the 3-story excavation for the garage, there were detailed shoring requirements for the project. Both the south and east sides of the site used wide-flange steel beam soldier piles, while the west used soil nails. Concrete retaining walls, extending up to the podium, were placed directly inside the footprint from this shoring. Foundations were spread footings, varying in size but generally about 6' deep. The slab on grade is 5" thick normal weight concrete. In addition to the retaining walls, concrete shear walls which extend up to the podium are placed throughout the footprint. Columns are reinforced concrete supported by the footings, varying between 14"x24" to 16"x24" with #10 vertical bars. The below-grade slabs for the garage are post-tensioned concrete, with drop caps at columns varying from 4' to 12' wide. The project utilized a tower crane to accelerate the placement of concrete and forms.

Above the podium level, the structure splits into a five-story wood framed building and an eight-story structural metal stud framed building. While the wood stud portion is fairly standard for such a system, the metal stud portion is designed as a proprietary EcoSpan system, which comprises the deck and joists. EcoSpan joists are similar to a typical lightweight open web K-joist (spanning about 25'-40'), while the deck is similar to a 1" composite corrugated metal deck. Both building sections have standard roof trusses spanning 25'-40' to support the roof system. Also, both sections have fully grouted CMU stairwell shafts extending from the podium to the roof to support shear. See Chapter 2 for a more detailed description of the above-grade structural systems.

1.5.2 Building Façade

The north leg of the building is treated entirely with brick, which also wraps around the "end-caps" of this leg and therefore covers a small portion of the east and west sides as well. The brick is standard running bond, local Virginia brick. The remainder of the Plaza's exterior is treated with alternating vertical sections of 2 different shades of smooth fiber cement panels. Sections were delineated by the extruded and indented portions of the façade (see Figure 2) which reflected the units within. Both colors of cement were produced by Certain Teed at 5/16" thickness and came primarily in 4' by 8' pieces. See Chapter 3 for a detailed analysis of the Plaza façade.

1.5.3 Mechanical System

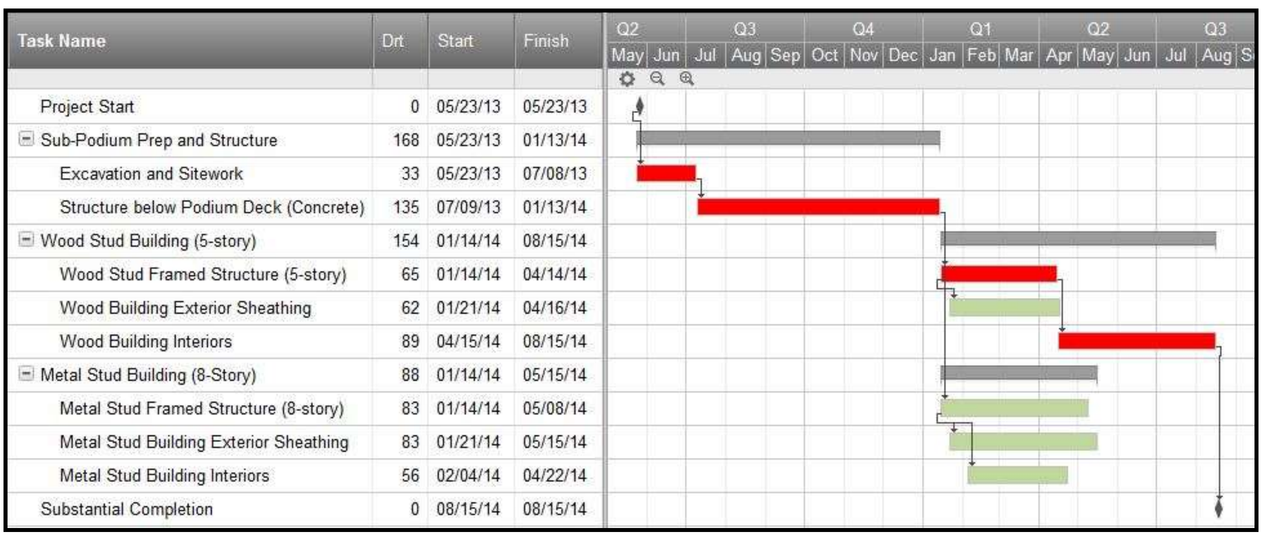
The mechanical system for the project was designed for simplicity and cost-effectiveness. Every apartment unit has a separate air-cooled split system heat pump rooftop unit, as does every separate public or common space. Refrigerant is fed from each rooftop unit through lines traveling down mechanical shafts that run the height of the building. These lines feed a separate air handling unit in each apartment, giving occupants climate control. The residential units range from 600 CFM to 1200 CFM, and from 17 MBH to 34 MBH. Public and common area units have values as high as 2000 CFM and 58 MBH, which are still well within a normal range for commercial projects. See Chapter 3 for a further description of mechanical equipment used on the Plaza.

1.5.4 Electrical System

The Plaza's electrical system is effectively split in two based on the division of the wood and metal stud buildings. Each building has a separate utility transformer and main electrical utility room on the L1 level, the first level below grade. This allows the design to minimize wire and conduit runs, while also helping to maintain a difference between the wood and steel stud buildings for fire separation and structural isolation. The wood building is serviced by 3000A switchgear while the metal stud building has 4000A switchgear. These primary panels each feed four separate main distribution panels which range from 800-1200 amps. From there, each floor has a separate load center that supplies the branch wiring for a certain number of a certain type of room. Within the units the actual electrical components are relatively standard; mostly kitchen appliance connections, typical lighting fixtures, switches, and receptacles.

1.6 Schedule Summary

The schedule for this project became condensed due to the timing of the acquisition, construction delays due to manpower shortages and design issues, and adverse weather delays. Prior to these issues the schedule was already aggressive for such a large building, and the completion date was non-negotiable due to the beginning of tenant leases. The design began in early 2012, with a GMP negotiated in early May 2013 and a June construction start. The concrete work up to the podium was completed in December 2013, with framing finishing in April 2014. While the steel stud portion could be built-up as the studs were installed, the wood building had to be built-out from the top down due to wood stud loading requirements (see Chapter 2 for a detailed discussion). Substantial completion was achieved on August 15, 2014. A summary schedule can be seen in Figure 4.



Task Name	Drt	Start	Finish
Project Start	0	05/23/13	05/23/13
Sub-Podium Prep and Structure	168	05/23/13	01/13/14
Excavation and Sitework	33	05/23/13	07/08/13
Structure below Podium Deck (Concrete)	135	07/09/13	01/13/14
Wood Stud Building (5-story)	154	01/14/14	08/15/14
Wood Stud Framed Structure (5-story)	65	01/14/14	04/14/14
Wood Building Exterior Sheathing	62	01/21/14	04/16/14
Wood Building Interiors	89	04/15/14	08/15/14
Metal Stud Building (8-Story)	88	01/14/14	05/15/14
Metal Stud Framed Structure (8-story)	83	01/14/14	05/08/14
Metal Stud Building Exterior Sheathing	83	01/21/14	05/15/14
Metal Stud Building Interiors	56	02/04/14	04/22/14
Substantial Completion	0	08/15/14	08/15/14

Figure 4: Plaza Summary Schedule

1.7 Cost Summary

1.7.1 Actual Project Costs

As mentioned, detailed cost data for the project is being withheld at the request of the owner. An approximation of $50 million is being used for this report. In addition, the system breakdowns from the original Hardin estimate are not available, so subcontractor lump-sum costs from the actual project have been used to estimate system costs. There will be some inherent inaccuracy in this method, as subcontractors do work across multiple systems and those costs are impossible to separate. The following chart summarizes the comparison of actual costs and an RS Means square foot estimate for the building systems, but includes only system percentages in lieu of lump sum numbers, as the totals were too different to be truly informative.

Table 1: Actual and Square Foot Costs

Cost Source	$/GSF	Structure	Plumbing	HVAC	Electrical
Actual Costs	$100	33%	5%	3%	10.4%
RSMeans	$174	43%	11%	9.5%	8%

The RS Means estimate was based upon a mix of parking garage and apartment building types. The estimate did not accurately reflect the system percentages, which is likely because the actual cost for structure, plumbing, and HVAC were very low due to VE and cost-saving measures.

1.7.2 General Conditions Estimate

The General Conditions estimate for the project totals roughly $2,432,000, which is approximately 5% of the total project cost. A breakdown of the GC costs can be seen in the table below:

Table 2: General Conditions Cost Breakdown

Site Personnel	Office Personnel	Other GCs	Total
$639,265	$1,129,700	$663,175	**$2,432,140**

The overall total for personnel came out to $1,769,000. This number is slightly higher than one might expect as a fraction of the overall budget. However, this can be explained by the very economical nature of the design and construction of the Plaza. The cost per square foot of the overall building is quite low, so the staffing costs seem more reasonable when considered in terms of the size of the overall building, rather than the cost of the overall building. The staffing costs were driven largely by the need for multiple superintendents to manage multiple, disparate parts of the project. Specifically, the team utilized separate superintendents for the exterior façade, concrete, interiors, and hardscaping/landscaping and pool. Many of the design features of the project (such as the two-type stud system and fiber cement façade panels) were chosen to decrease project costs. However, due to subcontractor inexperience with these techniques and difficulty scaling them up to meet the demands of such a large commercial building, multiple cost-saving strategies most likely ultimately increased the project cost, due to greater staffing and labor requirements.

The other costs in the GC estimate that do not come from the staffing plan are fairly standard for a large commercial building of this size, and are mostly composed of things like office rent, dumpsters, temporary toilet facilities, and safety allowances. One notable deviation from the standard GC arrangement was that the owner chose to handle all temporary utility costs for the project. The owner paid for both temporary water and temporary power for the entire project duration. Some other items that are included in the GC's that are slightly unusual are very high travel, fuel, and food costs. This is due to the inclusion of three team members who lived in other states, and had to be flown in each week and lodged in hotel rooms for the duration of the project.

1.8 Site Layout

The Plaza site was tightly constrained, which created logistical difficulties for the duration of the project. Fronted on the north and west by roads, and on the south and east by railroad property, the site had virtually no laydown space or room for material storage. Site logistics plans which show these issues can be found in Appendix A.

Locating the job trailer on site would have been impossible, so the project team moved to a rented office space across the street to the north. The office was close enough that an individual could still quickly access the project. In the first stages of the project, when the site was still being cleared and excavation was just beginning, the access ramp to the excavated portion was located in the northeast corner of the project. This meant that deliveries had to be brought in from the major road to the north, which was less than ideal. However, the ramp was purposefully placed in this location so that the northernmost foundations could begin first, as the project was built in a north-to-south direction. Once the mass excavation was complete, another access ramp was created in the southeast corner of the project, which became the main access point for the remainder of the project. This kept trucks from having to pull in off of the major northern road, as well as allowing a truck washdown station to be erected in the alley adjacent to the ramp.

The next major driver of logistics was the erection of the tower crane, as shown in Site Plan 2. All subcontractors had previously been sharing two crawler cranes, but the congestion of trades and bottleneck with crane resources slowed the project. The tower crane was erected on its own foundation at B2 level, and remained until approximately a month before substantial completion. As the crane was located directly inside of the building and protruded through 3 PT slabs and the central courtyard, this provided some logistical challenges for dismantling the crane and “patching” the hole in the decks where it had been. The remainder of the project was fairly straightforward logistically, although continuously constrained by a lack of space for materials and resources. Having to erect scaffolding for the façade on the north side of the project eliminated the team’s major laydown area. After this point, both courtyards of the project became makeshift storage areas for the remaining duration.

1.9 LEED Evaluation

Sustainability was not a major feature of the Plaza and LEED was not incorporated into the project at all. There were some green features, however, these mostly arose from an attempt to save money on operating costs. It would have been difficult to comply with any level of the LEED program while operating within the restrictive cost, site, and schedule parameters of the project. However, the following table shows a point breakdown that would have made it possible to achieve LEED Certified, and would have required only a moderate increase in cost or schedule. The recommended points were specifically chosen for their feasibility within the existing site and schedule constraints (which could not be impacted), and for only requiring a slight increase in cost. The table also includes a count of the actual points that would have been achieved if the team had been tracking LEED on the original design, compared to the "recommended" plan.

Table 3: LEED Point Summary

Credit	Actual Points	Recommended	Total Possible
Integrative Process	0	0	1
Location & Transportation	10	11	16
Sustainable Sites	1	5	10
Water Efficiency	2	7	11
Energy & Atmosphere	0	4	33
Materials & Resources	0	7	13
Indoor Environmental Quality	3	7	16
Innovation	1	1	6
Regional Priority	0	0	4
Total	**17**	**42**	**110**

This demonstrates that there is significant capacity for improvement in terms of LEED points which would be possible with minimal effort. Additionally, had the team pursued and been awarded LEED Certification, this may have been seen as a "selling point" to potential future tenants. Overall, this analysis suggests that a more targeted effort towards achieving sustainable goals on the Plaza may have increased value for the project. One potential strategy that could have been investigated to improve the energy efficiency and sustainability of the building will be investigated in Chapter 3: Façade Material Analysis.

1.10 BIM Use Evaluation

There was absolutely no BIM used on the Plaza project. Because the MEP systems were all fairly simple and did not require large amounts of space or complex routing, coordination was not considered to be a large concern. Additionally, the owner did not feel that having a model would be advantageous for maintenance, again, because of the simplicity of the major services. It would have been prohibitively expensive to place a BIM Engineer on the project within the confines of the owner's budget.

Chapter 2

Analysis #1: Structural Stud Analysis

2.1 Problem Identification

The designer chose to use wood studs for the structure in approximately half of the building, but steel studs for the remaining half. It is unusual to use two different structural systems in one building that has the same occupancy throughout, and also fairly unusual to see wood studs in commercial applications. Wood studs are a viable structural system up to around 5 stories, which was also the story limit imposed on the Plaza on the north side due to code. The rationale behind this two-system decision was that the wood stud system is cheaper and would therefore be used on the north side, where the building height was already limited to 5-stories. Structural steel studs would be used on the south side of the project to allow an 8-story height, which was required to fit all of the programming needs into the footprint.

However, the team discovered issues with the application of a wood stud system to such a large building: all local subcontractors were familiar with small residential wood stud buildings, not multi-story commercial buildings. Consequently, there were numerous quality, rework, and schedule issues related to the wood stud installation. Additionally, wood stud buildings need to be loaded from the top down, so the structure had to be topped out before any interior trades could begin. On the other hand, the construction of the steel stud half of the building took far less time because the interior trades were able to chase the structure up. All of this suggests that there may have been significant schedule advantages and perhaps some cost advantages to using steel studs throughout the building.

2.2 Research Goals

The purpose of this analysis is to determine whether eliminating the wood stud structure in favor of the steel stud structure used in the rest of the building will yield cost, schedule, quality, safety, or other improvements, and be an advantageous change for the project overall.

2.3 Methodology

1. Determine the original cost and schedule of the wood stud and structural steel stud installation.

2. Determine any actual cost or schedule escalation of either system.

3. Interview the DPR team to determine the logistics of how the two systems were built. Identify any quality, safety, or logistical concerns that arose during construction.

4. Redesign an exterior load bearing wood stud wall with the structural steel stud system already in use on the project, creating a “typical” exterior steel stud panel. This will be Breadth #1, the Structural breadth.

5. Conduct a detailed estimate of the original wood stud and redesigned steel stud panels, and compare both the cost of the two detailed estimates.

6. Use any projected cost and schedule impacts, as well as other impacts (safety, logistics, etc.), to assess if the change to steel studs would have been advantageous for the Plaza.

2.4 Background Information

2.4.1 Wood Stud Background

Wood studs are traditionally used in residential applications, and are limited to one, two, or occasionally three stories. It is extremely unusual to see wood studs used as the structure in such a large building. Consequently, the team was not able to find a local subcontractor that had installed wood studs in such a large commercial application. This was not a problem with the steel stud portion of the building; for this scope the team had multiple highly experienced subcontractors from which to choose. Additionally, research on the use of wood studs in commercial applications across the industry suggests that the cost tends to increase disproportionately as the size of the building increases. This is due to the same reasons suggested by the Plaza team; acceleration costs and rework tend to magnify when small, inexperienced residential subcontractors try to build a large commercial building. Also, there are unavoidable schedule impacts due to having to top out a wood stud structure before interior trades can begin.

As with any stick-built system, wood stud walls will require a significant amount of on-site material staging and storage which must be protected from the weather. Additionally, wood stud walls generally have very high levels of material waste in order to cut pieces to size, which remained true for the Plaza. Significant amounts of cutting increase the time required for installation, increase the amount of carrying or transportation, and can clutter the work area due to discarded wasted materials. The latter two of these issues are also sources of safety problems on a jobsite. It is also somewhat difficult to perform quality control on wood stud installation. Each wall must be constructed according to a specific panel drawing, which means that the installers and any quality control managers must have that specific panel drawing with them in the field, and check every component against only that specific panel's design.

One more factor to consider with wood stud systems is that they require the use of wood joist and floor systems. There is significantly less mechanical flexibility allowed with a wood joist system than with a steel joist system because joists are typically spaced closer together and it is not possible to run duct between the webs of a wood joist.

2.4.2 Steel Stud System

The steel stud system used in Building A of the Plaza was composed of a proprietary light-gauge, high-strength family of structural metal stud products from the Steel Network, the main component of which is the load-bearing SigmaStuds. The unique shape of the SigmaStud (see Figure 5) increases the load capacity dramatically when compared to traditional C-shaped studs. Structural efficiencies of around 30-40% can be expected over traditional studs when using the Steel Network's Sigma line of products for structural metal stud design.

Figure 5: SigmaStud Profile

Prefabrication was utilized for all load-bearing metal stud walls on the project. Panels were prefabricated at a shop approximately 2.5 hours away from site, then trucked to the project using just-in-time delivery. The height of the panels (10') technically exceeded the maximum trucking width requirements of the state, however, a permit was easily obtained to exceed these requirements. The lengths of the panels varied substantially from around 3' to 40', none of which exceeded the 48' maximum length for trucking requirements. The maximum freight weight allowable for the trucks was 48,000 pounds which was not a significant limitation due to the lightweight nature of the steel stud system. Panels were picked from the truck by the tower crane and placed directly on the level upon which they needed to be installed. The tower crane was also used to hold the panels up while the framing crews bolted them in place.

2.4.3 EcoSpan Structural System

The steel stud portion of the Plaza (referred to as Building A) used a proprietary joist/floor system called EcoSpan which is manufactured by Vulcraft. EcoSpan is a lightweight, shallow, composite floor system composed of joists, deck, and connectors. The system uses open web joists at 48” on center and between 10” to 24” deep, and is able to span fairly long distances due to the lightweight nature of the components. Vulcraft specifies their own multi-span sheets of light-gauge steel decking for use with this system, which also decreases the overall weight. A new connection type known as the Shearflex screw was designed for use with this system, which is a patented, self-tapping and self-drilling connector, installed with Vulcraft’s propriety Shearset tool. A diagram of the system can be seen in Figure 6.

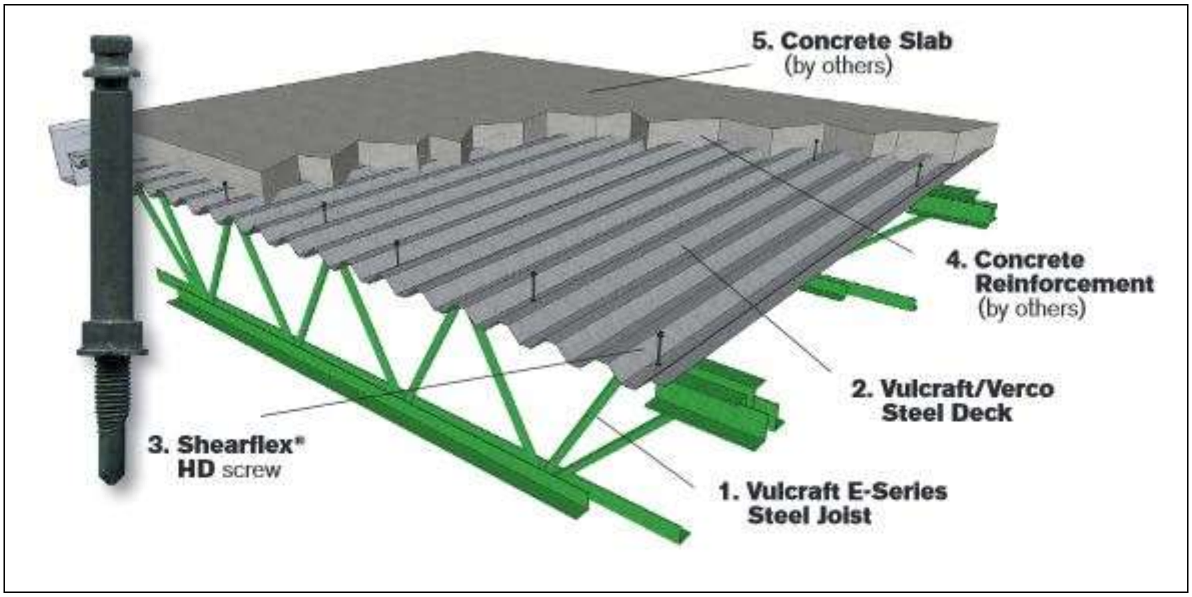


Figure 6: EcoSpan Diagram

Although the system is not structurally sound for heavy commercial applications, it is appropriate for multi-family residential and light commercial applications. There are economic advantages to the system because it does not require the use of formwork, shoring, or welding, which can yield significant cost and schedule savings. It is compatible with any wall type, including structural steel studs. The use of open web joists also allows for greater mechanical and electrical flexibility, and improved ease of installation. Typically the floor is composed of a lightweight 1" deck with 2.5" normal weight concrete (3.5" total depth). Sub-trades may begin work the day after concrete is poured due to the fact that shoring is not required.

The economical and schedule advantages of this system make it a good choice for the Plaza. As such, the same system will be used in the proposed redesign of the wood stud portion of the building, because the wood floor joist and floor system will also need to be reconfigured with the new design. Building A, the original steel stud portion, used 16" deep EcoSpan joists at 48" on center in all units. The same configuration will be used in the redesign for continuity.

2.5 Cost and Schedule of Original Structural Systems

2.5.1 Original Schedule

The wood stud structure was arguably the controlling factor for the project's schedule. This was due to a number of reasons, the most important of which is sequencing limitations. As previously mentioned, wood stud structures must be loaded from the top down in terms of interiors and finishes. This is because the studs at the bottom floors will shrink a few inches under the load of the upper floors' structure, and this shrinkage will destroy any drywall which has already been attached to the studs. The shrinkage also changes the dimensions of openings, which can damage MEP rough-ins. Because drywall and MEP rough-ins are usually the first work in an interior space, all interior and finishes trades must wait for the structure to be completely topped out, then complete their installation moving from the top floor to the bottom floor. In the steel stud structure, however, the interior finishes trades are allowed to begin on each floor after the floor above is sheathed/weather protected, which can occur immediately after the erection of the structure. This allows the interior trades in the steel stud portion to "chase" the structural sub up the building. This is much more efficient in terms of schedule. Because of these sequencing issues, the wood stud structure and finishes dominated the critical path of the schedule after the sub-podium concrete, as can be seen in the following summary schedule.

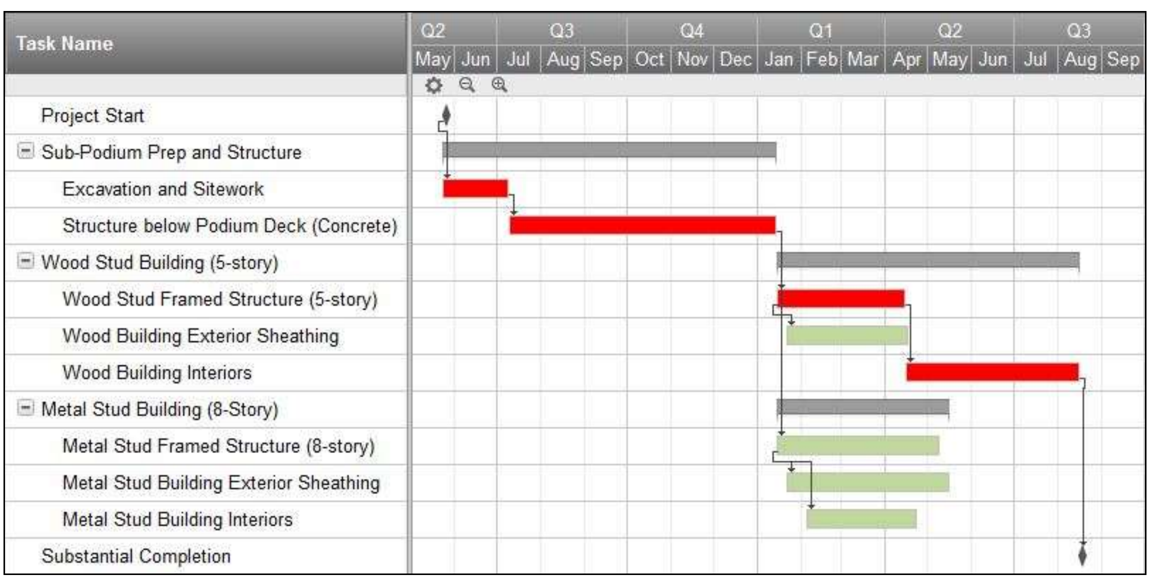


Figure 7: Summary Schedule with Critical Path

It is important to note that this schedule reflects the original durations for the project. In reality, the wood stud installation exceeded the planned durations. This had a significant effect on all remaining scopes of work and subcontractors, who were forced to accelerate to make up for lost time. Accelerating the schedule was critically important because substantial completion absolutely could not be extended past the planned date (8/15/14). In order to attempt to keep the framing on schedule, DPR opened the project for weekend work. This allowed the wood framing subcontractor to work both Saturdays and Sundays to try to offset schedule lapses experienced during the work week. Despite this measure, the wood stud structure was not completed until a week after the planned end date for this activity. The steel stud structure was completed on time, largely without the use of weekend work.

2.5.2 Original Cost

The original contract cost of the structure for the wood stud building was $2.7 million, while the original contract cost of the structure for the steel stud building was $3.5 million. The total area of each type is approximately the same, at around 150,000 square feet, so it is appropriate to compare the total costs of each system rather than the unit costs. Although the original contract cost of the wood structure was only $2.7 million, this scope experienced significant cost escalation throughout the project. The metal stud scope, on the other hand, did not experience cost escalation.

A significant increase in cost for the wood stud scope occurred because of quality control issues. As previously mentioned, each structural wall had to be built to the exact design of a specific panel drawing. This meant that the installers had to have buildable plans in the field at all times, and follow the precise layout shown on those plans. The wood stud subcontractor had some difficulty with this direction. Their difficulty can likely be attributed to the fact that most wood stud buildings are small residential structures, and do not require panel drawings with anywhere near the complexity of those used on the Plaza. The labor force of the wood stud subcontractor, as well as their firm as a whole, was familiar with wood stud installation for residential structures, but not familiar with wood stud installation for large commercial structures.

It consequently proved difficult to control the accuracy of the installed work to the panel designs. Mistakes in the stud layout also tend to have significant negative effects for subsequent trades. For example, the electrical subcontractor may not have enough room to run wire, or the opening allowances may be out of tolerances for the doors, frames, and hardware subcontractor. Both of these and other issues were encountered with the wood stud installation on the Plaza.

Because of these issues and the manpower shortages experienced by the wood stud subcontractor, the DPR team chose to take on their quality control and punchlist scope a portion of the way through the wood stud installation. DPR dedicated a carpentry crew to this task for 14 weeks, which created a significant labor cost.

In order to obtain an accurate estimate of the final cost of the wood stud system, the cost impacts of these quality issues had to be accounted for. This was accomplished by analyzing the change orders and backcharges associated with this subcontractor, as well creating an estimate for the GC labor to manage the punchlist and rework. Costs were separated by item into the following categories: impacts to electrical work, impacts to other subcontractors (mainly plumbing and doors, frames, and hardware corrections for openings out of tolerance), quality issues (ie- rework), and GC labor to manage punchlist. The results of this analysis are summarized in the table below.

Table 4: Quality Costs of Wood Studs

Quality Impact Area	Cost
Electrical Subcontractor	$ 115,000
Other Subcontractors	$ 85,495
Rework	$ 29,584
GC Labor to Manage Quality/Punchlist	$ 290,978
Subtotal	**$ 521,057**
Original Contract Value	$ 2,650,000
Total Scope Cost	**$ 3,171,057**

Another cost which was created by the wood stud installation was acceleration costs. As discussed in the previous section, the wood stud structure was completed a week after the planned date. Because the substantial completion date was firm and could not change, this forced the remaining trades (facade and interior trades) to collectively accelerate a week. The fiber cement façade was ultimately unable to accelerate (see Chapter 3 for a further description), so the responsibility for acceleration fell to the interior and finishes trades.

These acceleration costs also need to be estimated in order to provide a holistic assessment of the wood structure, as the week delay was a direct consequence of the wood stud installation. An unrelated activity earlier in the project had delayed the entire Plaza schedule by a week, and the responsibility for this acceleration was ultimately also passed to interior and finishes subs. Therefore the interior and finishes subs had to make up two total weeks of the project schedule. It is difficult to separate out the acceleration costs for each of these two weeks, so they will be estimated together.

The process to estimate these acceleration costs involved the review of subcontractor quotes, change orders, and backcharges, as well as an assessment of the cost of GC personnel for overtime periods and discussions with the project team. Table 5 gives a summary estimate of these acceleration costs for the two week period.

Table 5: Interior and Finishes Acceleration Costs

Activity	Cost
Insulation and Drywall	$ 338,501
Underlayment	$ 17,724
OT for MEP rough-ins	$ 378,082
OT for finishes	$ 164,948
OT for 3rd shift cleaning	$ 46,401
GC Supervision for OT work	$ 86,602
Rent for additional staging	$ 102,734
TOTAL	**$ 1,134,992**

If the costs are assumed to be uniform throughout the two weeks, this would mean that the one-week delay of the wood stud structure ultimately caused a $567,000 increase in acceleration costs for the interior and finishes subcontractors. If this estimate is combined with the cost escalation due to quality of the wood stud system and the original contract cost of this scope, it yields a final total cost of $3.74 million. This represents an increase of approximately 41% from the original contract cost, which is quite substantial. The drastic increase in cost of the wood structure is in contrast with the metal stud structure, which did not experience cost escalation.

Table 6: Total Final Cost of Wood and Steel Structures

	Wood Stud Structure	Metal Stud Structure
Original Contract Value	$ 2,650,363	$ 3,508,651
Cost Escalation (Quality)	$ 521,057	$ -
Acceleration Costs	$ 567,496	$ -
Total Final System Cost	**$ 3,738,916**	**$ 3,508,651**

2.6 Breadth #1: Structural Redesign of Wood Studs to Steel Studs

2.6.1 Purpose and Goal

Exploring the structural efficiencies of the EcoSpan and SigmaStud components of the metal stud system will facilitate a more holistic comparison of the proposed metal stud design and the original wood stud design. The first purpose of this breadth is to gain a thorough understanding of the innovative components of the metal stud system, and how these contribute to a more effective structure. The second purpose of the breadth is to redesign a typical load bearing wood stud wall with the metal stud system. This will provide a uniform basis of comparison for the two systems which will aid in the decision of whether to implement the proposed change.

2.6.2 Design Process

The first step in the design process was to choose a "typical" load-bearing wall which was originally designed as a wood wall, in order to redesign it with the metal stud system. The wall in question would have to be an exterior wall, because the location of interior load bearing walls varied greatly between the two systems. The largest repeated exterior wall was chosen because it should constitute a good standard configuration (variability decreases in larger units). Also, this wall should have the highest complexity, so all smaller wall panels can conservatively be estimated with a scaled material takeoff from the largest wall panel. The panel chosen for this analysis is the exterior wall of typical apartment unit D1, seen with basic dimensions in Figure 8. The influence and tributary areas of the wall were also required in order to design the studs and joists needed for the metal stud system. The depth of the room was 30'-10" so the influence and tributary areas were found to be 1350 sf and 675 sf, respectively.

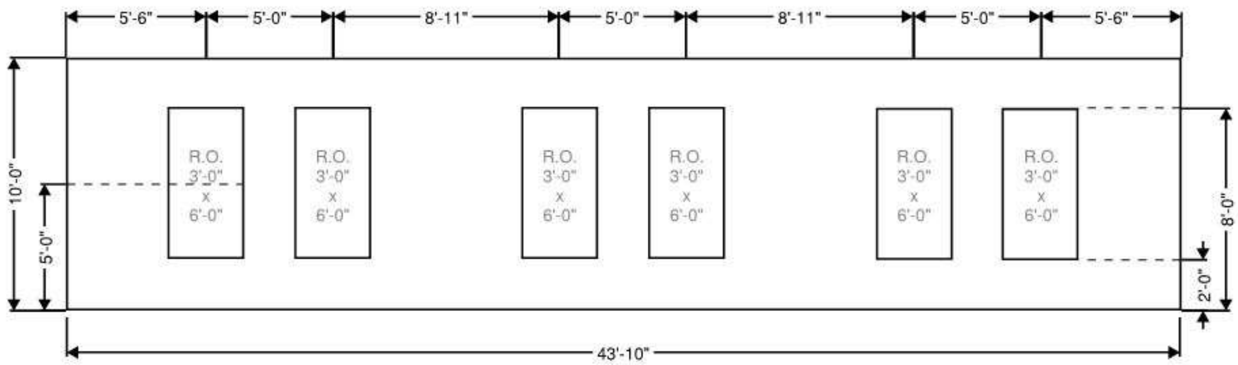


Figure 8: Unit D1 Exterior Wall Dimensions

Next the loads for the wall had to be determined. For the sake of simplicity, it was decided that the wall would be designed for the 5th floor, which is the second floor from the top. This will require one floor of dead and live loads to be factored into the structural design, as well as the roof loads. The pertinent dead and live loads for the Plaza were determined based on ASCE Standards. Nonstandard loads, such as the joist and floor allowance for the EcoSpan system, were gathered from manufacturer literature. ASCE 7-05 was used to determine that the loads should be combined using LRFD Load Combination #2: [1.2(D) + 1.6(L) + 0.5(L_r + S + R)]. This yielded a total uniform load for the 5th floor of 178.9 pounds per square foot (psf). This number is only pertinent within the apartment units and does not apply to corridors. Load calculations are shown in the following table.

Table 7: Plaza Load Calculations

	Wt.	Unit	Fctr	Wt	Unit
Misc. Dead Loads	10	psf			
Floor Allowance (In Unit)	42	psf			
Partitions	15	psf			
Dead Load Subtotal	**67**	psf	1.2	80.4	psf
Residential Live Load	40	psf			
Live Load Subtotal	**40**	psf	1.6	64	psf
Roof Dead Load	30	psf			
Roof Live Load	20	psf			
Flat Roof Snow Load	19	psf			
Roof Load Subtotal	**69**	psf	0.5	34.5	psf
TOTAL LOAD	**176**	**psf**		**178.9**	**psf**

The next step was to design the typical wall and floor area using the EcoSpan and SigmaStud products. The manufacturers were contacted, and the design manuals for each product were obtained. First, the floor and joist system was designed. The EcoSpan system specifies Vulcraft E-series joists, which are unique to this system. These joists are somewhat similar to a K-series joist, although lighter in weight and can span longer distances. A joist depth of 16" and 4'-0" on center spacing was used for continuity with the existing metal stud portion of the Plaza. The E-series load tables were used to determine sizing. A 1.0C Vulcraft deck with 2.5" normal weight concrete (3.5" total depth) was chosen for the floor system.

Next, the SigmaStud product information was used to design the typical stud wall. A 6" wide stud at 16" on center was considered the basis of design for continuity with the rest of the Plaza and due to fastening requirements of the exterior façade. The following assumptions were also used in the design process:

- The wall was designed for L/600 façade deflection requirements in order to be congruent with the alternate façade material discussed in Chapter 3.
- Strapping and bridging were included in the design. This design was performed in accordance with all Steel Network design manual guidelines.
- The Steel Network's proprietary JamStud was used in lieu of boxed headers.
- Blocking for appliances and other wall-hung items was not included, as nothing is typically attached to the exterior wall of Unit D1.
- No live loads were reduced in accordance with ASCE guidelines.
- Clips and attachments were excluded from the design. This would require significant structural calculations outside the scope of this study.
- Wind loads for the Plaza were determined to be 19 psf. These were within the allowable limit for the completed design.
- Self-weight allowance was checked once the design was complete and found to be acceptable.

The typical panel wall produced through this process can be viewed in its entirety (including a bill of materials) in Appendix B. A view of the panel is also shown here for reference.

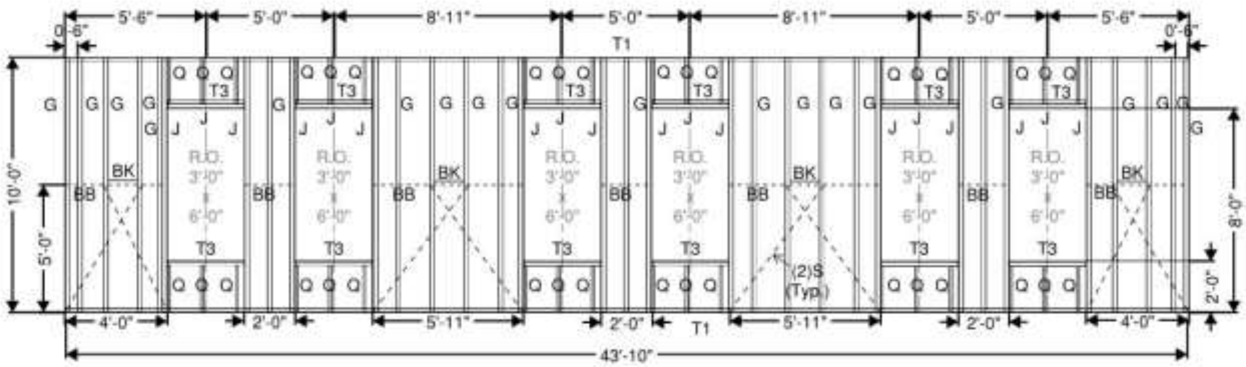


Figure 9: Redesigned Metal Stud Typical Panel

2.7 Estimate of Panel Redesign

A detailed estimate was performed for both the original wood stud design of the D1 panel and the redesigned metal stud D1 panel. The estimates also included the joist and floor system costs for both systems for the influence area of this wall, which was approximately 1,355 square feet. This allowed the costs of the two systems to be compared in a very specific application, in order to get a better sense of how the whole system costs were composed. The takeoffs and calculations can be found in Appendix B, but the following table gives a summary:

Table 8: Redesigned Panel Estimate

System	Material Cost	Labor Cost	Equip. Cost	Total Cost
Steel Studs	$ 772	$ 582	$ -	$ 1,354
Steel Joists and Floor	$ 5,737	$ 1,462	$ 198	$ 7,397
Steel System Total	**$ 6,509**	**$ 2,044**	**$ 198**	**$ 8,752**
Wood Studs	$ 484	$ 1,394	$ -	$ 1,878
Wood Joists and Floor	$ 4,862	$ 1,808	$ 54	$ 6,725
Wood System Total	**$ 5,346**	**$ 3,202**	**$ 54**	**$ 8,603**

The unit prices for these estimates were obtained from RSMeans, so they reflect only standard or typical materials for these systems. The manufacturers of the EcoSpan and SigmaStud systems were contacted to obtain an estimate of how much these systems tend to save on labor costs, as well as the typical material cost increase of these proprietary systems over traditional systems. These factors were applied to the steel stud estimate to obtain a more accurate assessment. The factors and final totals can be seen in the following table.

Table 9: Factored Redesigned Panel Estimate

System	Material Cost	Labor Cost	Equip. Cost	Total Cost
Steel Stud Factors	10%	-15%	0%	
Steel Joist and Floor Factors	0%	-10%	0%	
Factored Stud Costs	$ 849	$ 495	$ -	$ 1,344
Factored Joist/Floor Costs	$ 5,737	$ 1,316	$ 198	$ 7,251
Factored Total Costs	**$ 6,586**	**$ 1,811**	**$ 198**	**$ 8,595**

It can be seen in Table 8 that if typical materials were used, the metal stud system would be slightly more expensive than the wood stud system. However, when the factors for the material and labor costs of the innovative aspects of the metal stud wall are applied, the total cost for the metal stud system becomes slightly less than the wood stud system (Table 9). These factors include a material markup for the Steel Network's proprietary products (SigmaStud), a decrease in labor for the stud walls due to the SigmaStud's ease of installation and the off-site prefabrication of the panels, and a decrease in labor for the joist and floor system due to EcoSpan's streamlined installation process.

This estimate reflects the advantages of the innovative aspects of the metal stud design. Although wood stud systems are generally considered to be less expensive than metal stud systems, the use of EcoSpan and SigmaStud decreased the structure weight drastically, allowing a more efficient structure to be designed in terms of materials. The use of these products and the application of prefabrication also significantly decreased the labor to install the metal stud structure. Overall, the detailed cost estimate performed on the redesigned panel coincides well with the actual construction cost analysis performed in Section 2.5.2. Both estimates suggested that ultimately, the wood stud structure is slightly more expensive than the metal stud structure used on this project.

2.8 Other Implications of Redesign

2.8.1 Schedule Implications

Although cost is a very important factor in evaluating the viability of the redesign, there are other factors as well. The largest factor outside of the initial hard cost of the system is schedule. As previously noted, the wood stud structure dominated the critical path of the schedule due to its need to be topped out before interior trades could begin. With the metal stud system, the sheathing/weatherproofing contractor and interior trades can chase the structure up the building, which is significantly more effective from a scheduling standpoint. In the metal stud portion of the Plaza, the sheathing sub began their work five days after the metal stud subcontractor. This built in some space between the two subs, and allowed the sheathing installation to follow the structural sub in their progression around the building. The interior subs began 10 days after the sheathing subcontractor and 15 days after the structural subcontractor. This allowed one floor of stud walls and sheathing to be installed, as well as the floor above, creating a weathertight area in which the interior subs could begin. If the wood stud portion of the building was redesigned as steel studs the same schedule progression concept would be used. Allowing a 20 day delay between the start of structural installation and interiors installation because of the increased floor size of the 5-story building, and keeping the original durations, the schedule would appear as in Figure 10: Redesign Schedule with Original Durations.

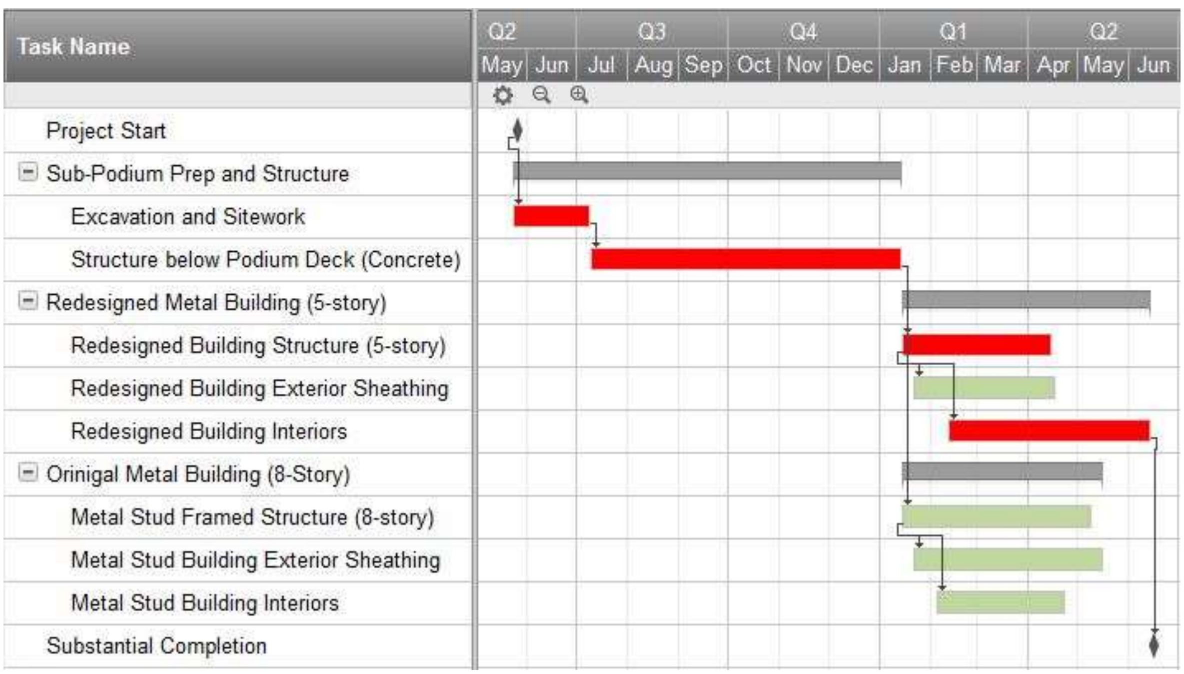


Figure 10: Redesign Schedule with Original Durations

This would put substantial completion at June 13th, approximately 2 months ahead of schedule. However, this assumes the metal stud subcontractor and all interiors subcontractors have the necessary labor force to provide that much manpower in a shorter period of time. Additionally, this schedule still reflects the previous durations for the interior subcontractors, which include the two weeks of acceleration previously discussed. Finally, this schedule assumes the use of weekends, because that was previously required to meet the schedule. All of these factors must be accounted for in order to provide a realistic schedule analysis of the impacts of the redesign.

The metal stud subcontractor on the project was quite large, and discussions with the DPR project team suggested that they would have a large enough labor force to commit the required manpower for the redesign within the above schedule. The interiors trades, on the other hand, were not as large and did not have the same labor force available. These trades would likely need an addition of 4 weeks to the above schedule because of manpower limitations. Adding 2 more weeks to the durations for interior trades would eliminate the original 2-week acceleration costs, and the need to use weekends for work. Factoring these aspects in, the final schedule for the redesign would appear as in Figure 11.

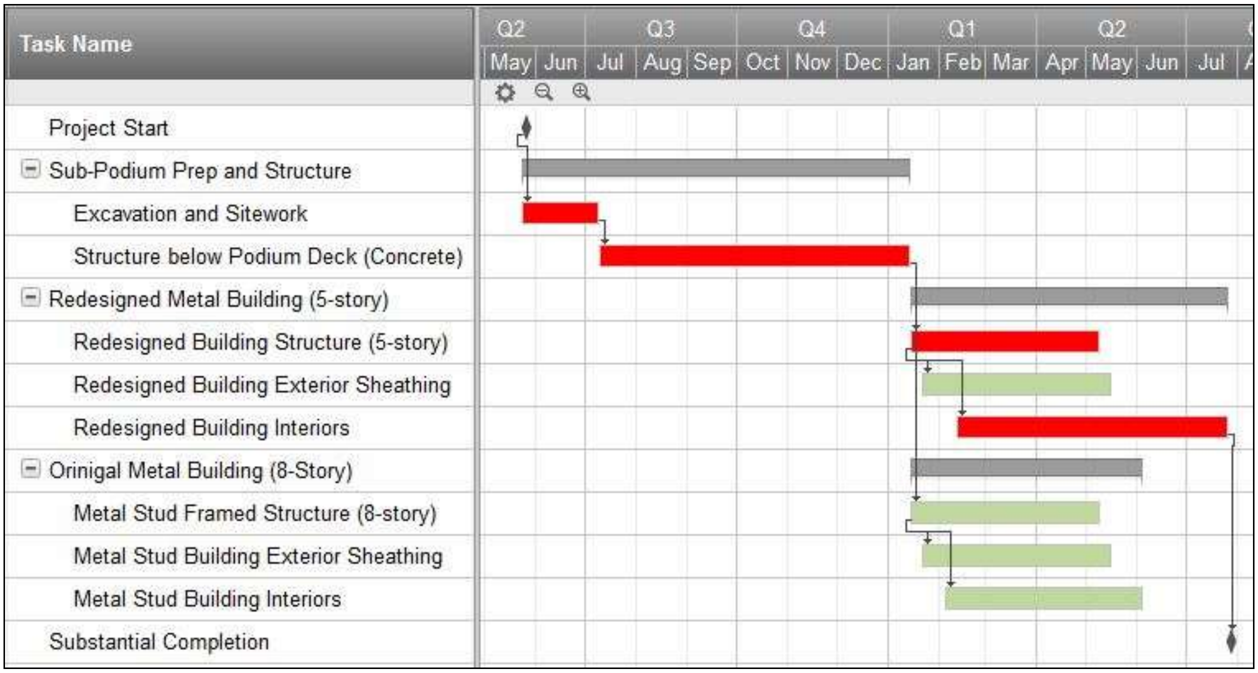


Figure 11: Redesign Schedule with New Durations

This puts substantial completion at July 25, 2014, which is approximately two weeks before the building had to be turned over to the owner. That two week period would ideally be used for a formal punchlist and QC process. This was not possible with the original schedule due to the delays and acceleration; subcontractorss were finishing work the day the building was turned over on the actual project. This would also allow the building to be turned over a few days before it was on the actual project, August 15, which would be an advantage for the owner as it would allow tenants to move in a few days sooner. Another consequence of this proposed schedule change would be the elimination of the two weeks of acceleration costs for the interior and finishes trades. As previously calculated (see Table 5), these costs were valued at $1,135,000. This would be a significant cost savings for the project.

In summary, the redesign of the wood stud structure to a metal stud structure has significant impacts on the schedule. It allows a more efficient progression of trades, which has ripple effects for the remainder of the project. By redesigning the wood structure to metal studs, the project could eliminate the 2 weeks of acceleration required by the interiors trades, largely eliminate the use of OT and weekends for the remainder of the project, and create a 2 week window for which could be used for either punchlist or early turnover.

2.8.2 Other Implications

There are other positive consequences of changing the wood stud structure to a metal stud structure. Many of these other consequences arise from the prefabrication of the steel stud panels. Safety is one important aspect of the project which would be improved by switching from a stick-built system (wood studs) to a prefabricated system (metal studs). By moving the majority of the stud work from the jobsite and into a factory-type environment, the potential for safety hazards decreases. Workers spend far less time in fall- hazard areas, and are performing most of the work in a controlled environment which does not have the general safety hazards of a jobsite (overhead loads from a crane, weather issues, etc.). In prefabrication the vast majority of work is completed at waist height, which is much more ergonomic and safe for the installers than having to work overhead or at ground level (both of which are necessary for stick-built stud systems).

Another safety hazard which is decreased with prefabricated systems is cutting and the creation of material waste. In stick-built systems, installers have to do a significant amount of cutting to get materials to the right size for installation. In prefabricated systems workers are generally supplied with materials which are already the right size, which decreases the amount of time they spend using dangerous cutting equipment. Cutting also creates material waste, which tends to not be properly disposed during stick-built installation, creating fall and tripping hazards. The decreased cutting in prefabricated systems is also a sustainability advantage, because far less material is being wasted. Eliminating the task of cutting materials to size also has positive cost and schedule implications when aggregated over an entire project, as it eliminates wasted of material and labor.

2.9 Conclusion and Recommendation

In conclusion, it is recommended that the 5-story wood stud portion of the building be redesigned with the metal stud structural system used on the 8-story portion of the building. This would have a negligible cost impact for the initial installed cost of the system. However, the change would have a very significant schedule impact. All of the previously incurred acceleration requirements would be mitigated, a significant portion of the weekend and OT work would be eliminated, and a 2-week period for a formal punchlist process would be created. Eliminating the need for acceleration of the interior trades would save the project approximately $1.1 million. Additionally, safety and quality would likely be improved with the prefabricated metal stud walls over the original stick-built wood walls.

Chapter 3

Analysis #2: Façade Material Analysis

3.1 Problem Identification

The façade material of the Plaza caused both schedule and quality issues, which also subsequently created cost issues. Cement fiber panels were chosen as the building's exterior skin, in every location except the north face. This decision was made based on a cost analysis of the most economical façade system. However, cement fiber is fairly uncommon in commercial construction, and as such, there was difficulty in finding a qualified local subcontractor with enough manpower to meet the schedule. Additionally, the local commercial construction labor force was not familiar with the installation process for the material, creating a significant learning curve, adding time and quality concerns to the process. This was exacerbated by the fact that the panels are prone to cracking and chipping at the edges, which led to an undesirable amount of rework and ruined/wasted material. Last but not least, every panel had to be trimmed in wood, which caused quite a few issues in terms of aesthetic quality control, material handling and staging, and defect-free installation. All of the rework and quality assurance measures necessary to manage this process created a strain on the schedule that may have been eliminated with a different façade choice.

3.2 Research Goals

The research goals are to determine the advantages of a terra cotta rainscreen façade system over the original fiber cement façade system, including an exploration of cost, schedule, quality, and thermal characteristics.

3.3 Methodology

- Interview the project team to determine the main issues with the original façade.
- Determine the installation process and associated quality issues for the original fiber cement façade.
- Determine the cost and schedule of the original system, including escalation.
- Review alternate façade material options and chose a feasible alternate system.
- Pick a specific product for the alternate system that fits within project requirements and determine the installation process for that product.
- Determine the thermal properties of the chosen alternate system.
- Identify and implement a methodology to measure heat loss through each envelope type.
- Investigate whether the mechanical system can be downsized, and if so, do so.

- Calculate the yearly energy costs associated with each system.
- Perform a payback analysis of the alternate system, including the installed cost of the façade, any mechanical system resizing, and yearly energy costs.
- Use the payback analysis and other factors (schedule, quality) to determine if the change would have been advantageous overall.

3.4 Background Information

Discussions with the project team suggested that substantial time was invested in attempting to maintain a quality system for the cement fiber panels. There was quite a bit of GC labor devoted to supervising the façade installation, which is not typical for traditional commercial façade materials. Additionally, there was a substantial amount of rework for the panels, which increased both labor and material costs for the subcontractor. Preliminary comparisons of this portion of the façade to the brick portion suggest that the cement fiber panels caused far greater escalation in cost and schedule than the brick.

Additionally, the rework and quality issues for the panels led to excessive and unplanned penetrations in an assembly which already did not have robust thermal properties. Looking at other common façade systems reveals that many have better thermal properties, in terms of both insulation and infiltration.

One advantage of the cement fiber panels is that they weigh significantly less than many traditional façade materials, such as brick or precast concrete panels. This was particularly important for the Plaza, as the steel stud structural system cannot bear as much weight as a structural steel I-beam structure. Another important factor for consideration on the Plaza was the aesthetic impact of the façade material. The BAR specified that the building's facade should use traditional-looking materials (brick, stone, etc.) in a traditional color palette (red or brown), and expressly warned against the use of metal panels in the facade.

General research into the cement fiber panel system shows that it is more often used in residential applications, and ultimately may not be the most efficient for commercial applications. This is due to subcontractor experience, material difficulties, and thermal properties of the system.

3.5 Original Façade System

The original façade system used cement fiber panels, specifically the WeatherBoards product manufactured by Certainteed. Each panel came pre-coated with the company's FiberTect Primer/Sealer and was ready for installation upon arriving at the site. The standard panel size was 4' (horizontal) by 8' (vertical), with a 5/16" thickness. Although there are many textures and patterns available for this product, the Plaza specified the standard smooth finish. Two colors of paint were applied to different areas after installation in order to highlight the indented and extruded portions of the exterior shape of the building, as can be seen in Figure 12.

Figure 12: Fiber Cement Color Application

Fiber cement is a fairly common façade material for residential applications, but is less common in commercial applications. Although the most common fiber cement products are siding and "shakes" (for residential projects), in commercial construction they typically appear in a vertical panel format. Panels are generally supplied in a standard size (usually 4 feet wide and between 8 and 10 feet tall), and can be field cut when necessary. However, any edges which have been field cut require re-sealing with 100% acrylic latex paint or primer. Generally the installation crew requires scaffolding, but the lightweight nature of the product also expedites the installation process. The WeatherBoard panels used on the Plaza weighed approximately 80 pounds per panel, or 2.5 pounds per square foot.

The exterior wall assembly that is used with the fiber cement panels is a fairly standard 1-hour fire-rated wall assembly which can be seen in Figure 13. From interior to exterior, the layers are 5/8" gypsum board, R-21 batt insulation between 6" metal stud framing, ½" fire retardant exterior sheathing (Gold Bond E2XP), a water resistive barrier (Typar MetroWrap), and the 5/16" fiber cement panels with 3.5" trim boards. These assembly materials are all fairly common and did not prove problematic for the project.

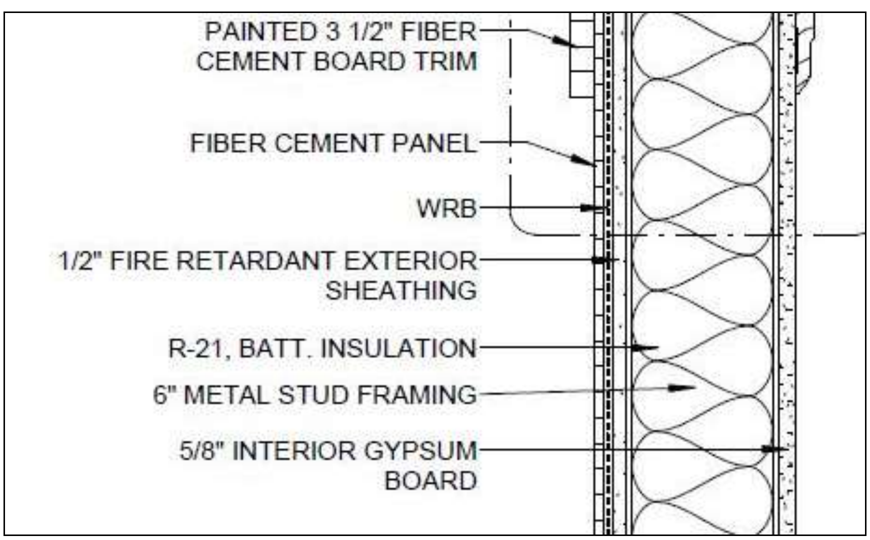


Figure 13: Fiber Cement Wall Detail

3.5.1 Fiber Cement Quality Issues

To install the panels, fasteners must be attached at least ¾” from horizontal panel edges and at least 3/8” from vertical panel edges, at a maximum of 6” on center. Applying fasteners any closer to panel edges will cause cracking and chipping and the entire panel will be rendered unusable. However, vertical joints must also occur over framing members, and the vertical edge fasteners must be attached directly to the framing members (in the steel stud portion of the building). This means that fasteners have a fairly small range of maximum and minimum distances from panel edges, which increases the difficulty of the installation. Because the panels are the final exterior surface, it is particularly important that fasteners be installed flush with the surface. It is also important to ensure that fasteners do not cut into the surface of the panels, as the fiber cement material is fairly “soft”. Because the panels are fastened directly onto the wall system without a rail or track, every panel must be very carefully squared and leveled before fastening.

Figure 14 from the Plaza illustrate some of the issues with the preceding requirements that the team encountered. From left to right, the figure shows an overly large gap at a corner with the panels not properly squared and aligned, excessive chipping at panel edges, an excessive number of screws which are also not flush with the panel face, and panels which were not cut properly and extend past a corner. For each of these issues the panels would have to be removed from the wall, scrapped, and the substrate patched before a new panel could be properly installed. This became an issue on the project and led to significant rework costs and material wastes.

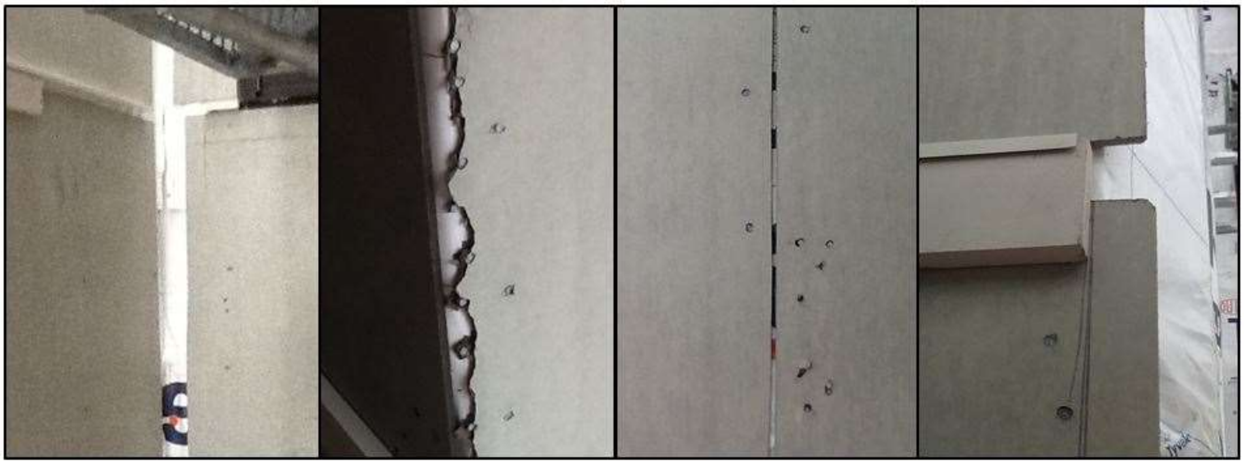


Figure 14: Fiber Cement Quality Issues

Once the panels were installed, they had to be trimmed and painted. The trim was also a mild source of issues for the façade. First, the trim pieces were delivered in ¾" thick, 4" wide boards with a maximum 12 foot length. However, due to the outer shape of the building, most of the exterior walls do not have dimensions divisible by 12 feet. This meant an unusually high amount of cutting and resealing board edges, which lead to very high amount of material waste for the trim boards. Second, the trim dominated the exterior aesthetic of the building, so it was extremely apparent if any pieces were even slightly out of plumb or level. This slowed down the installation crew and increased rework. Third, as can be seen in the rightmost photo in Figure 14, z-flashing had to be installed with the top leg under the upper panel, and with the lower leg over the trim. This was a critical step because any irregularity could lead to water leakage into the assembly, but proved difficult for the installation crew because of the small tolerances afforded by the z-flashing. Once the z-flashing and the trim was installed, the joint had to be caulked. Any joints at windows, doors, or corners required a 1/8” gap and additional flashing and caulking. It was also particularly important that fasteners be installed flush with the surface of the trim and not over-driven, because water leakage can easily occur if the FiberTect sealant layer on the outside of the trim is breached.

The fiber cement system is also somewhat prone to issues during the operation phase of the building after installation. There are a high number of possibilities for water intrusion, as previously mentioned. Additionally, fiber cement is prone to efflorescence (the white powdery deposit often seen on brick), which is exacerbated with even very minimal openings for water intrusion. Fiber cement is also prone to the growth of mold and mildew over time, even if the system has been properly installed, but particularly if there are any openings. Both the panels and trim must be stored in a dry area off the ground prior to installation. Any exposure to moisture can linger in the product until post-installation, and create the potential for mold. The manufacturer recommends washing the entire façade every 6 to 12 months to mitigate the buildup of efflorescence and potential mold, which is a significant endeavor on a building of this size. Also, the paint applied to the exterior surface will weather and fade with time, and eventually need to be re-applied. Perhaps the largest concern is that the fiber cement panels themselves only have a service life of 50 years (assuming regular detailed maintenance), which implies that the entire facade will need to be replaced before the building does.

3.5.2 Fiber Cement Cost and Schedule Analysis

The fiber cement façade system was originally chosen for the low initial cost, however, the quality and schedule issues with the system led to a significant escalation in cost. The following table summarizes the original and escalated costs associated with the system.

Table 10: Fiber Cement System Costs

Base Costs	Siding	$ 607,218
	Trim	$ 215,389
	Scaffold	$ 535,632
	Ext. Paint	$ 300,000
	SUBTOTAL	**$ 1,658,239**
Add Costs	Cranes	$ 55,535
	Scaffolding	$ 320,949
	Quality	$ 45,236
	Other subs	$ 157,521
	GC Labor	$ 119,364
	SUBTOTAL	**$ 698,604**
	TOTAL	**$ 2,356,843**

This demonstrates the severity of the issues with the system: the escalation due to schedule and quality issues caused a cost increase of about 42% of the originally quoted price of the system. The dollar amounts in Table 10 were calculated with information obtained from DPR, and are verified project costs based on change orders, timecards, and backcharges from other subcontractors. It was also noted in conversation with the DPR team that they estimate there are about $300,000 in out-of-pocket costs for the siding subcontractor which are not included in the above numbers.

In order to analyze these costs more thoroughly, the amounts of the brick and fiber cement façade types on the building were broken down. Calculating the total square footage of the fiber cement façade only without any windows allowed a cost per square foot to be determined. Those calculations can be seen in Appendix C, but a summary of the costs can be seen in the following table.

Table 11: Cost per SF of Fiber Cement

	Amount	% of Original	Cost per SF
Original Contract Value	$ 1,658,239.00	100%	$ 11.80
Original With Escalation	$ 2,356,843.44	142%	$ 16.78
Add Estimated Out-of-Pocket	**$ 2,656,843.44**	**160%**	**$ 18.91**

It is clear that the economic properties of the system were less advantageous than originally considered. As previously noted, many of these issues arose from the schedule. Because the system is most often used in residential applications and the subcontractor market was not familiar with such large commercial projects, they significantly under-estimated the required manpower for the job. In fact, they did not even have a large enough labor pool in the entire local region to appropriately staff the project.

This was exacerbated when the wood stud portion of the building began to lag in the schedule (see Chapter 1 for a more detailed discussion), and the fiber cement subcontractor was asked to accelerate their 12-week schedule into an 11-week schedule. However, at the time acceleration was requested, weekends were also made available by the GC for the subs to be on-site in order to mitigate schedule risks. Despite this, the fiber cement subcontractor was not able to meet the new schedule, requiring the full original 12 weeks (and weekends). Their delay had a cascading effect on the rest of project, as the envelope was on the critical path and a precursor to all interior trades (due to watertightness). Each subsequent subcontractor therefore had to accelerate, which came at a cost to the project. Section 2.5.2 of this report gives an estimate of the total acceleration costs for the interior and finishes trades. These costs were calculated using information obtained from DPR and are based off of change orders, pricing quotes, and time cards.

That analysis estimated roughly $134,000 for a total of 2 weeks or 14 working days of acceleration. Assuming these costs were distributed equally across both weeks, this would imply that if the fiber cement installation finished in 11 weeks as planned, the project would have saved half of this acceleration total, or approximately $567,500 dollars. Discussions with the DPR team suggest that this is a conservative estimate, as there are probably out-of-pocket costs for the acceleration of each interior finishes subcontractor which are not reflected in this total. If the week of acceleration costs are added to the fiber cement system costs shown in Table 11, the total for the system becomes approximately $3,224,500 which is around $23 per square foot.

Aside from manpower, another strain on the schedule and budget was the quality with the fiber cement system, and subsequent rework. Scaffolding had to be extended past the period of installation on many elevation s to allow workers to go back and complete rework, which increased the scaffolding rent significantly. A water intrusion incident during the construction of the façade ruined installed interior work, causing both cost and schedule implications. Material costs were higher than anticipated due to the large amount of material waste. A few weeks into the compressed schedule, it became apparent that the fiber cement subcontractor did not have the necessary manpower to oversee the quality control program for their scope. Consequently this responsibility passed to the GC, who assigned dedicated personnel to the task, adding a significant labor cost.

3.6 Alternate Façade Options and Selection

3.6.1 Necessary Characteristics of an Alternate System

The cost escalation and quality concerns of the fiber cement system suggest that another façade type may have been more effective for the Plaza. However, there are a variety of prerequisite qualities that a material must have in order to be an eligible option for this project. The most limiting requirement is likely the aesthetic requirements imposed by the BAR as discussed in Chapter 1. Because of the historical nature of the city and the Plaza's location along a prominent thoroughfare, the BAR was particularly strict about the traditional aesthetic of the façade. It was effectively mandated that the northern façade be brick masonry. The other facades were allowed more latitude, however, they were required to be a somewhat "natural" or "historical" material (ie- brick, wood, clay, etc.) and had to be in a traditional color palette such as red, brown, or gray. Metal or aluminum panels were expressly disallowed, even if designed to look like wood or stone.

Another limiting characteristic for potential façade types is weight. The structural metal studs in use on the project are designed for lighter-weight construction types, and cannot support the same loads as a regular commercial steel I-beam structure can. The fiber cement system was chosen for this project in part because it is arguably the lightest commercial façade type available on the market. While it would be impossible to find multiple alternate options which are even lighter than the fiber cement, it was determined that the alternate façade system chosen for the Plaza should be able to be supported by the original structure. Doing otherwise would cause a detrimental increase in structural costs that would almost inevitably outweigh any cost efficiencies gained with a different façade type.

The last limitations are the most common: cost and schedule. Both of these aspects had a significant impact on the choice of materials throughout the project, and any alternates must fit within the owner's requirements. It is unlikely that another system will have a lower first installed cost than the fiber cement, however, when factoring in the quality and maintenance issues of this system, as well as possible paybacks from increased insulation with an alternate system, there may be cost efficiencies from alternate over the long term. Any identified alternates must have a low enough first installed cost to warrant further examination of a possible payback period. The identified alternates also must be able to be installed within the accelerated 11-week time span required by the project schedule.

3.6.2 Selection of Façade Alternate

A list of common commercial façade types was created and compared to the requirements set forth in the previous section. The façade material options identified as being most common in modern commercial construction were brick veneer, stone, metal panel systems, and precast concrete panels. In interviews with the DPR project team, terra cotta rainscreen was identified as another potential option. Some DPR team members had previously been on a project which used this system, and testified that it produced significantly fewer quality, rework, and schedule issues. Additionally, there was an unrelated project very close to the Plaza that was under construction in the same time period and which had a terra cotta rainscreen. The project was nearly as large as the Plaza, however, the façade installation occurred much more quickly, with less rework, and produced a more aesthetically pleasing façade in the opinion of the team. Consequently, both single-skin and double-skin terra cotta rainscreen were added to the list of potential options. A preliminary comparison of each of the mentioned façade types to the project requirements can be seen in the following table, including the original fiber cement system.

Table 12: Analysis of Potential Facade Options

	Acceptable to BAR	Weight (psf)	OK for Structure	Approx. Cost ($/SF)	Reasonable Cost	Can Meet Schedule
Fiber Cement (Original)	✓	3 psf	✓	$23	✓	✗
Brick Veneer	✓	40 psf	✗	$20	✓	✓
Stone (Non-Brick)	✓	40 psf	✗	$80	✗	✓
Metal Panels (ACM)	✗	3 psf	✓	$25	✓	✓
Precast Concrete Panels	✗	80 psf	✗	$27	✓	✓
Single-Skin Terra Cotta	✓	7 psf	✓	$33	✓	✓
Double-Skin Terra Cotta	✓	7 psf	✓	$42	✗	✓

As shown in the table, single-skin terra cotta rainscreen is the only option which passed the preliminary analysis for suitability on the plaza project. Of the more common options, metal panels /ACM and precast concrete panels were discarded because of BAR requirements, which is a non-negotiable requirement for the Plaza. Brick veneer and stone were discarded due to weight; the structural steel studs as designed would not be able to support such heavy loads. While double-skin terra cotta has greater aesthetic flexibility and wind loading characteristics than single-skin, the single-skin system is more than adequate for the Plaza in those regards, and comes at a lower cost. While the terra cotta system has a greater cost per square foot then the cement fiber, the following analyses will determine if this can be made up for through improvements in quality, schedule, and thermal performance.

3.6.3Background for Selected Alternate

The specific product chosen to analyze for the Plaza is the Zephir Evolution single-skin rainscreen panels manufactured by Terreal North America, as can be seen in Figure 16. As discussed in the previous section, a single-skin system was determined to be more appropriate than a double-skin system for the Plaza due to cost concerns. Part of the cost-savings from a single-skin system come from the increased installation speed, which is also an important aspect for the Plaza. A product from the Terreal line was chosen because of their location in North America. Terra cotta systems tend to be more popular in Europe, so many of the manufacturing plants are located there, which can make material transportation prohibitively expensive. The Zephir Evolution panels come in 12 inch vertical modules in lengths up to 4 feet. The 4' wide panels would be used as the standard size on the Plaza, however, smaller panels of 1', 2, or 3'could be provided where necessary. This eliminates the excessive need for cutting required by the fiber cement panels. A variety of colors and textures are also available from Terreal, so the designer may customize the aesthetics to the project. This will allow the system to achieve the traditional look desired by the BAR.

Rainscreen systems such as the Zephir Evolution are a fairly new addition to the US façade market. A rainscreen system is composed of an inner skin, a ventilated cavity, and an outer panel, as can be seen in Figure 15. The main concept behind the idea is that it is virtually impossible to make a fully watertight system with the pressure differentials present in typical façade assemblies, as it pulls precipitation into the wall. In a rainscreen, the majority of precipitation is deflected by the outer layer, but some precipitation is purposefully allowed into the ventilated cavity through the open panel joints. This eliminates the pressure differential because pressure is instantaneously equalized between the cavity and the outside. Consequently there is no tendency to "pull" water into the assembly. The water that is allowed into the cavity is prevented from moving any further into the assembly by the inner skin (typically rigid insulation and a Weather Resistant Barrier), and is removed through drainage. This configuration creates an extremely tight assembly for both water and air, which has been shown to substantially decrease mold and moisture problems as well as air infiltration.

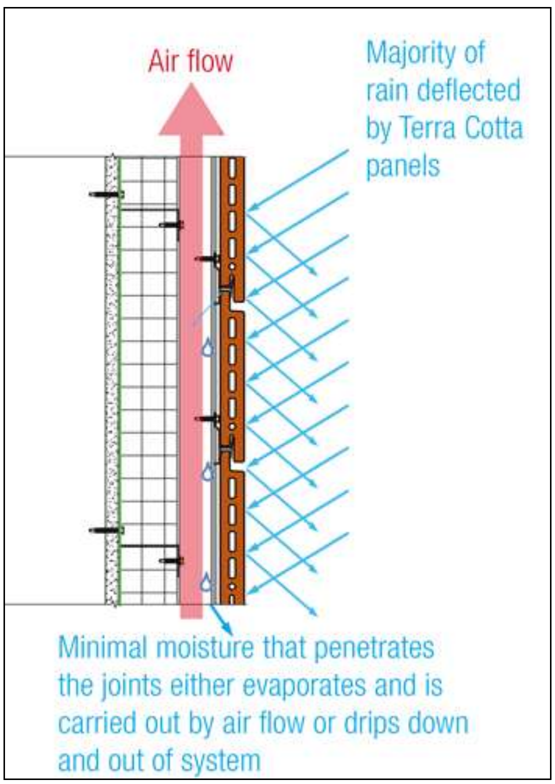


Figure 15: Rainscreen Concept

The installation of a rainscreen system is fairly straightforward. First, the interior assembly is put in place, generally with 2" or 2.5" rigid insulation as the outer layer. Vertical support profiles are attached to the assembly using propriety clips, and horizontal support rails are then attached to the vertical supports (see Figure 16). Although this step is not complicated and usually only involves standard screw connections, it is extremely important that all supports are installed plumb, level, and within location tolerances. This is by far the most time-consuming part of a rainscreen installation, but can be made more efficient with laser levels.

Figure 16: Zephir Evolution Supports

After the rails are installed, the last remaining step is to attach the panels. Because the Zephir is a single-skin system the panels simply need to be "hung" on the rails, unlike a double-skin system which requires clips and time-consuming connections for the panel attachment. This significantly increases the speed of installation. Also, because the panels are simply hung on the supports, it is extremely easy to remove or replace a damaged panel.

Figure 17 shows how Zephir Evolution panels rest on the support rails.

Figure 17: Panel Connection to Supports

3.7 Breadth #2: Mechanical Analysis of Alternate Façade

3.7.1 Thermal Properties

The recommended assembly for use with the Zephir Evolution consists of the following layers, from interior to exterior: framed exterior support, ½” exterior sheathing, WRB, 2.5” rigid insulation, support members, and 1-3/16” terra cotta panels. A typical detail of a Zephir Evolution wall can be seen below.

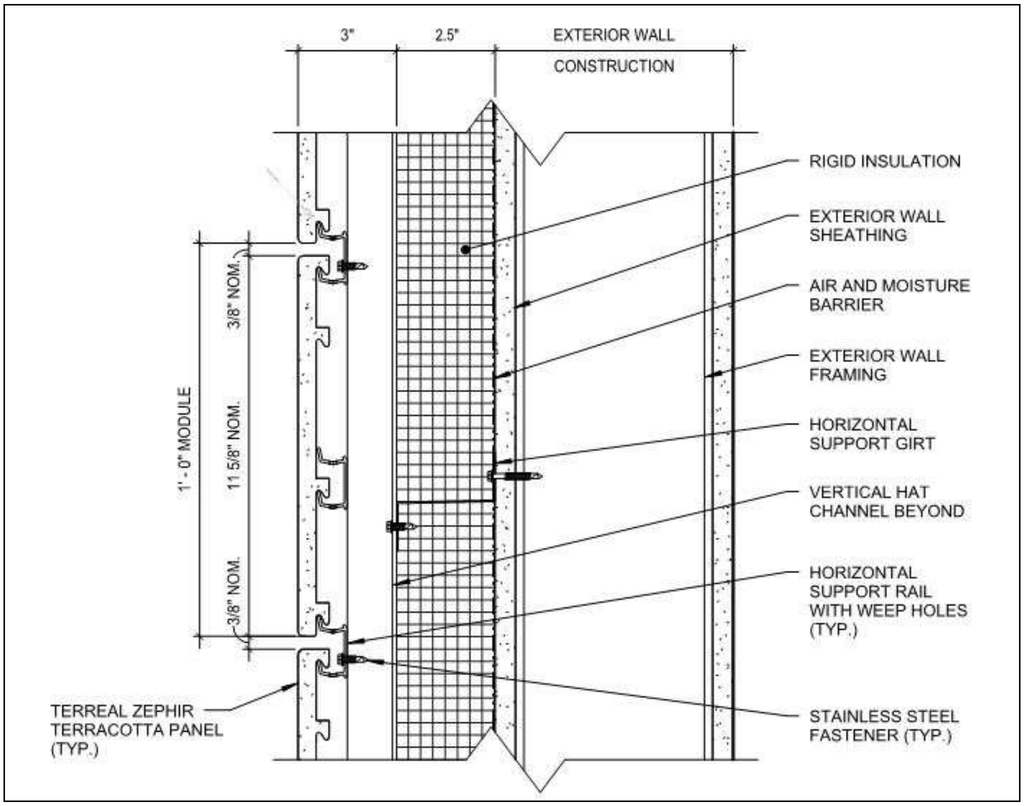


Figure 18: Typical Zephir Wall Detail

For the application to the Plaza, rigid mineral wool insulation was chosen in lieu of a more standard XPS product for the exterior insulation. Rigid mineral wool can be as low as half the cost of traditional XPS, with only a slight decrease in thermal properties (R-4.3 per inch as opposed to R-5 per inch). Aside from the final exterior layer, the insulation is the only layer which differs between the fiber cement and rainscreen facades. The rigid mineral wool material used in the rainscreen system has significantly better insulation capacity than the batt insulation used in the fiber cement assembly (as will be discussed further in the next section). It is also more expensive than batt insulation per inch, although a thicker layer of batt insulation is required to compare thermally. The 2.5” of mineral wool used in the rainscreen assembly will be slightly more expensive than the 6” of R-21 insulation in the stud cavity for the fiber cement assembly. Despite this, the overall cost to install each insulation layer will probably be similar, because the batt insulation requires more labor. There is a substantial amount of cutting required to install batt insulation between studs in a 16” o.c. stud wall, which increases labor costs and slows installation. Consequently, the insulation layers for the fiber cement and rainscreen systems will be considered comparable from a cost perspective for the remainder of this analysis.

3.7.2 Thermal Comparison

In order to compare the fiber cement and terra cotta rainscreen systems for mechanical system impact, the thermal properties of each system had to be identified. The first step was to obtain the R-values of each layer in both assemblies. This value is an indicator of the insulating abilities of a material or assembly. To be as accurate as possible, information was obtained from the specific manufacturer of each product/layer whenever possible. If not, the information was obtained from PACE Building Envelope Representatives. This research yielded the following breakdowns of each assembly.

Table 13: Fiber Cement R-values by Layer

Assembly	Layer	Thickness	R-value
		in	(hr*sf*F)/BTU
Fiber Cement	Interior Air Film	0	0.68
	Interior Gypsum Board	5/8	0.56
	Metal Studs with R-21 Batt Insulation	6	7.4
	Exterior Sheathing	1/2	0.04
	Weather Resistive Barrier	0	0.03
	Fiber Cement Panel	5/16	0.15
	Exterior Air Film	0	0.17
	TOTAL	7.4375	**9.03**

Table 14: Terra Cotta R-values by Layer

Assembly	Layer	Thickness	R-value
		in	(hr*sf*F)/Btu
Terra Cotta	Interior Air Film	0	0.68
	Interior Gypsum Board	5/8	0.56
	Metal Studs with Air Space	6	1.19
	Exterior Sheathing	1/2	0.04
	Weather Resistive Barrier	0	0.03
	Rigid Mineral Wool Insulation	2-1/2	10.74
	Air Space	2-7/16	2
	Terra Cotta Panel	9/16	0.45
	TOTAL	12.625	**15.69**

The total R-value of the fiber cement assembly is 9.03, while the total for the terra cotta assembly is 15.69. This is a fairly significant difference, most of which stems from the variance between the two insulation layers. Although the batt insulation specified for the stud cavity in the fiber cement assembly was R-21, the R-value used in this analysis was only 7.4. This is in accordance with the ASHRAE 90.1 stud correction factors. The stud correction factors account for the portion of the wall which is taken up by studs (creating heat paths which bypass the insulation), and the typical insulation gaps found with batt installation in stud cavities. These issues reduce the efficacy of stud cavity batt insulation, in this case by a factor of about 0.35.

Another important difference between the two systems is infiltration. This refers to the amount of air “leakage” through an assembly, which decreases the thermal effectiveness of an envelope. While it is not often measured and is somewhat difficult to estimate theoretically, it is very important to the analysis of an assembly’s thermal performance. Infiltration is usually measured in Air Changes per Hour (ACH), which refers to the proportion of the total volume of the room or building which will leak through the envelope in one hour. To give a frame of reference, 0.5 ACH is typically considered to be a “good” value for tight, new construction. The minimum value for health purposes is generally considered to be 0.33 ACH which is better than the “good” value because fewer changes indicate better performance. Reports from manufacturers of terra cotta rainscreen systems suggest that 0.35 ACH is a reasonable average to expect from these systems. This is due to the decrease in connectors and holes in the assembly compared to traditional construction, as well as the elimination of the pressure differential to the exterior, which pulls air into the building. A 0.6 ACH rating is generally considered reasonable for new but mildly “leaky” envelopes. This value will be used for the fiber cement assembly due to the number of connectors and quality issues discussed in previous sections. The implications of the difference in infiltration rates will be discussed in the next section.

3.7.3 Mechanical Analysis

The mechanical system for the Plaza is composed of a separate Rooftop Unit (RTU) for each apartment unit, sized based on the number of occupants. The magnitude of the thermal difference between the fiber cement and terra cotta assemblies suggests that the mechanical operating costs and original sizing of the mechanical units both may be able to be decreased with the terra cotta assembly. In order to asses this hypothesis, it is necessary to estimate the heat loss of the conditioned spaces and design capacities for the mechanical equipment with each envelope type in order to compare them. Because the mechanical equipment is sized by the number of occupants per unit, it is necessary to separate the analysis by the same metric. The Plaza has four sizes of units, from one to four occupants. A thermal analysis of each envelope type was performed for a typical unit in each of these four sizes.

The first step in the analysis was to identify a typical unit for each of the four sizes. The most common unit type for each size was used for this exercise. Once the typical unit was determined, the total surface area of windows, the exterior surface area of façade (non-window), and total volume of the unit were calculated. These results are shown in the following table.

Table 15: Typical Unit Data

Unit	No. of Openings					Opening Area (sf)					Extd. Opening Area (sf)					SF Open	SF Wall	Wall Less Open	Unit Area	Unit Vol.
	A	B	C	D	G	A	B	C	D	G	A	B	C	D	G					
A1	3	0	0	0	0	18	36	52	48	54	54	0	0	0	0	54	360	**306**	719	**7190**
B1	1	2	0	0	0	18	36	52	48	54	18	72	0	0	0	90	521.6	**431.6**	993	**9930**
C1	0	3	0	0	0	18	36	52	48	54	0	108	0	0	0	108	670	**562**	1224	**12240**
D1	2	2	0	1	0	18	36	52	48	54	36	72	0	48	0	156	935.8	**779.8**	1425	**14250**

Once the data for each typical unit was collected, the online BIS Heat Loss Calculator was used to calculate the heat loss of each typical unit. This program was chosen for its simplicity and adaptability; it allows the user to specify the total R-value of each wall or window rather than forcing the user to pick from preset options for layers of these components. This was important in this analysis because the rainscreen façade is not yet common in the US and is not an option in most software packages which require you to specify layers of the envelope. Consequently, such a program would force the user to add a substitute material, adding error to the calculation. It was also important that the program allows the user to calculate heat flow through only one component (exterior wall) without being forced to create a model of the entire room or building. Lastly, the program had the ability to incorporate infiltration into calculations, the adaptability to specify your own weather/location data, and calculated the desired variables for further analysis, including the Design Loss (BTU/hr) and Year Loss (million BTU/yr), broken down by wall, window, or infiltration as the reason. The following assumptions were in place for the use of this program:

- The design temperature for the city is 15 degrees Fahrenheit and there are 4506 degree days per year (Source: www.weatherdatadepot.com)
- Solar gain was not included in the calculations. There are many window directions and configurations which would complicate this calculation significantly.
- The city's climate is heating-controlled rather than cooling-controlled.

- Internal occupant gains were not included. This should give a conservative estimate of design loss, which is desirable.

The following summary table shows the inputs and total results of the heat loss calculator for each unit type with each envelope option. For a more complete set of results broken out by walls, windows, and infiltration for each unit, please see Appendix D.

Table 16: Summary Table of Heat Loss Results

Façade	Unit	Wall	Wdw	Vol.	UA	Design Loss	Year Loss
		SF	SF	ft^3	BTU/(hr*F)	BTU/hr	MBTU/yr
Fiber Cement	Unit A1	306	54	7190	137	7529	14.8
	Unit B1	431.6	90	9930	197	10851	21.3
	Unit C1	562	108	12240	245	13482	26.5
	Unit D1	156	779.8	14250	313	17242	33.9
Terra Cotta	Unit A1	306	54	7190	90	4958	9.7
	Unit B1	431.6	90	9930	132	7278	14.3
	Unit C1	562	108	12240	164	9000	17.7
	Unit D1	156	779.8	14250	213	11699	23.0

The terra cotta façade significantly outperformed the fiber cement façade in terms of thermal performance. The yearly heat loss through the external walls of each typical unit was about 34% lower, on average, with the terra cotta façade than with the fiber cement façade. While the R-value of the wall assembly played a large part in this discrepancy, infiltration was also a substantial factor. The weakness of the fiber cement system to infiltration significantly decreased its overall thermal performance relative to the terra cotta assembly. The consequences of the decrease in yearly heat loss with the terra cotta system will be further discussed and analyzed from a cost perspective in Section 3.8. The decrease in design loss with terra cotta system affects the necessary size of the mechanical system, which will be discussed next.

The values for design heat loss were used to determine if the original mechanical equipment could be downsized. The specific product used on the Plaza was the Bryant Evolution 13 SEER Heat Pump. Each of the four unit types had a different equipment size, ranging from 1.5 to 3 tons. In order to get a more holistic sense of the impact of a potential downsize, the quantity of each size of equipment had to be determined. This was accomplished by counting the number of each of the four room sizes which are present in the fiber cement portion of the building (being careful not to include units from the brick façade area). Subcontractor pricing was used to determine a rough cost for each size unit. Finally, the design capacity of each specific size of pump was identified, and compared to the design heat loss to determine if a smaller piece of equipment could be used. The following tables summarize the original equipment selection and the potential equipment redesign with the fiber cement façade.

Table 17: Original Mechanical Design Capacities

Façade	Unit	No. Units	Design Loss	Eqpmt Size	Eqpmt Capacity	Unit Cost	Tot. Cost
			BTU/hr	tons	BTU/hr	$/ea	$
Fiber Cement	Unit A1	5	7529	1.5	9400	$ 1,419.00	$ 7,095.00
	Unit B1	84	10851	2	13500	$ 1,459.00	$ 122,556.00
	Unit C1	13	13482	2.5	18500	$ 1,489.00	$ 19,357.00
	Unit D1	62	17242	3	20200	$ 1,579.00	$ 97,898.00
	TOTAL						**$ 246,906.00**

Table 18: Redesign Mechanical Design Capacities

Façade	Unit	No. Units	Design Loss	Eqpmt Size	Eqpmt Capacity	Unit Cost	Tot. Cost
			BTU/hr	tons	BTU/hr	$/ea	$
Terra Cotta	Unit A1	5	4958	1.5	9400	$ 1,419.00	$ 7,095.00
	Unit B1	84	7278	1.5	9400	$ 1,419.00	$ 119,196.00
	Unit C1	13	9000	1.5	9400	$ 1,419.00	$ 18,447.00
	Unit D1	62	11699	2	13500	$ 1,459.00	$ 90,458.00
	TOTAL						**$ 235,196.00**

There was a substantial ability to downsize the equipment realized with the terra cotta system. The two and three-person units (B1 and C1) were able to downsize from 2 and 2.5 ton systems to 1.5 ton systems. The four-person units (D1) were able to downsize from a 3 ton system to a 2 ton system. Although this was a fairly significant change from a mechanical perspective, it did not have a large cost impact due to the relatively similar costs of the different sizes of pump, and the overall inexpensive nature of the system. The downsizing of all the units combined only yielded savings of about $11,700. The cost implications of the mechanical changes will be discussed further in the following section. It is worth reiterating at this point that this was designed to be a conservative thermal estimate due to the exclusion of solar heat gain and internal occupant gains.

3.8 Cost and Schedule Implications

There are multiple up-front and operational financial factors to consider when evaluating the adoption of the alternate terra cotta rainscreen façade design. The upfront factors are the initial installed cost of the system, the initial installed cost of the mechanical equipment, and the cost implications of the schedule. The operational factors include the energy cost for the mechanical system as well as the eventual cost of replacing the façade if necessary.

As previously mentioned, the terra cotta rainscreen system is significantly more expensive for initial installation than the fiber cement system. Even including all of the additional costs and escalation factors on this project, the fiber cement system material cost would be $23 per square foot. Research into other DPR projects which have used terra cotta rainscreen, as well as discussions with Terreal, the manufacturer of the Zephir Evolution, suggest that the minimum installed cost on this project would be about $33 per square foot. This is quite low for a terra cotta rainscreen system due to the use of a single-skin product rather than the more common but more expensive double-skin products. The material price of single-skin panels is less than that of double-skin panels because they use less material and are less complicated to manufacture. Single-skin systems also have lower labor costs because they require significantly less time to hang the panels. A general laborer can install about 80 square feet of a single-skin panel per hour, while double-skin installation requires more skilled labor and only occurs at a rate of about 40 square feet per man-hour. Installation of the support profiles requires about the same amount of time for both single and double-skin panels.

Although the overall installation of a rainscreen façade is somewhat time-consuming, inquiries to local subcontractors have returned affirmation that they would be able to install the Zephir Evolution system on the Plaza within the original 11 week schedule (which includes weekends). This is reasonable because most of the schedule issues with the original façade installation occurred due to manpower shortages rather than physical constraints. The fiber cement subcontractor was not held up by scaffolding, access issues or a predecessor subcontractor's speed, but rather by the number of crews they were able to commit to the project. The terra cotta rainscreen subcontractors contacted have suggested that if the scaffolding would be in place at multiple elevations around the building for them to have multiple crews running at once, they would be able to meet the schedule. The original scaffolding was deployed with this idea in mind so this is an acceptable caveat. By installing the façade within the original 11 week schedule, the rainscreen subcontractor would be able to avoid the scaffolding and other escalation costs experienced by the original fiber cement subcontractor. This would also eliminate one week of the acceleration costs for the interior and finishes subs, as factored into the fiber cement cost at $567,500. The overall completion date would remain the same, but an extra week would be allowed for the interior and finishes subcontractors to complete their scopes. Even with the schedule improvement of the terra cotta façade, it is still quite a bit more expensive than the fiber cement system for the initial cost, as seen in Table 19.

Table 19: Initial Costs of Facade Systems

	Fiber Cement	Terra Cotta	Difference
Façade Total Cost	$ 3,224,500.00	$ 4,635,642.00	$ (1,411,142.00)
Façade SF Cost	$ 22.95	$ 33.00	$ (10.05)
Initial Mechanical Cost	$ 246,906.00	$ 235,196.00	$ 11,710.00
Total Cost of System	**$ 3,471,406.00**	**$ 4,870,838.00**	**$ (1,399,432.00)**
Total SF Cost of System	$ 24.71	$ 34.67	$ (9.96)

Factoring in the cost savings associated with the downsizing of the mechanical system, the terra cotta façade system is about $4.9 million in initial cost, which is around $1.4 million more than the initial cost of the fiber cement system (approx. $3.5 million). If this was the only factor, it would be prohibitively expensive, and the terra cotta alternate would be rejected. However, there are operational advantages to the terra cotta façade after the initial installation. Most notably, the terra cotta façade significantly outperformed the fiber cement system from a thermal perspective, which should decrease operational energy costs. In order to analyze this claim, the total yearly energy costs with the fiber cement system were calculated and compared to those of the terra cotta system.

Although the yearly heat loss data was previously obtained in the mechanical breadth, calculating the yearly energy costs also required the cost of operation. The Bryant heat pumps in place on the project had an HSPF of 7.7. Using this factor, combined with the cost of $0.12 per kilowatt-hour for electricity, it was possible to calculate the cost per BTU of heating for this equipment. This value came out to $15.56 per million BTUs. That rate was then applied to the yearly heat loss for each typical unit with both façade types. Finally, the costs were extrapolated out to the whole building by multiplying the cost for the typical units by the quantity of that number of unit which originally had the fiber cement façade, as previously determined in the mechanical analysis. The results are shown in the table below.

Table 20: Yearly Energy Costs by Facade Type

Façade	Unit	UA	Design Loss	Year Loss	Fuel Cost	Cost per Unit	No. Units	Tot. Cost
		BTU/(hr *F)	BTU/hr	MBTU/ yr	$/MBTU	$/yr		$
Fiber Cement	Unit A1	137	7529	14.8	$ 15.56	$ 230.29	5	$ 1,151.44
	Unit B1	197	10851	21.3	$ 15.56	$ 331.43	84	$ 27,839.95
	Unit C1	245	13482	26.5	$ 15.56	$ 412.34	13	$ 5,360.42
	Unit D1	313	17242	33.9	$ 15.56	$ 527.48	62	$ 32,704.01
	TOTAL							**$ 67,055.82**
Terra Cotta	Unit A1	90	4958	9.7	$ 15.56	$ 150.93	5	$ 754.66
	Unit B1	132	7278	14.3	$ 15.56	$ 222.51	84	$ 18,690.67
	Unit C1	164	9000	17.7	$ 15.56	$ 275.41	13	$ 3,580.36
	Unit D1	213	11699	23.0	$ 15.56	$ 357.88	62	$ 22,188.56
	TOTAL							**$ 45,214.25**

The yearly energy costs are significantly lower with the terra cotta system, by approximately 33%. Although the cost savings in energy expenditures from switching to terra cotta do not balance the greater installed cost for the first year, these energy savings will compound over time. An overall payback analysis was performed to determine how many years it would take for the efficiencies of the terra cotta system to offset the higher initial cost.

The initial costs for the façade package and mechanical system for both façade types were summed to create a total initial cost. The yearly operational energy costs for each façade type were extrapolated out 100 years using a 2.5% yearly increase rate in the cost of electricity, which has been the average yearly increase rate since the year 2000 (Source: Edison Electrical Institute). A 100 year timespan was used because it is considered an ambitious goal for the lifespan of new modern buildings. The cement fiber façade is generally considered to only have a service life of 50 years, while the terra cotta rainscreen system is considered to have a 100 year service life. Consequently, the analysis should also consider the cost to replace the cement fiber system at 50 years, the end of its lifespan. In order to create an estimate for this activity, the original contract cost of the fiber cement system (without escalation, acceleration, etc.) was extrapolated out to the 50 year mark using a 2% inflation rate and the standard interest rate formula. This should provide a very conservative estimate of the façade re-installation, as it is does not include the escalation costs originally experienced with the system, and because it is generally much less expensive to install new construction than to renovate an existing building. In a similar manner, the analysis also included a cost to replace the mechanical system every 25 years, as that is generally regarded as the service life of the type of equipment used on the Plaza. This was extrapolated out using a 2% inflation rate.

In order to make the payback calculation more realistic, it must also include the time-value of money. This is the concept that an individual would rather receive the same amount of money now than later. If they were to receive it now, they could invest it, making it worth more later due to the return on that investment. Therefore the value of money can be seen as "depreciating" over time at the rate that one could invest it and receive interest. Consequently, in order to truly understand the effect of the future electricity payments, all costs must be evaluated in Present Value (PV). The equation that can be used to calculate these costs is as follows: [$PV = C / (1 + i)^n$] where C is the future cost, "i" is the interest one could receive on an investment, and n is the number of compounding periods of that interest. An annual value of 3%, or 0.03, was used in this report for the interest rate. This is a "real interest rate" which assumes a conservative 5% interest rate for risk-averse investment and an average inflation rate of 2%. This value and the preceding equation were used to calculate the present value of each year's costs. These costs were then cumulatively summed to determine at what year the terra cotta façade would achieve payback, if at all. The detailed calculations can be seen in Appendix E, but Figure 19 shows a summary of the results.

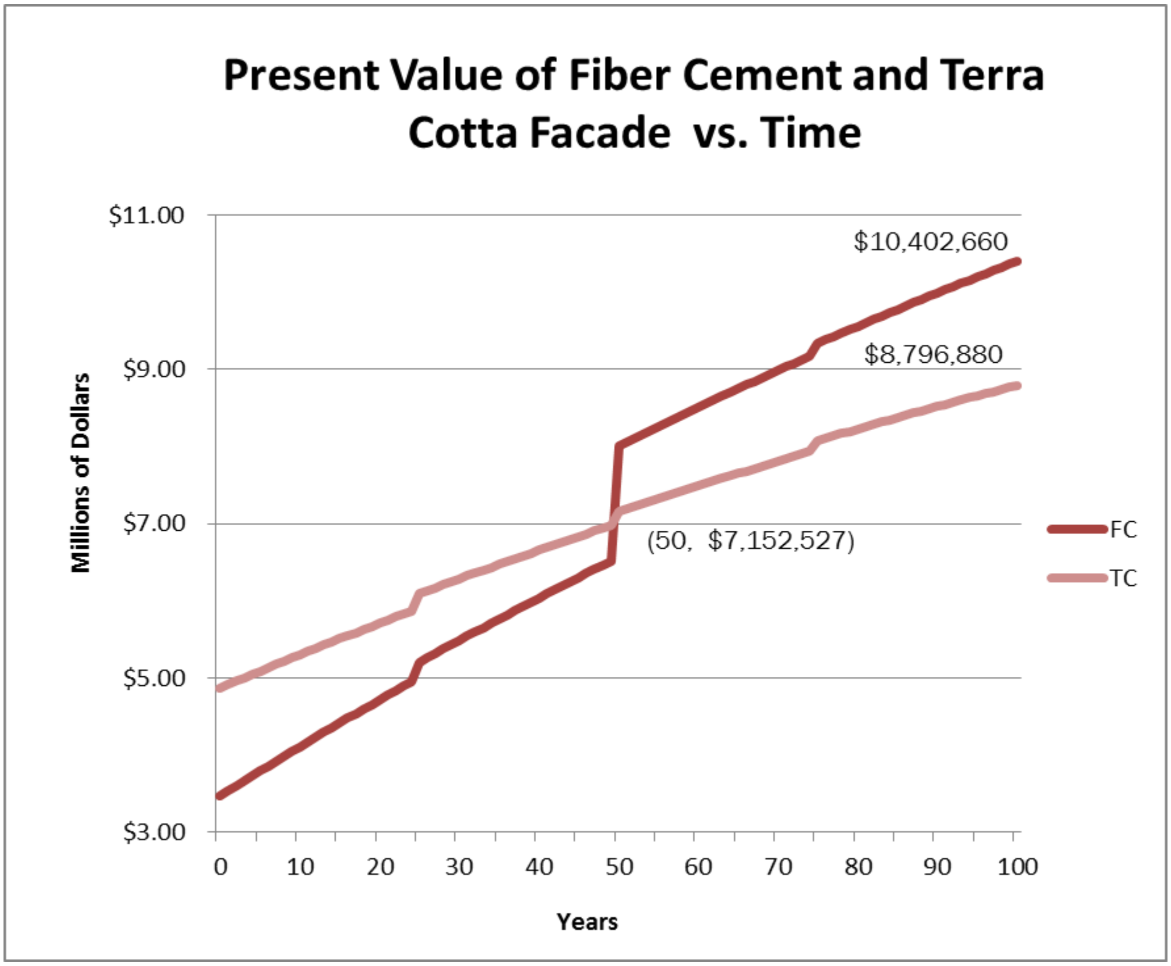


Figure 19: Payback Calculation of TC Facade

The breakeven point for the terra cotta façade occurs in year 50, due to the required re-installation of the fiber cement façade. For a 100-year building the terra cotta system significantly outperforms the fiber cement system, by about $1.6 million (present value). However, if the Plaza were to be considered only a 50-year building, the fiber cement system would not have to be replaced. The fiber cement would then be less expensive than the terra cotta rainscreen at year 50, by about $0.4 million (present value). It is important to note, however, that the 50-year lifespan for the fiber cement façade assumes it is being regularly and properly maintained, and was installed perfectly with no leakage. If not, the fiber cement will probably have to be replaced sooner than 50 years, which is likely the case on the Plaza.

While some commercial buildings do have a 50-year lifespan, they are generally designed to last longer than that. It is recommended that commercial buildings be designed for at least 60 years, while a "very good" building target is often around 100 years. It is therefore safe to assume that the Plaza would be designed to last longer than 50 years, and the fiber cement façade would have to be replaced at some point in the building's lifespan (likely sooner than 50 years). Assuming conservatively that the building is only designed for a 60-year lifespan, the terra cotta rainscreen is more cost-effective over that period than the fiber cement by roughly $1 million (present value).

3.9 Other Implications

There are factors other than cost and schedule to consider when comparing the two façade types. Although generally transportation and material staging are important factors, these will have a negligible impact in this analysis. Both the fiber cement and terra cotta panels are manufactured in the same geographic region, trucked to site with similar pallet and shipment sizes, and have almost identical storage requirements. Safety is also an important concern which has relatively similar factors for both façade types. Both façade systems use similar equipment and tools, and neither require any unusual or dangerous procedures for installation.

One important other factor is mold and mildew. Although it is impossible to predict with certainty, the tendency of the fiber cement system to leak and the quality issues with the installation of this system suggest that the façade may experience mold or mildew issues at some point in the building's lifespan. This is expensive to remove and is detrimental to the health of the building's occupants. A related concern is the efflorescence which can accrue on the fiber cement façade. While not dangerous, this causes a detrimental aesthetic affect unless removed, which, again, adds cost. The aesthetics of the fiber cement system in general are considered less modern and less desirable than those of the terra cotta rainscreen. Switching to the terra cotta system may attract more potential tenants to the building, especially considering the young, modern clientele which the Plaza is targeting.

A substantial issue for the fiber cement system was installation quality, which would likely be easier to control with the terra cotta system. The main factor in this is the labor force;

the subcontractors that install rainscreen are used to large commercial buildings and have a specific labor force of installers who are very familiar with the system. Additionally, there are fewer connections, layers, and tolerances which need to managed in the rainscreen system. The support rails simply need to be screwed into the underlying structure and the panels hung on the support rails. The biggest concern is the levelness of the supports which can easily be managed with laser levels. In the fiber cement system, on the other hand, there is a significant amount of z-flashing and caulking which need to be installed within specific tolerances. Each instance of this creates a potential quality issue. This leads to high levels of rework, increasing costs, lengthening schedule, and inconveniencing other trades. Additionally, quality issues in the façade create potential for air and water leakage, which can increase the likelihood of mold issues and the level of air infiltration as discussed in the mechanical breadth. A greater level of quality control with the terra cotta façade would decrease all of these potential issues.

3.10 Conclusion and Recommendations

It is recommended that the alternate terra cotta rainscreen system be implemented in place of the original fiber cement façade. Although the terra cotta rainscreen alternate has a higher installed cost, it costs less than the fiber cement façade when viewed from a 60-year lifecycle perspective, by about $1 million. This is due to a decrease in operational energy costs arising from an improved thermal performance, and the longer lifespan of the terra cotta facade. The alternate system also has the potential to allow an extra week for the interior and finishes trades, and to improve the aesthetic and quality aspects of the exterior façade of the Plaza.

Chapter 4

Analysis #3: Constructability Review Analysis

4.1 Problem Identification

One unforeseen cost issue of the project was the unanticipated number of design discrepancies/issues and late design changes. There were many revised drawing sets issued on the project, with extremely significant changes throughout. This was particularly difficult to manage in the beginning of the project, when the highest rate of changes was being made. Due to the project delivery system, the drawings were issued immediately before construction was to start, with no time built in for review by the contractor or subcontractors. There was a significant amount of manpower devoted by the GC to identifying and rectifying design discrepancies, mostly through an unusually high number of RFIs. These RFIs reflected a high amount of unclear work, delays, and rework, which all increase costs.

4.2 Research Goals

The goal of this analysis is to estimate the potential efficacy of a third-party constructability review for the Plaza project, and determine whether this would have been an advantageous service to implement from a cost perspective.

4.3 Methodology

- Investigate the use of constructability reviews in the construction industry.
- Determine typical issues eliminated with constructability reviews.
- Investigate industry averages of the estimated cost effectiveness of constructability reviews.
- Estimate the field and office costs of issues which would have been eliminated with a constructability review.
- Determine if the effectiveness of the service would have outweighed the cost and it would have been an advantageous service for the Plaza.

4.4 Background Information

Although third-party constructability reviews are somewhat rare in the design and construction industry, they are gaining in popularity. Noticing this trend, professional societies such as the Construction Industry Institute (CII) and Construction Managers Association of America (CMAA) have commissioned studies to investigate the costs and advantages of these services. The original attitude in the industry in the early 90's seemed to be that these reviews should not be necessary because the same capacity/ability to perform these services should already be present within the design team. However, more recent surveys of construction industry professionals and owners suggest that the attitude towards these services has significantly improved in recent years, and they are now viewed in a rather favorable light (Pocock et al, 2006). Most owners are more comfortable utilizing a third-party firm for constructability reviews and recognize that this can add value to the project.

For the purposes of this report, the term constructability will be defined as “the integration of construction knowledge and experience in the planning, design, procurement, and construction phases of projects consistent with overall project objectives” (Pocock et al., 2006). A typical third-party constructability review checks the plans for completeness, code issues, agency approvals, typical coordination of trade items, and general mistakes in references to details/elevations/notes. A more advanced review can also include suggestions on Value Engineering (VE), time tables for activities, phasing, logistics and a review of the project manuals. There are no common standards for the scope or methodology of a constructability review at this time, and most firms which provide this service follow a unique process developed internally. However, it is widely accepted that constructability reviews are more effective the earlier they can be conducted, before time impacts of changes can begin accruing. Projects with traditional project delivery systems tend to benefit more from third-party reviews than projects with more integrated delivery systems. This is because the trade integration and design-assist factors of a more integrated project tend to catch many of the issues which would later be illuminated by a third-party constructability review, and therefore render them less cost-effective. The Plaza is consequently a very good candidate for a third-party constructability review due to the traditional project delivery system and absence of any design-assist activities from either the GC or subcontractors.

4.5 Cost and Effectiveness Estimates of Constructability Review Services

4.5.1 Typical Effectiveness Estimates

It is very difficult to accurately assess the cost consequences of these services due to the unique nature of the products of the construction industry. Because every building is different it is impossible to compare the cost outcomes of two identical products, one which implemented a constructability review and one which did not. Despite this, varied attempts have been made to quantify the cost savings achieved as a result of implementing constructability reviews on commercial projects. The most widely accepted estimate is from the Construction Industry Institute and suggests that a cost savings equal to about 3%-5% of the total project cost can be achieved by implementing a constructability review. Another widely accepted estimate comes from the CMAA and says that owners can expect to save about $10 in total project costs for every $1 spent on the project (Pocock et al., 2006). Many providers of these services will suggest they can provide a $20-$30 savings for every $1 they are paid, however, these estimates are likely somewhat optimistic. Costs of these services vary widely based on the type and size of building as well as the scope of review and the company providing the service.

4.5.2 Cost and Effectiveness Estimates for the Plaza

In order to compare the effectiveness of a review to the initial cost, an estimate had to be obtained for the initial cost of a review for the Plaza. The Foreman Group was contacted to obtain a pricing estimate for the project, as they are considered a leader in the Plaza's geographic region for these services. This is important because a good constructability review should also factor in local codes and construction practices. The Foreman Group estimated that a very thorough constructability review for this project (including all of the aspects discussed in Section 4.4) would cost around $80,000, while a more standard review would cost about $70,000. The standard pricing option will be used for the purposes of analysis because the scope for the standard option is more typical of a third-party constructability review than the advanced option offered by the Foreman Group.

Using this initial cost estimate and the effectiveness estimates from the previous section, the potential cost savings of implementing constructability review services on the Plaza were calculated. If the CII estimate of 3%-5% savings of total project cost is used, the average estimated savings for the Plaza is $2,000,000. If the CMAA estimate of $10 of savings per $1 of review is used, the overall estimated savings is $700,000. There is a very significant difference between these two estimates.

4.6 Constructability of the Plaza Building

4.6.1 Constructability Impact Categories

In order to have a more realistic assessment of the potential Plaza cost savings due to a constructability review, an estimate of the theoretical impacts of such a review must be performed. These impacts can essentially be broken down into two categories: hard cost impacts and soft cost impacts. In this instance, hard costs refers to the field costs required to implement a design change or fix. This includes the labor and material costs of rework due to design changes, the cost of change order markups which were caused by design issues and omissions (but which did not require rework), and the costs of acceleration due to design issues. Soft costs refer to the office-based costs required to manage the design issues and changes, including the labor to review drawing changes and manage the RFI process, as well as the printing costs for new drawing sets.

4.6.2 Hard Cost Estimate

An estimate was performed of the hard cost issues which could be mitigated with a constructability review of the Plaza. The first step of this estimate was to review all of the non-owner requested project change orders. Those change orders which arose as a result of design omissions and errors were separated from the change orders which arose as a result of construction errors. The design-caused change orders were then further separated into two categories: rework change orders due to design changes made after work was installed, and change orders which added necessary components that were missed in the original design. A detailed breakdown showing the categorization and cost of all relevant change orders can be found in Appendix F.

The first category of change orders, rework costs, can be attributed directly to the design. This is because work was installed according to current plans, and the increased costs were incurred solely because of late design changes. These change orders only reflect large and drastic changes to the design, as smaller scopes of rework were completed at-cost by the subcontractors without change orders. Consequently it is assumed that a constructability review would have caught all these fairly major issues. As such, these change orders will be considered to be able to be entirely eliminated with a constructability review. The second category of change orders, however, would not be wholly eliminated with a constructability review. This is because these change orders reflect the addition of portions of work which were not shown in the original design, but were necessary to build the Plaza. Ideally the scopes added by these change orders would have been included in the original design. Therefore it can be expected a constructability review would have marked these missing scopes in the plans before CDs were issued, therefore changing the scopes from change orders to portions of the original design. As such, only the change order markup of these change order items can be expected to be eliminated with a constructability review. Although the value of change order markups varies across the industry, 10% can be assumed to give a very conservative estimate for purposes of this report. In summary, it can be expected that the entire total of category 1 change orders and 10% of the total of category 2 change orders would be eliminated with a constructability review. A summary of these costs can be seen in the following table.

Table 21: Change Order Cost Categories

	Category 1	Category 2
Total Cost of all Change Orders	$ 136,173.00	$ 1,621,354.00
Markup	NA	10%
Cost of Markup	NA	$ 162,135.40
Cost for Constructability Review	**$ 136,173.00**	**$ 162,135.40**

The other source of hard costs is delay impacts of the drawings, which require costly acceleration measures. By far the biggest source of this on the Plaza occurred during the installation of foundations. Very soon before the foundations were scheduled to begin it was discovered that the structural and architectural plans did not perfectly align. Although the misalignment was slight, the foundations could not be set until this issue was reconciled. This caused a marked delay for the foundation installation. Because foundations occur at the beginning of the project and are on the critical path, a delay in this activity would have had a cascading effect on the entire project schedule. In order to eliminate that possibility, the concrete structure was accelerated to meet the original end date, compressing the schedule. That acceleration had an associated cost of $142,000. This cost can also be expected to have been eliminated with a constructability review, as it arose from a discrepancy in the drawings. A summary of all hard costs reasonably eliminated with a constructability review is shown in the following table.

Table 22: Summary of Hard Costs

Hard Cost Type	Total Cost
Category 1 Change Orders	$ 136,173
Category 2 Change Orders	$ 162,135
Acceleration Costs	$ 142,545
TOTAL	**$ 440,853**

4.6.3 Soft Cost Estimate

An estimate was also performed for the soft costs of the project. The main components of the soft costs that were identified were printing expenses for new design revisions, GC labor costs to review new revisions for changes, and GC labor costs to manage the RFI process. There were an unusually high number of drawing revisions published on the Plaza, all of which had to be printed. Due to missed changes early in the project which had undesirable cost effects, DPR also chose to review all published drawing revisions by page. In order to calculate the cost of printing and review labor, the number and page count of all drawing revisions had to be determined. A summary of this data can be found in the following table.

Table 23: Drawing Revisions Summary

Revision	No. of Pages	
	Full Set	Partial
Construction Set	547	
Revision 1		108
Revision 2	567	
ASI 1	567	
ASI 2 thru 13		347

As shown, there were three published full sets of drawings (including the original construction set) and multiple partial-set revisions. There were two current sets of plans maintained in the field office at all times, so each sheet of each revision had to be printed twice. A cost of $0.95 per sheet was used to estimate the printing costs, based on a vendor quote. Each revision sheet published also had to be reviewed by a DPR Project Engineer in order to identify the changes from previous sheets. It was estimated that it took 4 minutes per sheet on average to review the full set revisions, and 2 minutes per sheet on average to review the partial set revisions. The difference is because the partial sets only include sheets which have been changed, whereas it is more difficult to find the changes in the full sets. A rate of $55 per hour was used for the Project Engineer's time. The application of these costs to the number of sheets yielded the following printing and labor totals (the construction set was excluded because it was not a result of a design change).

Table 24: Summary of Printing and Review Costs

Revision	No. of Pages		Printing Cost	Labor Cost	Total Cost
	Full Set	Partial			
Construction Set	547		$ -	$ -	$ -
Revision 1		108	$ 205.20	$ 392.04	$ 597.24
Revision 2	567		$ 1,077.30	$ 4,178.79	$ 5,256.09
ASI 1	567		$ 1,077.30	$ 4,178.79	$ 5,256.09
ASI 2 thru 13		347	$ 659.30	$ 1,259.61	$ 1,918.91
Total	**1681**	**455**	**$ 3,019.10**	**$ 10,009.23**	**$ 13,028.33**

The other aspect of the soft costs was the labor to manage the RFI process. Although a small portion of RFIs are requests made by the subcontractors which they feel can improve the design, the vast majority of RFIs are a result of design flaws. There are functionally three categories of underlying design issues which can be used to classify the RFIs on the Plaza: missing information, unclear information which requires clarification, and patent design issues (such as MEP clashes) which require a redesign of that instance. Of these, the RFIs to clarify unclear design aspects are the most simple, because they merely seek to confirm information which is already known. RFIs concerning missing information are also fairly simple, although somewhat more time-consuming because a more detailed description of the sought-after information is required. Finally, RFIs which require design changes are the most complex and require the most time to create. This is because a detailed description of the underlying problem must be included, as well as a detailed recommendation or request for redesign.

To obtain an accurate picture of the labor required to manage the RFI process, the actual RFIs for the Plaza must be broken down into these categories. However, because the calculations are attempting to quantify only the cost which could reasonably be expected to be eliminated with a constructability review, it would be overly optimistic to include all project RFIs in this tally. Therefore, the analysis only looked at those RFIs occurring before January 1, 2014. This was the period of time when the most design changes occurred and when the majority of the design issues were ironed out through the RFI process.

Next, an estimate of the time required to create a typical RFI in each of these categories must be obtained. The DPR Project Engineer who managed the RFI process was contacted for this information. Note that the time estimates for these categories include both the time to understand the issue from the subcontractor identifying the problem, as well as the time to create the actual RFI. It also includes an allowance for those RFIs which require more than one submission or communication with the architect, which mostly applies to the category of design changes. Again, a rate of $55 per hour was used to estimate the cost of the Project Engineer's time. These values were used to calculate an estimate of the labor cost to manage the RFI process for the GC only, as shown in Table 25.

Table 25: General Contractor Cost of RFI Management

RFI Type	Qty	Time (hrs)	Rate ($/hr)	Total Cost
Clarifying/Confirming	143	0.25	$ 55.00	$ 1,966.25
Missing Information	81	0.33	$ 55.00	$ 1,470.15
Design Changes	207	0.75	$ 55.00	$ 8,538.75
TOTAL	431	-	$ 55.00	**$ 11,975.15**

However, there was also a time commitment made by the subcontractors for the RFI process. Subcontractors were responsible for communicating identified constructability issues to DPR, which was usually performed by a subcontractor superintendent. An hourly rate of $50 was used as an average value to estimate the labor cost of these individuals. Again, the General Contractor PE for the project provided an estimate of the time it took subcontractors to communicate the constructability issues they found. An estimate of the subcontractors' costs to manage the RFI process was calculated as shown in Table 26.

Table 26: Subcontractor Costs of RFI Management

RFI Type	Qty	Time (hrs)	Rate ($/hr)	Total Cost
Clarifying/Confirming	143	0.17	$ 50.00	$ 1,215.50
Missing Information	81	0.25	$ 50.00	$ 1,012.50
Design Changes	207	0.33	$ 50.00	$ 3,415.50
TOTAL	431	-	$ 50.00	**$ 5,643.50**

If the costs to manage the RFI process are combined with the printing and management costs of design revisions, it provides a total estimate of the soft costs that could reasonably be expected to be eliminated with a constructability review.

Table 27: Summary of Soft Costs

Soft Cost Type	Total Cost
Printing Costs	$ 3,019
Design Revision Review	$ 10,009
RFI Management	$ 17,619
TOTAL	**$ 30,647**

4.7 Impact Assessment of Constructability on the Plaza

If the hard and soft cost impacts considered attributable to a constructability review are summed, it yields a total of approximately $471,500. It should be noted that this is likely a conservative estimate. There were a number of delays on the project which were most likely due to constructability challenges, but which were not included in this estimate because that conclusion could not be made with complete certainty. With that said, the Plaza cost impact estimate is much less than the estimates created with typical effectiveness rates, as seen in the table below.

Table 28: Constructability Review Impact Estimates

Source	Cost Savings	% of Project
CII	$ 2,000,000.00	4.0%
CMAA	$ 700,000.00	1.4%
Actual Project Costs	**$ 465,856.00**	**0.9%**

Although the estimate created with the actual project costs is much less than the estimates created with typical industry data, this is not a large concern because it still represents a significant savings above the cost of the review itself. Using the quote of $70,000 for constructability review services for the Plaza, the $466,000 calculated impact value still reflects a savings of about $6.7 per $1 spent on review services. Subtracting the cost of the service from the estimated savings suggests that the Plaza would save approximately $400,000 with a constructability review. Again, this is likely a conservative estimate, but is still a substantial cost savings. It should be noted that this estimate does not overlap with either of the cost savings identified in the previous two analyses.

One potential obstacle for the implementation of these review services on the Plaza is the owner buy-in for such a service. The owner needs to feel that a constructability review will add value outside of what the design team is capable of providing, and that such a service will save them more money than they spend on it. This was one reason why the Foreman Group was chosen to discuss pricing: they guarantee that they will save the project more money than their fee, and if not, they waive that portion of their fee. Consequently it is impossible for the owner to lose money in procuring their services. This guarantee should be able to eliminate any hesitations or concerns of the owner, and obtain their buy-in for the implementation of a constructability review.

4.8 Conclusion

In conclusion, it is suggested that using a third-party constructability review service would have been an advantageous approach on the Plaza. Using actual project data, it is estimated that such a service would have yielded a total of $400,000 project cost savings on the Plaza project. While the Plaza has already been built so it is too late for the owner to implement these services, this could be an extremely beneficial service for them to investigate as a serial builder of similar facilities.

Chapter 5

Analysis #4: Personality and Teamwork Study

5.1 Problem Identification

There was a high rate of turnover on this particular project team, which ultimately increases labor costs and decreases productivity. This is because new team members have to take time and effort to overcome the learning curve of the project, and original team members must learn to communicate with their new colleagues. Communication among team members appeared to be an opportunity for improvement on the Plaza project, and an analysis of the different personality types among team members may show reasons for this issue, as well as potential suggestions for how to improve. Additionally, the project delivery system for the Plaza was fairly traditional, so most team members did not interact on a personal level until the project was into construction, if at all. This meant that interpersonal trust was not already built into the team, and increased the amount of time and effort it took team members to communicate.

5.2 Research Goals

The goal of the research is to explore the study of personality within the framework of construction project teams. A review of current literature on personality within team frameworks and within the construction industry will be performed to understand these topics from a high-level theoretical perspective. Insight from this exploration will be applied to the Plaza team to suggest possible reasons for communication issues and strategies for improvement. The research will also explore the relationship between project delivery methods and team personality. This will be done by performing the same personality analysis on a team with a more integrated project delivery system. Comparing the two analyses will yield insight on how the effect of construction team personality varies with delivery systems.

5.3 Literature Review

5.3.1 Introduction

Although research on the effect of personality on individual task performance has increased in recent years, there is little research on how this may be aggregated into groups to evaluate team-based work. There is also little research on how these concepts are applicable to the construction industry. This literature review provides an overview of the issues related to personality composition in team-based task performance, as well as a summary of the current research on personality within the construction industry.

A review of existing literature on the topic suggests that Construction Management Personnel (CMPs) tend to be fairly homogenous, with a preference for logical, left-brain oriented thinking. Group problem-solving abilities appear to increase with the diversity of the project team’s personalities, which suggests that construction teams may improve performance with the integration of difference personality types (Kramer, 2014). Heterogeneity of construction teams may be increased with the addition of female CMPs and CMPs of different ages, which may subsequently improve construction team performance.

5.3.2 Personality Assessment Tool- MBTI

Personality assessment was largely popularized by the development of the Myers-Briggs Type Indicator (MBTI) in the 1950's (Kuprenas & Nasr, 2000). Although the concept of personality testing and categorization had been present for a few decades, the development of the MBTI system made the original research by Carl Jung more accessible to both researchers and the general public (Carr, 2004). This system analyzes subjects based on four functions, or pairs of opposite traits, and categorizes each subject as one of 16 personality "types" based on their specific combination of traits.

The first pair of traits is usually referred to as attitude, and reflects the way in which one interacts with the world. Attitude can be classified as either Extroversion (E) or Introversion (I). Extroverts tend to focus on the outside world and interaction with others, while introverts prefer to focus on their own inner world. The next function is information-gathering preference, which is classified as Sensing (S) or Intuition (N). Sensors gather information from their five senses and focus on tangible, physical phenomena, while intuitors focus on interpretation and add their own meaning. The third function is decision-making preference, which can be either Thinking (T) or Feeling (F). Respectively, these mean making decisions based off of logic or off of personal values and emotions. The last function is known as the structure or lifestyle preference, and is classified as either Judging (J) or Perceiving (P). Judgers require greater organization and order, while perceivers are more comfortable with ambiguity and uncertainty (Johnson & Singh, 1998).

The MBTI assessment is administered by asking subjects a variety of questions about their preferences. Answers are given on a 5-point Likert scale, and at the conclusion the subject is placed somewhere on a spectrum between the two extremes of each function. Whichever trait they exhibit a greater affinity towards is recorded, and the combination of the four preferred traits is called the subject's type. It is important to note that all people have some level of each trait, but the result reflects the preference for one side of the dichotomy over the other. Each of the 16 types has certain associated characteristics and overall descriptions. For example, a subject with a preference for Introversion, Sensing, Thinking, and Judging will be type ISTJ, which has been shown to be the most common type for engineers (Kuprenas & Nasr, 2000). This type is described as being quietly systematic, logical, organized, and detailed (Myers & Briggs Foundation, 2014).

However, it is important to note that the type classification cannot reflect the extremity of each factor; an intense preference towards one trait is indistinguishable from a very mild preference for the same trait. This has been cited as one weakness of the MBTI system, as the dichotomy leads to poor retest capability for those with moderate trait preferences (Higgs, 2001). Retest capacity (also referred to as repeatability) refers to the chances that a test will return the same result for a particular subject if they take it twice within a short period of time. Studies have shown that the MBTI instrument's repeatability is not as high as many other personality based tests, which has led to the decline of the MBTI as a research tool in the intellectual community (Higgs, 2001). Validity is another concept which is important to researchers in the study of personality measurements. It is important to distinguish psychometric validity, which is similar to repeatability, with construct validity, which refers more to the accuracy of the results. The MBTI instrument does not have high psychometric validity, due to the repeatability characteristics previously mentioned. However, the construct validity of the MBTI is generally believed to be fairly high. Studies have shown an acceptable correlation with other established instruments that also attempt to measure the same Jungian characteristics (Higgs, 2001). Overall, the MBTI's profile of repeatability and validity suggest that the instrument may not be appropriate for statistical research, but is well-suited for developmental applications such as self-insight and team-building (Higgs, 2001).

5.3.3 Personality Assessment Tool- Five Factor Model

Another common personality assessment tool is the Five-Factor Model (FFM), which is more commonly known as the Big Five personality assessment. The five factors in this test are conscientiousness, agreeableness, neuroticism, openness to experience, and extraversion, which all have the same meaning in this context as they do in common vernacular. Unlike in the MBTI assessment, the FFM results place the subject along a continuous scale for each of these factors, rather than using opposing categorical variables for each factor. By using numerical values rather than categories, the retest capability was improved dramatically compared to that of the MBTI (Barrick & Mount, 2006). The Big Five system subsequently rose to prominence in the 1980's as researchers sought a personality inventory with high repeatability to use in their studies. While there are some similarities between the MBTI and Big Five systems, studies using the FFM have been able to show a correlation between Big Five profiles and individual task performance which have never been replicated with the MBTI (Barrick & Mount, 2006). Specifically, the conscientiousness factor has a significant positive correlation with performance across all tested task types. However, there is a lack of repeatable research yet to date that establishes a clear statistical relationship between team Big Five results and team performance (Kramer, 2014).

While the FFM has these advantages over the MBTI in the realm of research, it has not replaced the MBTI for use in the general populace. Although the Big Five model has experienced relative popularity in the business world, the MBTI is still very commonly used in a variety of developmental applications. This is likely due to the fact that the MBTI yields simple dichotomized preferences rather than the sliding values obtained from the Big Five assessment. Test subjects appear to appreciate the 16 pre-developed MBTI type descriptions more than the ambiguity of the Big Five's sliding scales (Harvey et al., 1995).

5.3.4 Personality in Construction

Although the study of personality in the workplace is growing increasingly popular and common, there is still little research on this topic within the construction industry (Giritli & Civan, 2008). The literature which does exist on the topic varies significantly in scope and approach, so it is difficult to compare studies and results. One of the first large statistical studies conducted in this area was administered by Singh (2002) when he surveyed 51 Construction Management Professionals (CMPs) in the Hawaii State Department of Engineering Construction (SDEC). Singh gathered data on self-reported characteristics of the CMPs and utilized these characteristics to label each subject as either left-brained or right-brained. Individuals who are left-brained exhibit characteristics such as being analytic, scientific, linear, methodical, and logical. Right-brained individuals, on the other hand, are oriented to be more spatial, visual, intuitive, artistic, and instantaneous. Singh differentiated the SDEC employees as either Construction Engineers or Design Engineers, and ran a statistical analysis on the self-reported characteristics of each group. Upon comparing the groups, Singh concluded that the Design Engineers were primarily right-brained while the Construction Engineers were primarily left-brained. At first this may not seem surprising, given that the descriptions of left and right-brained thinking fit society's stereotypes of engineers and designers rather well. However, Singh was startled by the magnitude of the difference, particularly within a single organization. He hypothesized that a significant amount of inefficiency and conflict within SDEC is due to the extreme polarization of the two types of engineers, and that increased diversity in thinking styles may help to improve communication between Design and Construction Engineers.

Building off of this study, Atalah (2014) conducted the largest survey to date of personality in construction. Subjects were identified through communication with contractors from the Top 400 Contractors list of ENR and included estimators, superintendents, and project managers. Again, neither the MBTI nor the FFM assessment were used; the subjects were interviewed for four to six hours by a professional psychologist who administered a variety of questionnaires (see study for full list). From these results the psychologist documented the traits of the test subject using a prepared list of 47 possible characteristics.

After analyzing the results of the test subjects compared to the population at large, 34 traits were found to be substantially different between CMPs and the general population (13 were found to be insignificantly different). The three traits that the CMPs displayed with the greatest magnitude were conceptual ability, teamwork, and conscientiousness. On the other hand, CMPs scored the lowest on the traits of vulnerability, office detail, and angry hostility. This demonstrates the need for construction professionals to efficiently handle complex problems while remaining calm and working as a team. Although Atalah separated the test subjects by Estimators and Project Managers before running the analysis, there were not significant differences between the traits of the two groups, only a slight difference in the traits of human services and gregariousness. This implies that there may be a greater level of homogeneity between sub-types of CMPs than originally thought.

While the research did not occur domestically, the work by Giritli and Civan (2008) which surveyed personality types within the Turkish construction industry also yields interesting statistical insight which can be applied to the U.S. construction industry. In this study, 230 architects and engineers within the construction industry were asked to self-report on 300 possible characteristics on the Gough Adjective Checklist, which was then broken down into 37 categories of characteristics. Results were then analyzed and compared based on age, gender, and position (architect or engineer).

There were too many significant results to discuss all of them here, however there were some overall patterns of traits that can be used to summarize the analysis. Architects scored the highest on the traits of dominance and aggression, while engineers tended towards more "passive" traits such as endurance and order. These profiles led the authors to hypothesize that architects tend to be more individualistic, creative, and adaptable than the conventional and logical engineers, which mirrors the results of Singh's hemispherity study as previously discussed. Females scored highest on attributes such as achievement, dominance, counseling readiness, and aggression, while males scored highest on order, endurance, and dominance. Curiously, females scored the lowest on the trait of "feminine attributes". Giritli and Civan suggested this may be because these attributes are seen as a liability in such a male-dominated industry, and as such, are downplayed or ignored. Conversely, by scoring significantly higher than their male counterparts in counseling readiness, the female subjects displayed a much greater comfort level with asking and answering questions. In terms of age, the top traits vary as the participants get older. For the youngest age group, 20-24 year olds, the highest rated trait is aggression. However, this changes as with the older age groups, moving to change, dominance, and order, sequentially. This is interesting because although the top trait changes, they are all fairly similar, and tend to coincide with left-brain attributes.

Another international study that provides statistical insight into personality is the Ashridge Myers-Briggs Type Indicator study by Carr et al. (2004). This study analyzed the MBTI results of approximately 8,000 managers from various European countries and across various industry sectors. While the report did not qualitatively analyze the results, the data is useful to gain an understanding of MBTI tendencies within the construction. According to the survey, the preferred traits were Extraversion, Sensing, Thinking, and Judgment. These are the same traits that are preferred by the general population as well. The magnitude of preference for Thinking and Sensing were significantly higher than in general population. Judging was only slightly more preferred and Extraversion was moderately less preferred than it is by the general population. This would imply that CMPs may be more introverted and logical but less intuitive than the general population. This also mirrors the left-brain thinking pattern proposed by Singh (2002). The study also compared gender profiles, although this was within the general population rather than specific to the construction industry. Females were found to prefer Extraversion and Feeling significantly more than males, and Intuition only slightly more. Gender appeared to have a negligible effect on the Judging/Perceiving dichotomy.

5.3.5 Team Composition by Personality

There is a significant amount of interest and research on how personality affects job performance. Studies have shown that the MBTI instrument has no discernible correlation with individual job performance in a wide variety of task types (Harvey, 1995). One the other hand, the Big Five trait of Conscientiousness has repeatedly been shown to have a positive correlation with performance in every studied task type (Barrick & Mount, 2006). Despite significant research into the effect of individual personality on individual performance, there is still little conclusive statistical research into the personality composition of teams and how this affects group performance (Kramer, 2014).

Varvel et al. (2004) conducted a case study of engineering students performing team-based term assignments for an entire semester with the same groupmates and found that personality composition had no effect on team performance. This conclusion was based upon statistical analysis of the students' MBTI types and the aggregation of these individual profiles into a group profile. While the study found no significant correlation between personality dimensions and team performance, it did conclude that there was a positive correlation between personality type training and "teamwork" characteristics. By introducing discussions of personality variance and training individuals on the traits of their teammates, the researchers found that communication, trust, and interdependence increased. This subsequently improved relationships between team members, as well as overall worker satisfaction.

A similar study was performed by Kramer (2014) using student work on group projects to study the effect of personality dimensions on team performance. The notable differences of this study are that the Five Factor Model was used in place of the MBTI tool, and that the study looked specifically at the effect of personality on additive and conjunctive tasks. Only the additive results will be discussed here, as there are extremely few conjunctive tasks in the professional management of construction. Kramer found that increased variability in extraversion was significantly positively correlated with team performance. The statistical analysis of the extraversion factor was possible due to the numerical, sliding nature of the Big Five dimensions (as opposed to the categorical nature of the MBTI).

There is a much-cited study by Carr et al. (2002) which attempted to analyze the impact of group personality within the AEC industry. While the research was fairly groundbreaking in the examination of team composition within the construction industry, the major weakness was that the study focused solely on CMPs providing design services. The study therefore limited itself mostly to the design phase of the building process, excluding those individuals who purely manage construction. Despite this, there are still some broad conclusions which lend insight into the optimal team composition of CMPs. Carr found that diverse personality profiles were ideal for the first stages of design, when multiple viewpoints could produce more solutions or clarity to apply to the process. Conversely, homogenous personality composition was ideal for the detailed design stage, when the issue turned more to implementation than problem solving. Again, these conclusions were made solely on the basis of design professionals, however, the concepts may be useful for CMPs to consider. The amount of unforeseen issues and problem-solving inherent to the construction industry suggests that personality-diverse teams may be able to produce more creative, effective solutions. However, this has the potential to negatively affect implementation, as a more uniform team may have an easier time with the performance of set tasks.

5.3.6 Conclusion

There are few conclusive results on optimal team personality composition within the existing body of literature. Research on this topic has a high potential to improve task performance across a variety of industries as group work becomes increasingly preferred.

Utilizing very common personality assessment tools such as the Myers-Briggs Type Indicator may increase the potential for application, as these tests are familiar to both researchers and the general public.

The construction industry is known for performance issues due to interpersonal conflict and poor communication. Much of this conflict is unnecessary, and may be largely avoidable if a greater attempt at openness and understanding is given by CMPs. Training CMPs at the beginning of a project on different personality types and the tendencies of their new teammates may greatly improve their tolerance of one another's type. This has the potential to significantly improve teamwork, communication, relationships, and worker satisfaction, which subsequently tends to improve job performance. A high-potential area for future research is on the typical dysfunctions of construction teams, what personality interactions these stem from, and how these issues can be mitigated by improved team composition.

5.4 Methodology

- Identify an IPD project for use in the study.
- Discuss the project delivery method and organizational structure of both projects.
- Determine the personality assessment tool which will be used for the study.
- Determine any human subjects research or IRB requirements.

- Distribute survey and permission forms and collect results.
- Discuss survey results within the context of each project.
- Compare survey results between the projects.
- Identify other areas for potential future research.

5.5 Project Delivery Systems

5.5.1 Plaza Project Delivery

As briefly discussed in Chapter 1, the project delivery system for the Plaza was a traditional CM-at-Risk with a GMP. Drawings were delivered to the contractor at 100% and there were no design-assist measures incorporated. There was no contractual tie between the architect, Niles Bolton, and the contractor, DPR, and no communication at all between the two parties prior to the start of construction. This created a very traditional project structure, and increased the difficulty of communication between the two parties for the duration of construction.

The traditional project structure also extended to the role of the owner. In such project structures, the owner's role typically consists of very high level oversight, with regular site attendance and management only occurring in the event of major project issues. Owners in these projects are fairly removed from the day-to-day progress and struggles of the project, increasing the difficulty of communication between the owner and contractor. This model describes the Plaza structure fairly accurately.

The lines of communication between parties in traditionally delivered projects are also defined and formal. In typical traditional construction projects, almost all outside communication flows into each party through the individual filling the Project Manager (PM) role. This individual is responsible for accepting all incoming information for the entire organization, then funneling it to the specific individual to whom it is directed. For example, it would be considered unusual and inappropriate in one of these projects for a superintendent from the contractor to directly contact a consultant of the architect. Rather, the superintendent would communicate his issue to the PM for the contractor, who would send it to the PM for the architect, who would finally forward it to the consultant in question.

A portion of the rigidity in communication paths stems from the hierarchical organizational structure of the project team as whole, as well as the organizational structure within each firm. Generally individuals are assigned to very standardized roles and titles within DBB projects. The chain of command is also usually quite firm and followed fairly strictly. This creates multiple very defined levels of authority, which have distinct roles and responsibilities. Individuals therefore tend to only interact with other individuals on their level, or supervisors/supervisees directly above or below them. Because the Plaza has already finished construction and the team has dispersed, it was difficult to obtain a specific list of individuals and roles for the architect and owner representation on the project. The contractor's organizational information was able to be obtained, and a diagrammatic representation of their organizational structure can be seen in the following image.

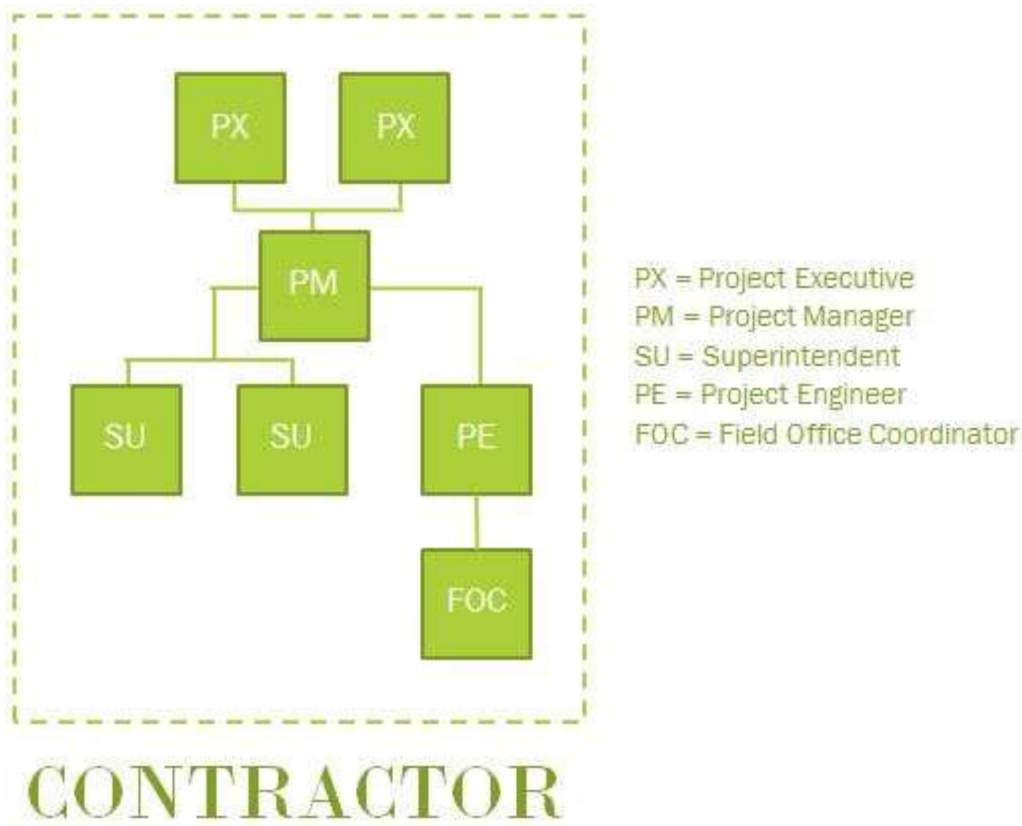


Figure 20: Plaza Contractor Org Chart

The entire organizational chart was verified with the project team for validity. The roles shown in this organizational chart have fairly standardized descriptions and responsibilities, and the chain of command is also very standardized and somewhat rigid. In essence, each individual member of the team had a very clear role for the project, and a very defined set of other individuals with whom they communicated.

5.5.2 IPD Project Delivery

In order to compare the effects of project delivery methods, a highly integrated project was sought for use in this analysis. Integrated Project Delivery (IPD) was identified as providing the most contrast to the Plaza's delivery method. Where the delivery used on the Plaza is considered to be traditional, rigid, and marked by distinct separation of the major parties, IPD is regarded as innovative, organic, and marked by integration of the entire team. An IPD project means that the Construction Management (CM) firm and occasionally the major trade partners (mechanical and electrical subcontractors) are procured at the very beginning of design, and the owner, architect, and CM all sign the same contract at the same time. This means that all parties are contractually tied to one another and integrated from the outset of the project, so they have more motivation and capacity to work together. Profit and risk are also shared between the parties, so each firm has a greater incentive to work for the good of the whole project rather than the good of their particular firm.

It was desired to use an IPD project being built by DPR in order to keep the contractor organization as a control variable in the analysis. A DPR project was identified (hereinafter referred to as "IPD Project") which utilized a pure IPD approach, and which was just beginning the integration and design process, an ideal stage for observation. The project team was approached about the study, and permission was obtained from the contractor, architect, and owner to observe and assess the team. The first step in the analysis of this project was to obtain the information of what the typical role of each individual would be, and create an organization chart that reflects what the project would look like had it been delivered in a traditional format, as seen in Figure 21.

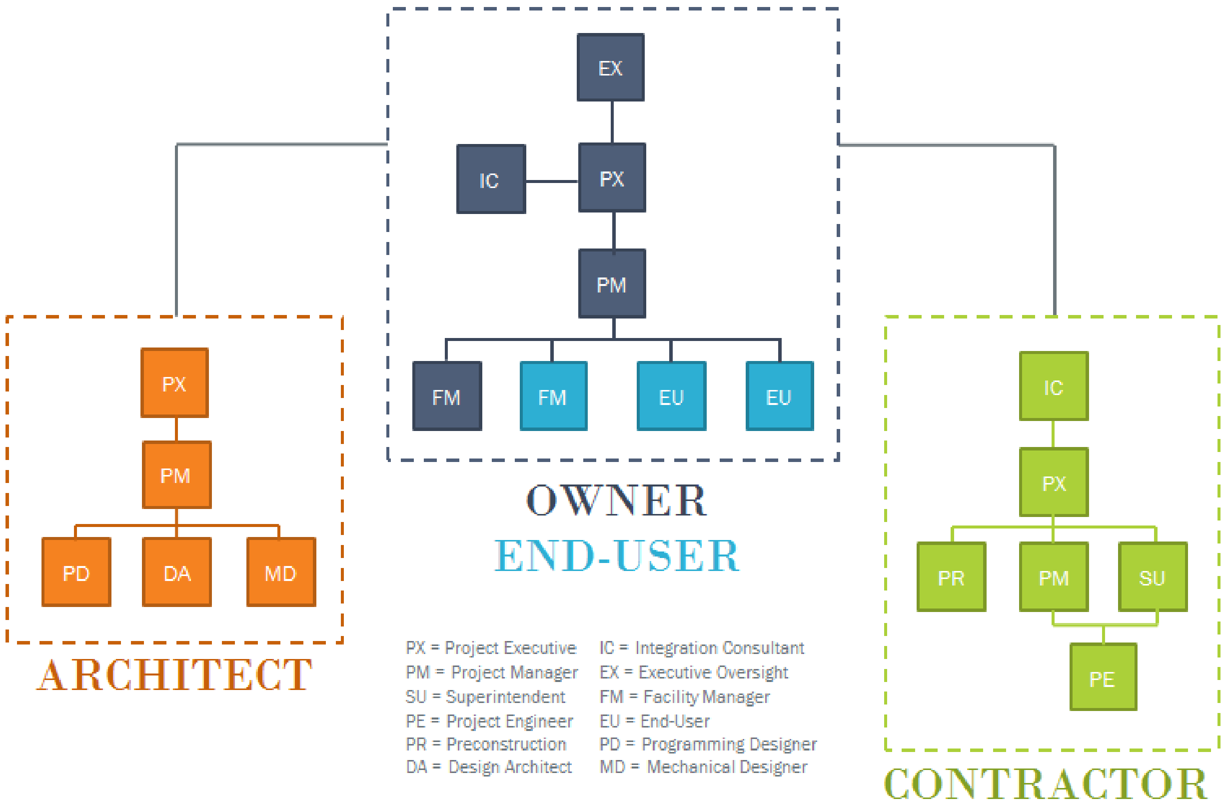


Figure 21: IPD Project Traditional Org Chart

Again, this diagram was verified with the project team as what the organizational structure would look like if the project had been DBB. However, it is important to note that the actual project organizational chart will look significantly different due the integration inherent in IPD delivery. Much of the architect-contractor integration in IPD comes from the fact that architect and contractor teams typically propose and are selected as one unit, so they are forced to interact even before design has started. This integration continues throughout the entire design and construction process, as the contractor is expected to provide significant input into design and the architect is expected to have a greater on-site presence during construction than in traditional delivery methods. As such, the architect and contractor team members know each other on a personal and individual basis. This is in marked contrast to the DBB system, where the architect and contractor often first communicate when CDs are issued, and do not get to know each other as individuals until near completion of the project, if at all.

Another difference from the IPD method to traditional methods is the organic and non-hierarchical organizational structure. Each of the three major parties (owner, architect, contractor) sign the same contract, so they all contractually become equals. The power structure typically expected between these three groups is greatly diminished in IPD. In addition to a greater sense of equality of the three parties, the power structure on an individual level is also far more flat. Because IPD projects require a fair amount of work which is different than in traditional project structures, it is very difficult to apply standard traditional work titles and roles to IPD team members. Instead, individuals tend to fill less defined roles. This makes it difficult to create levels of a hierarchy, let alone a rigid chain of command. The elimination of traditional roles and titles also eliminates the formal communication paths between organizations, because the PMs in IPD projects have different and far more fluid roles. While they do still receive much of the communication between parties, in IPD projects this is because that information is directed towards them, not because they are funneling it to other individuals.

All of these factors combine to create an organic project structure which is not conducive to display in a traditional hierarchical organizational chart. However, a visual of the IPD project team was desired in order to compare it to that of the Plaza. Mapping the organizational structure of an IPD project requires an analysis of the paths of communication between individuals rather than the chain of command between individuals. In order to begin such an analysis, a matrix was created which ranked the level of communication between every pair of individuals on the team. Individuals were separated by organization and labeled by title, with a ranking between 1 and 4 of the amount they will need to communicate with every other individual on the project. These rankings were based on the inter-organizational work groups on the project, as well as first-hand observations of team member interaction during the project team kickoff meeting.

Table 29: IPD Project Communication Matrix

		Architect						Contractor						Owner & End-User							
		PX	PM	MD	PD	DA	EX	PM	PX	PE	PR	SU	EX	PX	EX	PM	FM	EU	EU	IC	FM
Architect	PX	-																			
	PM	4	-																		
	MD	3	3	-																	
	PD	3	4	4	-																
	DA	4	4	4	4	-															
	EX	4	4	1	1	2	-														
Contractor	PM	3	4	3	3	4	3	-													
	PX	4	3	2	1	3	4	4	-												
	PE	2	1	3	2	4	1	4	2	-											
	PR	3	4	4	4	4	1	4	4	4	-										
	SU	1	2	3	1	3	1	4	3	4	2	-									
	EX	1	3	1	1	1	4	2	4	1	1	1	-								
Owner & End-User	PX	4	4	2	3	2	3	4	3	2	2	2	3	-							
	EX	4	2	1	2	1	2	2	4	1	1	1	2	4	-						
	PM	2	4	4	4	2	2	4	2	4	4	4	2	4	3	-					
	FM	1	1	4	3	2	1	1	1	2	4	2	1	2	1	3	-				
	EU	2	4	4	4	2	1	2	1	2	4	2	1	3	1	4	2	-			
	EU	2	4	4	4	4	1	4	1	2	4	1	1	2	1	4	1	4	-		
	IC	2	3	2	2	3	3	3	3	1	1	1	3	4	2	2	1	1	1	-	
	FM	1	4	2	4	1	1	2	1	2	4	3	1	1	1	4	4	4	4	1	-

Next, this chart was used to identify the individuals from each organization who were most important to team communication. This was done by summing the communication rankings for each individual: higher numbers indicate the person will communicate more with other team members. Not surprisingly, the individual with the highest total communication score from each organization was the Project Manager. This also happened to coincide well with the makeup of the Project Management Team, or PMT. The PMT is a small defined group of individuals who are responsible for making large decisions or resolving disputes. The PMT is a concept unique to

IPD, and reflects the most central decision-makers on an IPD project. Typically a PMT is composed of the PM from each major party. For this project the PMT included the PMs from the owner, architect, and contractor, as well as the PX from the owner.

Using the communication rankings from the matrix and the validation of the PMT as the central communicators for each organization, a more organic organizational chart was developed for the IPD project. First, individuals were grouped by organization in colored “pods”. The organizational color coding used is consistent throughout this analysis, and matches that of Figure 21. The PMT was distinguished with a white sub-pod. Next, those individuals who had a high level of communication with another organization’s members were placed closer to that other organization. For example, the Programming Designer (PD) for the architect was responsible for validating the needs of the end-users, so that individual was placed on the side of the architect’s pod which was closest to the end-user’s pod. Each individual team member was depicted with a separate bubble, labeled with their title code (see Figure 21 for a legend). The size of the bubble is directly scaled to the sum of their rankings from the communication matrix. Lastly, intra-organizational and inter-organizational communication lines were mapped based on the values from the communication matrix. Intra-organizational lines are shown in the color associated with that group, while inter-organizational lines are shown in black. Figure 22 shows the resulting organic IPD organizational chart.

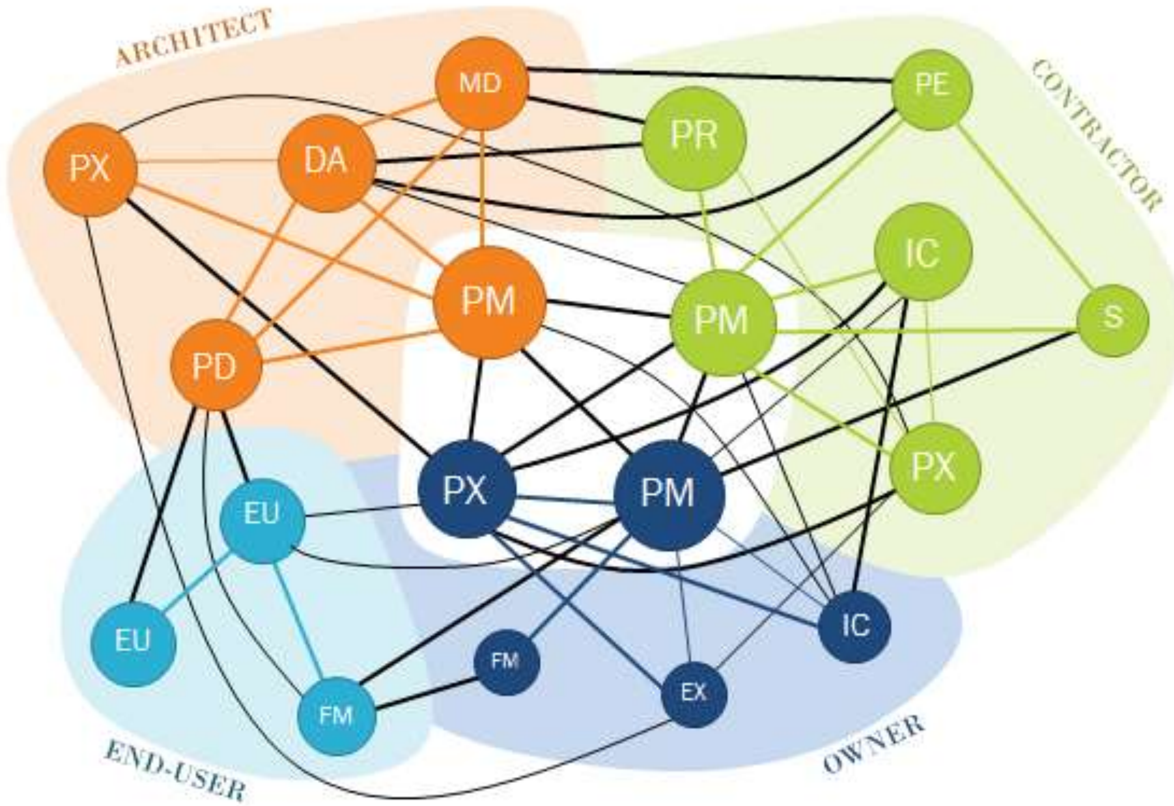


Figure 22: Organic IPD Organizational Chart

This is more representative of how an IPD team actually functions than a traditional hierarchical organizational chart, such as the one shown in Figure 21. One reason this more organic style of diagram is useful is because it can help to visually identify people who might be boundary spanners for the project (Franz, 2013). Boundary spanners are those individuals who provide a link between two otherwise separated groups of people. In the case of design and construction teams, these individuals would link at least two of the three major parties of architect, owner, and contractor. Boundary spanners are important because they provide a bridge of communication and culture between the two groups, improving cohesiveness and understanding. These are people who interact heavily with both internal organization individuals as well as individuals within at least one specific other organization. Consequently, they can be visually identified on a map such as Figure 22. On such a map they would be those bubbles which have many connecting lines, both colored and black. The most obvious boundary spanners on that map are the members of the PMT, which will be discussed further in the personality analysis of the IPD team.

5.6 Selection of Personality Assessment Tool

The first step in analyzing the Plaza's team personality composition is to identify the appropriate personality assessment system for this study. Due to their popularity and use in the existing literature, the MBTI and FFM were identified as the two most viable assessment tools for this study. Although the Big Five has slightly higher psychometric validity as previously discussed, the MBTI was chosen for this analysis for a variety of reasons. Firstly, the assessment is being performed in a case-study type format rather than a statistical analysis, so psychometric validity is less important. Secondly, one objective of this analysis is to create a framework which could theoretically be used to self-instruct teams on their own personality characteristics. The MBTI has been shown to be a highly effective teaching tool for individuals who are not familiar with personality and type (such as typical CMPs). Thirdly, the MBTI is a more neutral assessment and does not contain any factors which are commonly seen as derogatory, such as the Big Five's neuroticism factor. This is important if results are going to be used as a teaching tool in a group format.

Previous research has been conducted at Penn State by Dr. Robert Leicht and Dr. Gretchen Macht on the personality composition of construction teams using the Myers-Briggs Type Indicator, specifically on the South Halls project. The assessment of both the Plaza team and the IPD project team will consequently fall under the IRB used for their study. The IRB in question is under the supervision of Dr. Robert Leicht and is titled "Determining the Effects of Facilitated Collaboration on Team Performance and Project Outcomes". This is an exempt-type IRB, so consequently it does not need to be modified for this analysis because it falls within the IRB's original proposed scope. Appendix G contains the Informed Consent Form for this IRB which was distributed to all study participants before they were assessed.

5.7 Analysis of Assessment Results

5.7.1 Plaza Results and Discussion

The full results of the MBTI assessment on the Plaza can be found in Appendix H. A visual representation of these values and the average for each trait is included here for reference.

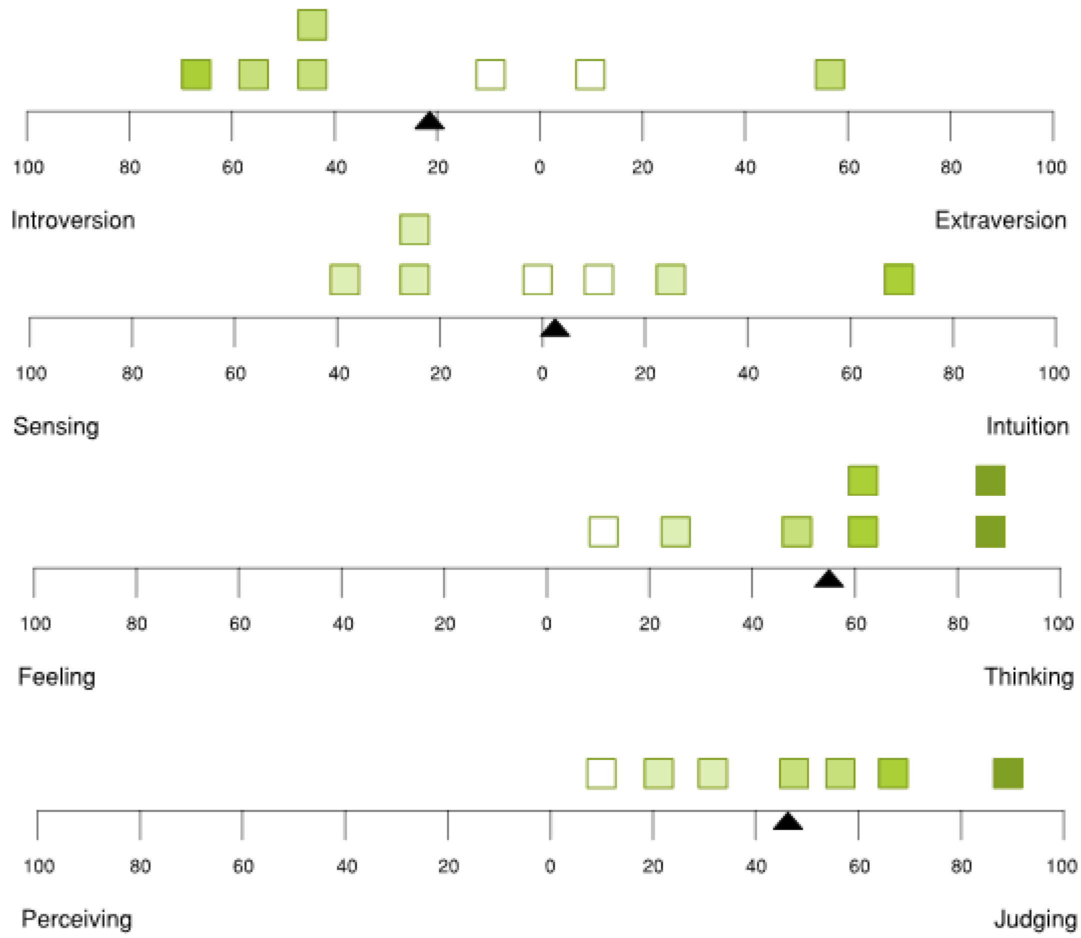


Figure 23: Plaza MBTI Scales

The most striking aspect of these results is the fact that every survey participant had Thinking and Judging traits, without exception. This is represented in the fairly condensed groupings of markers on the last two scales in Figure 23. The first two scales, E/I and S/N, had much more diverse results. These were grouped loosely around a neutral value for S/N, but a mild preference for Introversion on the E/I scale. Overall, the average preferred traits for this group were Introversion, Intuition, Thinking, and Judging (INTJ).

One strategy which is frequently used to help interpret MBTI results is mapping. In this process, a location for each of the 16 possible MBTI types is placed within a 4x4 square. A circular node is added at each location for each individual who has that type. The node is increased in size proportionally if more than one individual has that type. The final map makes it easier to quickly visualize trends in type than it is with raw data. While this is a helpful visual to identify group patterns, it is not particularly informative. It was desired in this analysis to have a sense of the nature and quality of the relationships between types, rather than simply what those types were. One classification system for the nature of MBTI type relationships is the TypeLogic indicators. This is a set of 16 descriptions of the relationships between types, based on which of the four factors are the same or different. The full list of relationship types and descriptions can be found at www.typelogic.com. It is important to note that these indicators are not scientifically validated psychological categories. Rather they are a rough approximation of the typical interaction between types based on theory and observation, which is helpful as a teaching and learning tool. The TypeLogic indicators were overlaid on the map for the Plaza team, which produced the following diagram.

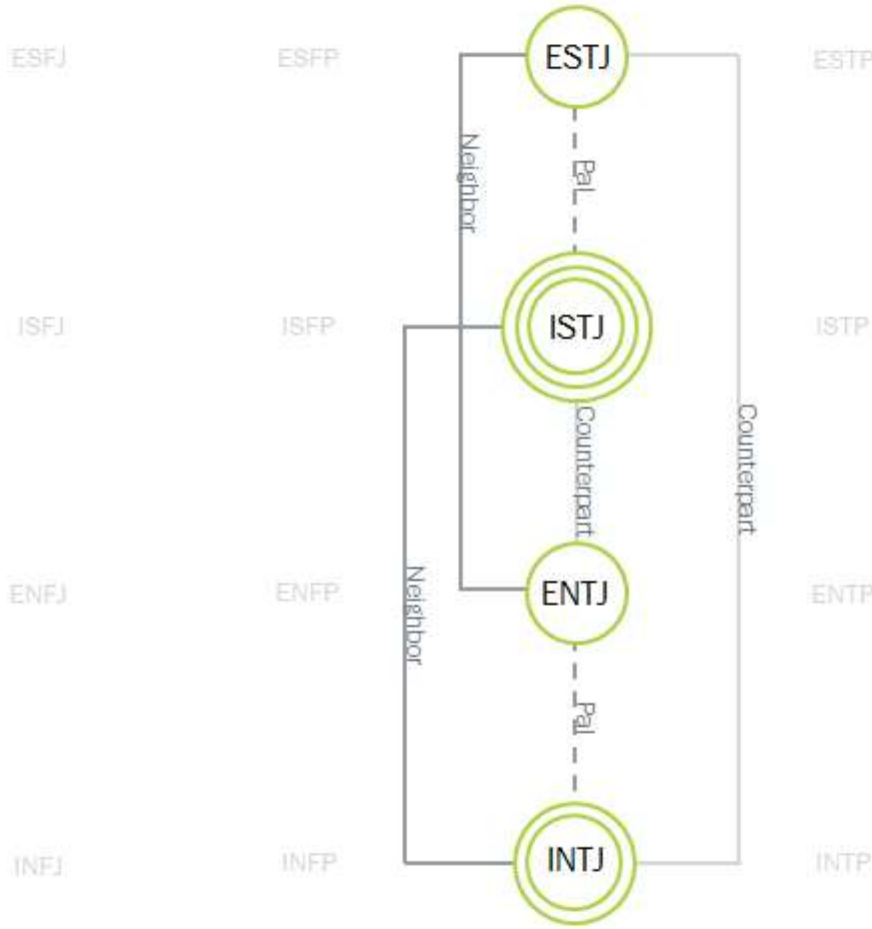


Figure 24: Plaza Team Map

The homogeneity of the team along the S/T and J/P dimensions is reflected in the fact that the team only has representation along the third column of the map. This reduces the total number of types among team members to three: Counterparts, Neighbors, and Pals. Line weights for indicators on the map reflect the nature of the underlying relationship; darker and thicker lines reflect difficult relationships with a higher potential for communication issues, while lighter lines reflect those relationships which are more natural for team members. Dashed lines designate those relationships which are viewed as favorable, and which should be naturally positive.

None of the three relationships among Plaza members are highly difficult to manage (see the discussion of the IPD team for more problematic indicators). However, of the three, Neighbors have the highest potential for conflict. A Neighbor relationship occurs when only the second dimension, S/N, varies between two individuals. The two individuals are described as arriving at the same conclusions, but by different processes, as the S/N dimension reflects how individuals process their surroundings. Although these individuals generally get along because they are so similar, issues can arise if they are forced to work together frequently to solve complex problems. This is because each person has a very difficult time understanding the other's thought process, and can become frustrated with the other person. The first Neighbor relationship on the Plaza is between the PM (ESTJ) and one of the superintendents (ENTJ). These two individuals handle field and office issues somewhat separately, but will need to explain the rationale behind their decisions to one another. That requirement for explanation is precisely where the tension in a Neighbor relationship lies. Consequently, the PM and superintendent may become frustrated with one another over the course of the project and subsequently stop communicating if this relationship is not navigated with care.

The second Neighbor relationship occurs between the two main nodes, ISTJ and INTJ. While at first this may seem quite worrisome because these nodes comprise the majority of the project team, integration with the discussion of the Plaza's organizational structure (see Figure 20) suggests that this relationship will probably be negligible. This is because both INTJ individuals are PXs, at the highest level of the chart, and the three ISTJs are a superintendent, FOC, and PE, respectively. The three latter individuals appear closer to the bottom of the organizational chart, with the PM between the two layers. As previously discussed, the Plaza project had a relatively hierarchical chain of command with considerable power distance. Individuals largely only interacted with other team members on their hierarchical level, or their direct supervisor/supervisee. Consequently, the two groups in this Neighbor relationship will likely not interact often, if at all, eliminating any effects this relationship could have had.

Although they have slightly less inherent potential for discord than a Neighbor relationship, Counterpart relationships can also prove problematic for communication. A Counterpart relationship occurs when the first two dimensions (E/I and S/N) differ between two individuals. The counterpart relationship on the Plaza team occurred between the PM (ESTJ) and the two PXs (INTJ). The TypeLogic definition says that these individuals will perform similar functions but in totally different realms, which fits the role descriptions of these individuals quite well. Both types are considered to be highly rational due to the Thinking and Judging dimensions, but an INTJ will typically handle more abstract managerial concepts while the ESTJ is well-suited to day-to-day project implementation. The potential discord in this relationship occurs because each type will have difficulty understanding the realm in which the other functions. For instance, the ESTJ may find the individual abstract thinking of an INTJ difficult to fathom compared to the ESTJ's hands-on role which requires a lot of interpersonal communication. The potential for discord between these individuals could have a significant effect on the Plaza team due to their roles. As previously mentioned, the chain of command was quite structured on this project, and the PM is the only individual on the hierarchical level between the PXs and the rest of the team. Functionally, this means that the direction of the PXs is funneled and translated by the PM into the direction for the entire rest of the team. A breakdown of communication between these two layers of individuals would have a very negative impact on the team's ability to implement the direction chosen by the Project Executives.

The third relationship type on the Plaza, Pal, is considered quite favorable with minimal natural conflict. While this is the last relationship type on this map, it is important to remember that the Plaza model was not able to incorporate the information of the owner or design team, and this is only an internal analysis of the contractor's representation on the Plaza. A full team model with the owner and architect types would contain more indicator relationship and associated communication trends. Although it cannot be forecasted with certainty, it is hypothesized that mapping the owner and architect types would reveal fundamental differences between the parties. Most notably, the contractor is extremely skewed towards the Thinking and Judging dimensions. The other two parties would most likely have some Feeling and Perceiving individuals. These individuals would be in sharp contrast to the existing team makeup, which could easily create a sense of isolation and misunderstanding in those team members.

5.7.2 IPD Results and Discussion

The full results of the MBTI assessment on the Plaza can be found in Appendix H, including the original data and the scale charts of each trait for each organization. A summary scale chart is included here for reference.

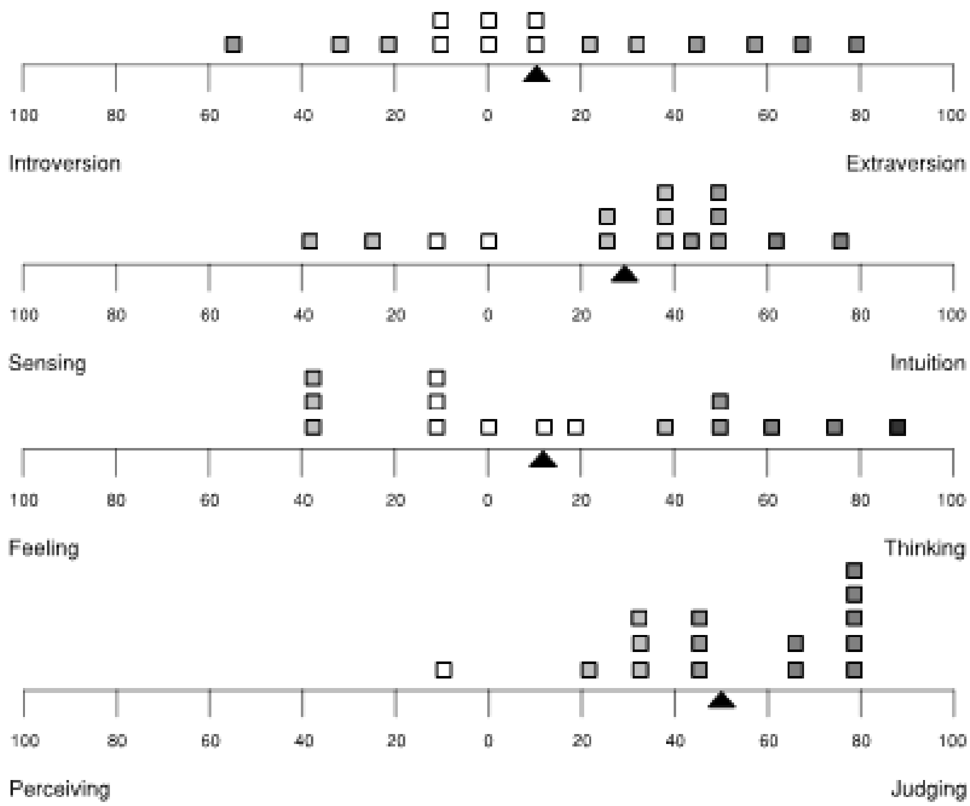


Figure 25: IPD Project MBTI Scales

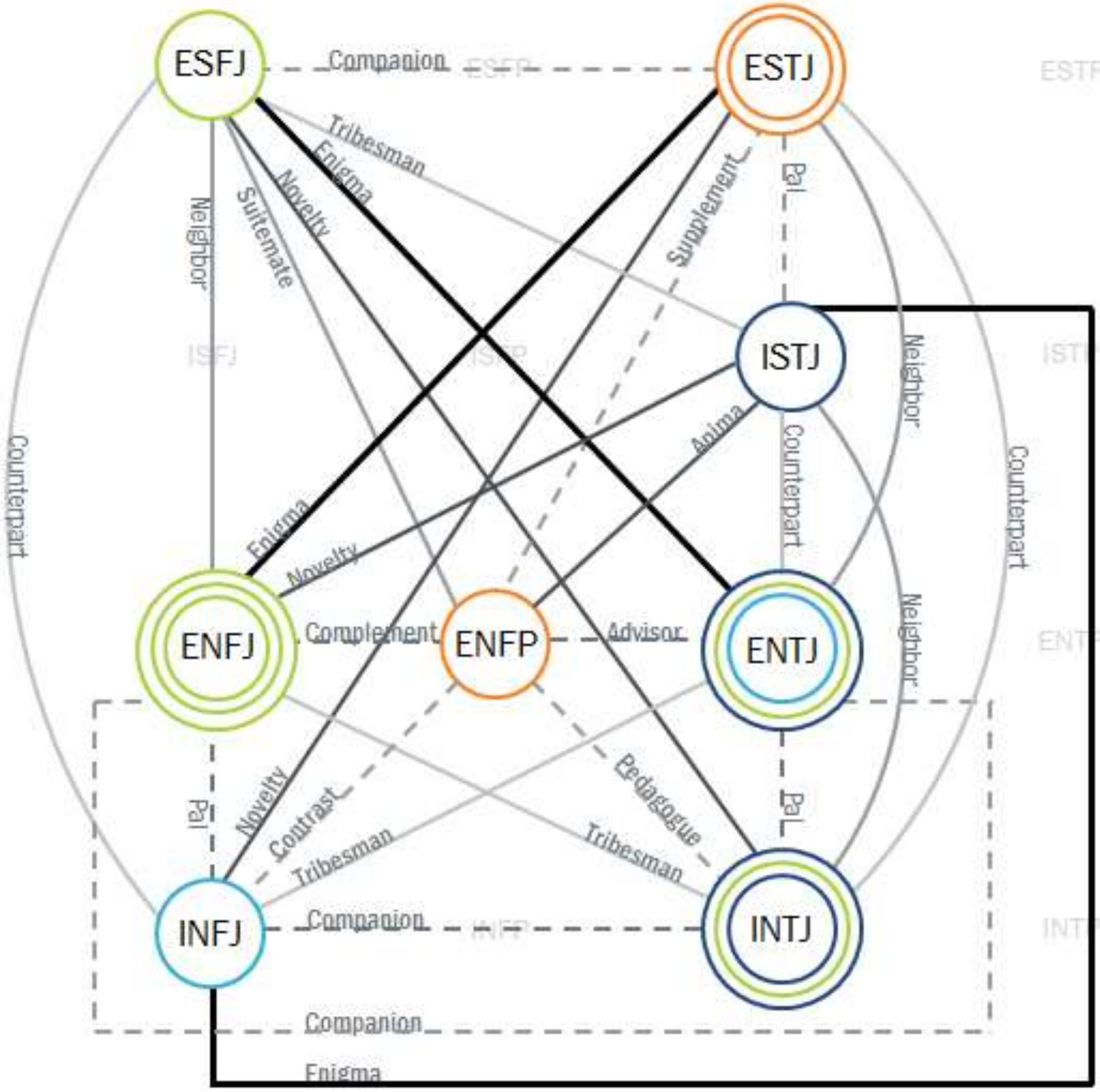
This illustrates the range of MBTI types among all individuals on the IPD project. If all team members' scores are used, the overall average type for the group would be an ENTJ. The preferences for Extraversion and Thinking are mild, while the preference for Intuition and

Judging are moderate. However, if the types are averaged by organization, each group returns a different overall average type, which can be seen in the following table.

Table 30: IPD Project Average MBTI Types by Organization

Group	Strength of Preference				Avg. Type
	E/I	S/N	T/F	J/P	
Contractor	37%	41%	4%	55%	ENTJ
Architect	8%	4%	27%	33%	ESTJ
Owner	3%	25%	41%	55%	INTJ
End-User	23%	41%	13%	56%	INFJ
TOTAL	**11%**	**29%**	**14%**	**50%**	**ENTJ**

The same mapping process that was used for the Plaza analysis was also used to map the IPD team. Color coding was used to differentiate the organizations with the same scheme previously used (orange=architect, green=contractor, blue=owner).



ESFJ
ESTJ
ESTP
ISTJ
ENFJ
ENFP
ENTJ
INFJ
INTJ
Companion
Tribesman
Enigma
Novelty
Suitemate
Neighbor
Supplement
Pal
Counterpart
Anima
Complement
Advisor
Pedagogue
Contrast

It can be seen from this map that the most homogenous trait amongst all the groups was Judging. In fact, there was only one individual with a Perceiving preference in the entire study. It is interesting to examine the bridging effect this Perceiving individual has on the team map. The Perceiving individual is a Project Manager from the architecture firm, and has an ENFP type. The other two team members from the architect are both ESTJ's, making that the most significant node for the architect. The most significant node for the contractor is ENFJ, as three contractor employees are represented by that type.

Comparing these two main nodes for the architect and contractor, the relationship between them is an Enigma. Enigma relationships occur when the two "external" factors (Introversion/Extraversion and Judging/Perceiving) are the same, but the two "internal" factors (Sensing/Intuition and Thinking/Feeling) differ. When applied to individuals this means that they appear to function similarly from the outside, but in reality, the way they gather information and make decisions is completely different. Enigmas see each other as "puzzling, and totally foreign in nearly every aspect" according to the TypeLogic description. Of all the type relationships, Enigmas tend to have the greatest discord. There is a significant potential for conflict on this team evidenced by the Engima relationship between the majority of team members from the architect and from the contractor. This illustrates the typical discord expected in the industry between the architect and contractor.

However, the Perceiving individual, the PM for the architect, can provide a bridging role between the two groups. This individual's type relationships with the major architect and contractor nodes are both positive, enabling them to act as an intermediary between parties. A bridging role is particularly suited to this individual, as they are also a boundary spanner as determined in the discussion of the IPD project's organizational structure (see Figure 22). The Project Manager position entails a high level of interfacing between the different groups. Additionally, this position comes with a spot in the PMT, which is responsible for all major decision-making on the project. It would be a major source of potential conflict if this individual was not able to communicate the work of their organization and coordinate it with the other PMT members. A visual depiction of the bridging function of this individual is shown below.

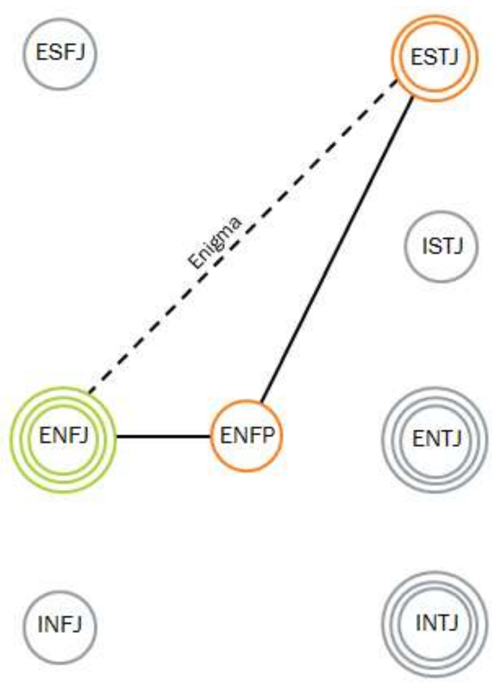


Figure 26: IPD Team Bridge 1

Another Enigma relationship shown on the team map is between ESFJ and ENTJ. While there are three individuals with the ENTJ type, the lone ESFJ will only commonly interact with one of those three, the contractor team member. This could prove to be a source of conflict within the contractor's organization. However, the Enigma designation for this relationship is somewhat misleading, because the lone ESFJ only has a 1% preference for Sensing. Such a mild preference means that the individual is almost an ENFJ, in which case, they would have a much more positive relationship (Companion) with the ENTJ's. As such, this Enigma relationship can be reasonably ignored. The last Enigma relationship on the map is between the ISTJ and the INFJ. However, these particular individuals will almost never interact due to their positions in their respective organization, so this relationship is also not a large source of concern.

Another potential source of discord can be found in the Novelty relationships. This relationship occurs between individuals when their first three traits are different, and only the Judging/Perceiving factor is the same. Novelties are characterized as being "intriguingly different" because they are so dissimilar that they have a difficult time even understanding how the other functions. However, the commonality of the J/P factor provides a link between the two that keeps them from being wholly foreign to one another. While the characterization of a Novelty is not inherently bad, the intriguing nature of the relationship can wear thin with high levels of contact between the individuals. This can create a potential for conflict if Novelty relationships are forced to work heavily with one another for extended periods of time.

The most central Novelty relationship on this project is between the ISTJ from the owner and the three ESTJs from the contractor. This is somewhat concerning because the ISTJ individual is the PM from the owner, and is particularly central to team communication. However, the potential for conflict is mitigated because most of the communication between the contractor and the ISTJ individual will occur through the PM from the contractor, who is not one of the ENFJs. This contractor PM individual (an ENTJ), provides a bridging effect for communication which decreases the potential for conflict in this area. Again, a bridging role is particularly suited to this individual because they were identified as a boundary spanner in the analysis of the organizational structure of the team. Although the ISTJ will be directly interacting with the three ENFJs on occasion, it will likely not be enough contact to wear through the intriguing nature of the Novelty. The boundary spanner/bridging ENTJ will also help ease the burden of this communication. Figure 27 shows this situation overlaid on the team map.

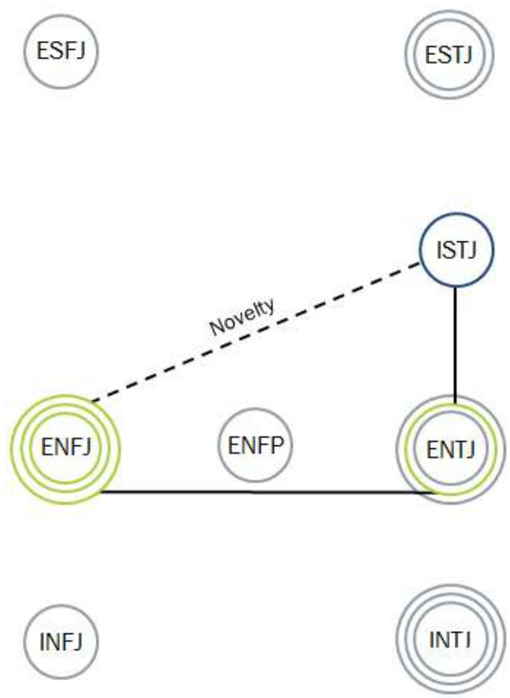


Figure 27: IPD Team Bridge 2

There are two other Novelty relationships on this team; one between the contractor ESFJ and the three varied INTJs, and one between the end-user INFJ and the architect ESTJs. Neither of these two Novelty relationships produce a high potential for conflict because these individuals will not regularly interact.

A somewhat similar relationship type to the Novelty is the Anima. An Anima occurs when every factor is different between the two individuals. Like the Novelty, this characterization is not inherently negative, but rather is described as a situation where one person's strengths are the other's weaknesses and vice versa. This can be quite useful in regards to the diversity of abilities amongst team members. However, the magnitude of the difference between the two individuals can wear on their ability to communicate effectively, similar to the Novelty.

The only Anima relationship present on this team is between the ISTJ from the owner and the ENFP from the architect. Both of these individuals are the PM from their respective organization, making this an important relationship. If the Anima relationship were to cause a breakdown of communication between these two individuals it would be quite detrimental for the entire team's ability to function in a positive, cohesive manner. Fortunately this relationship can also be bridged by another individual, the Project Executive (PX) from the owner, who is an ENTJ. This individual is the only member of the IPD team PMT other than the Project Managers from the three respective firms. Therefore, this owner PX will have a high level of interaction with all three PMs. Additionally, this individual was also identified as boundary spanner in the organizational structure due to their inclusion in the PMT.

Because of the fluid nature of the roles in an IPD project, the organizational structure can be set up so that the owner's PX will interact more with the architecture firm than the owner's PM, who will interact more with the contractor. This means that most of the information from the architect to the owner will likely flow through the PX (ENTJ), rather than go straight from the architect's PM to the owner's PM through the Anima relationship. This helps to bridge the potential gap in communication between the latter two individuals, and mitigates the potential for conflict arising from the Anima relationship. This is one potential advantage of both the fluid nature of IPD organizations, as well as the boundary spanning capabilities present in IPD teams. A diagram of this interaction within the team map can be seen below.

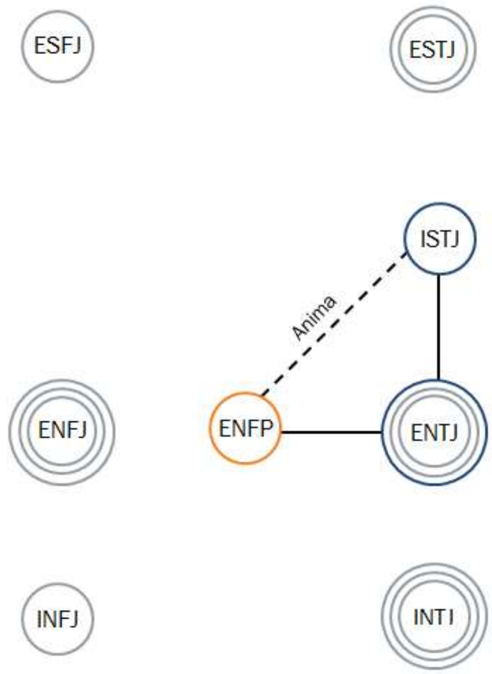


Figure 28: IPD Team Bridge 3

This analysis suggests that there are three important individuals on this project who provide a bridging function, or help to decrease the potential for communication difficulties due to type. The first is the architect's PM (ENFP) who bridges the Enigma relationship between the major architect node (ESTJ) and the major contractor node (ENFJ). The second is the PM from the contractor (ENTJ), who bridges the Novelty relationship between the owner's PM (ISTJ) and the major contractor node (ENFJ). The third is the owner's PX (ENTJ) who bridges the Anima relationship between the owner's PM (ISTJ) and the architect's PM (ENFP). Interestingly, these three individuals who provide bridging functions are all members of the team PMT, and were all identified as boundary spanners for the project. This suggests that those individuals who are responsible for a high level of communication between organizations are particularly well suited for their roles based on the team personality composition of this project. The three main bridging/boundary spanning individuals can be viewed together within the context of the team map in the following image.

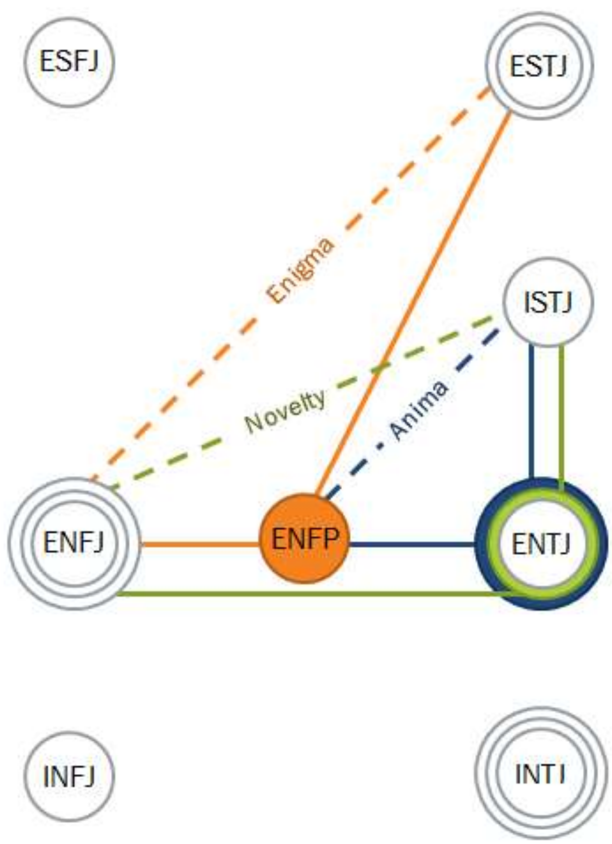


Figure 29: IPD Team Bridges (All)

5.8 Comparison of Analyses and Conclusion

The Plaza team results were much more homogenous than the IPD team results, although the Plaza analysis only included the contractor's information ,while the IPD project analysis also included the architect's and owner's information. Curiously, even when comparing only the contractor representation from the two projects, there are significant differences between the two groups for the first three MBTI dimensions. The IPD team was far more Extraverted, Intuitive, and Feeling than the Plaza team on average. Both teams were heavily Judging oriented. Appendix H contains scale charts showing the value for each individual along each dimension which can be used to visually compare the two teams.

While the different makeup of the two contractor groups may merely be due to natural variations in personality, the delivery methods of the two projects may also have had an influence on the personality type of the individuals assigned to the project. IPD projects are much more concerned with worker satisfaction, intangible success outcomes, and interpersonal communication than traditional projects. Consequently, when creating staffing plans for IPD projects, organizations may purposefully assign individuals that they feel align to these ideals. The MBTI traits that these ideals would roughly correspond to are Feeling, Intuition, and Extraversion. An interesting area for further research would involve analyzing the types of individuals who are typically assigned to more integrated projects, and how this differs from traditional project assignments.

Another interesting difference between the analyses of the two projects was how the organizational structure played into the personality structure of the IPD team. The identification of three major IPD individuals as both boundary spanners (organizational structure) and bridging nodes (personality structure) could have interesting implications for how the team communicates. This also suggests an interesting potential area for future research: identifying boundary spanners in IPD projects based on organic organizational structure and identifying the optimal type of those individuals to provide bridging effects for the team.

Chapter 6

Conclusions and Recommendations

This report analyzed four areas in which the Plaza may have been able to improve the building's delivery. Three technical analyses and one research analysis were included. The three technical analyses were a redesign of the wood stud structure to steel, a redesign of the building façade, and a study of implementing a third-party constructability review. The research analysis focused on the personality composition of construction project teams, particularly within the context of project delivery methods. The following sections summarize each analysis.

6.1 Stud Structure

It is recommended that the 5-story wood stud portion of the building be redesigned with the metal stud structural system used on the 8-story portion of the building. This would have a negligible cost impact for the initial installed cost of the system. However, the change would have a very significant schedule impact. All of the previously incurred acceleration requirements would be mitigated, a significant portion of the weekend and OT work would be eliminated, and a 2-week period for a formal punchlist process would be created. Eliminating the need for acceleration of the interior trades would save the project approximately $1.1 million. Additionally, safety and quality would likely be improved with the prefabricated metal stud walls over the original stick-built wood walls.

6.2 Façade Material

It is recommended that the alternate terra cotta rainscreen system be implemented in place of the original fiber cement façade. Although the terra cotta rainscreen alternate has a higher installed cost, it costs less than the fiber cement façade when viewed from a 60-year lifecycle perspective, by about $1 million. This is due to a decrease in operational energy costs arising from an improved thermal performance, and the longer lifespan of the terra cotta facade. The alternate system also has the potential to allow an extra week for the interior and finishes trades, and to improve the aesthetic and quality aspects of the exterior façade of the Plaza.

6.3 Constructability Review

It is recommended that a third-party constructability review service be utilized for the Plaza project. Using actual project data, it is estimated that such a service would have yielded a total of $400,000 project cost savings. While the Plaza has already been built and it is too late for the owner to implement these services, this could be an extremely beneficial service for the owner to investigate as a serial builder of similar facilities.

6.4 Personality and Teamwork Study

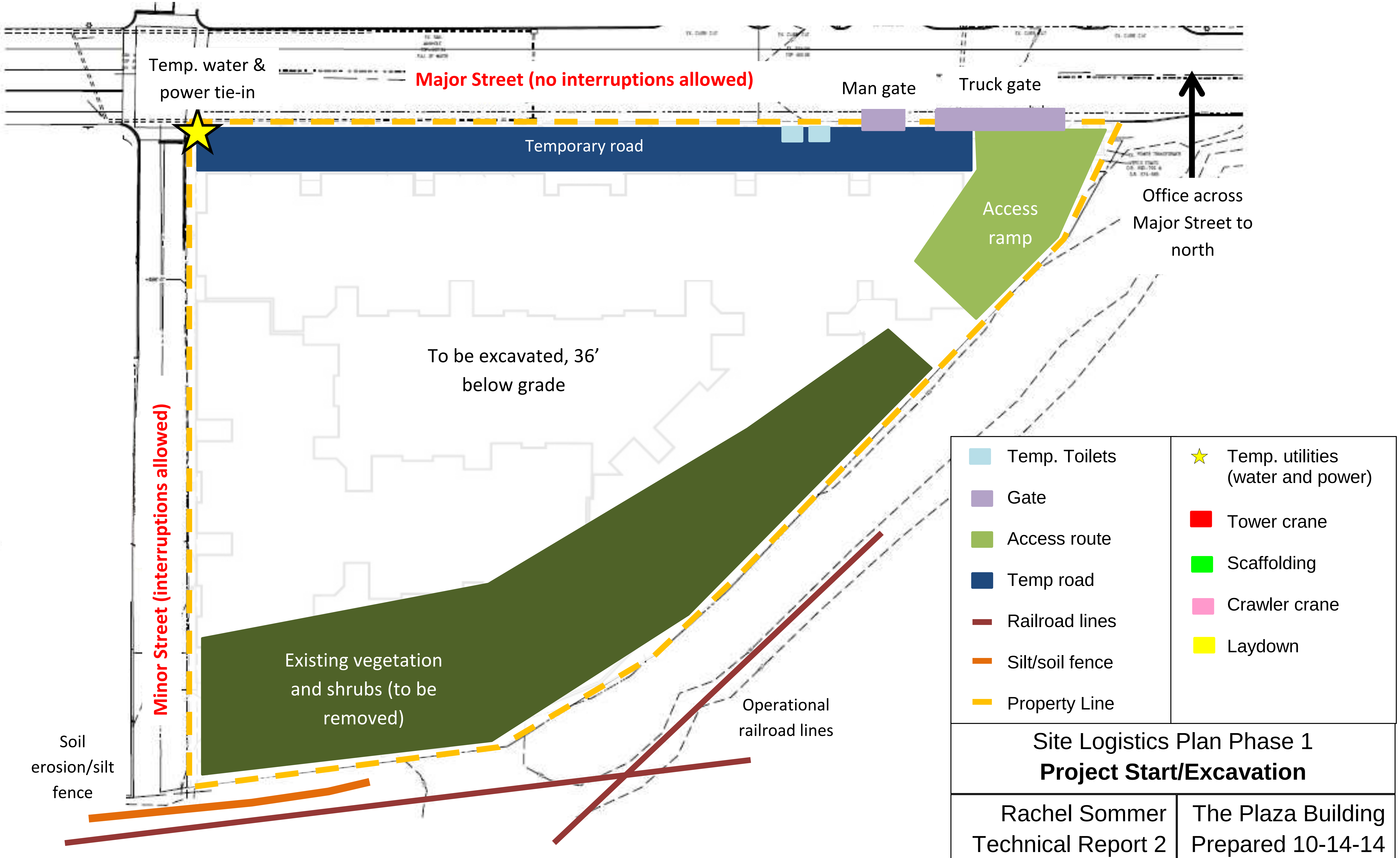
The organizational structure and personality analyses of the Plaza and IPD teams suggest that there are significant differences in both realms between the two project teams. The majority of the organizational structure and a portion of the personality composition of these projects can be attributed to the project delivery method. IPD teams have fairly fluid organizational structures, which allows for the creation of more organic paths of communication between individuals. Traditional delivery methods have more rigid organizational structure with formally defined paths of communication. Due to these differences, IPD teams may be able to eliminate some of the project communication difficulties by aligning organizational boundary spanners and individuals with bridging-type personalities.

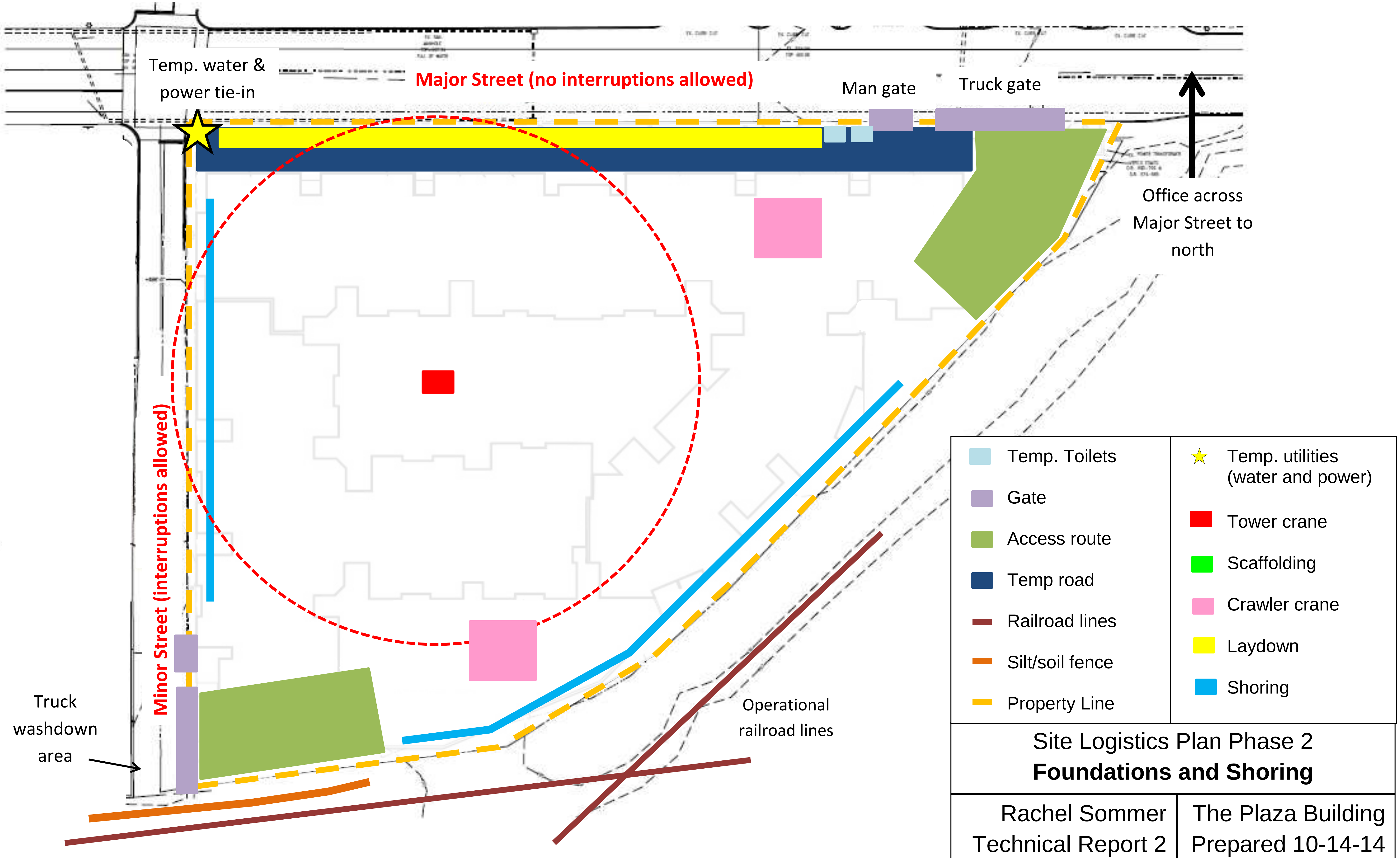
6.5 Summary of Impacts

If all of the proposed alternates/analyses were implemented, the project could expect to save $1.1 million on the stud change, $1 million on the façade change (over a 60-year lifespan), and $0.4 million on the constructability review savings. In total this would be about $2.5 million, or 5% of the total project cost. Although there were no cost impacts specifically studied in Analysis 4, research has shown that earlier involvement of the contractor (such as in IPD) can reduce conflict and mitigate the scale of unwanted cost escalation (Franz, 2013). This would be a good area for further research.

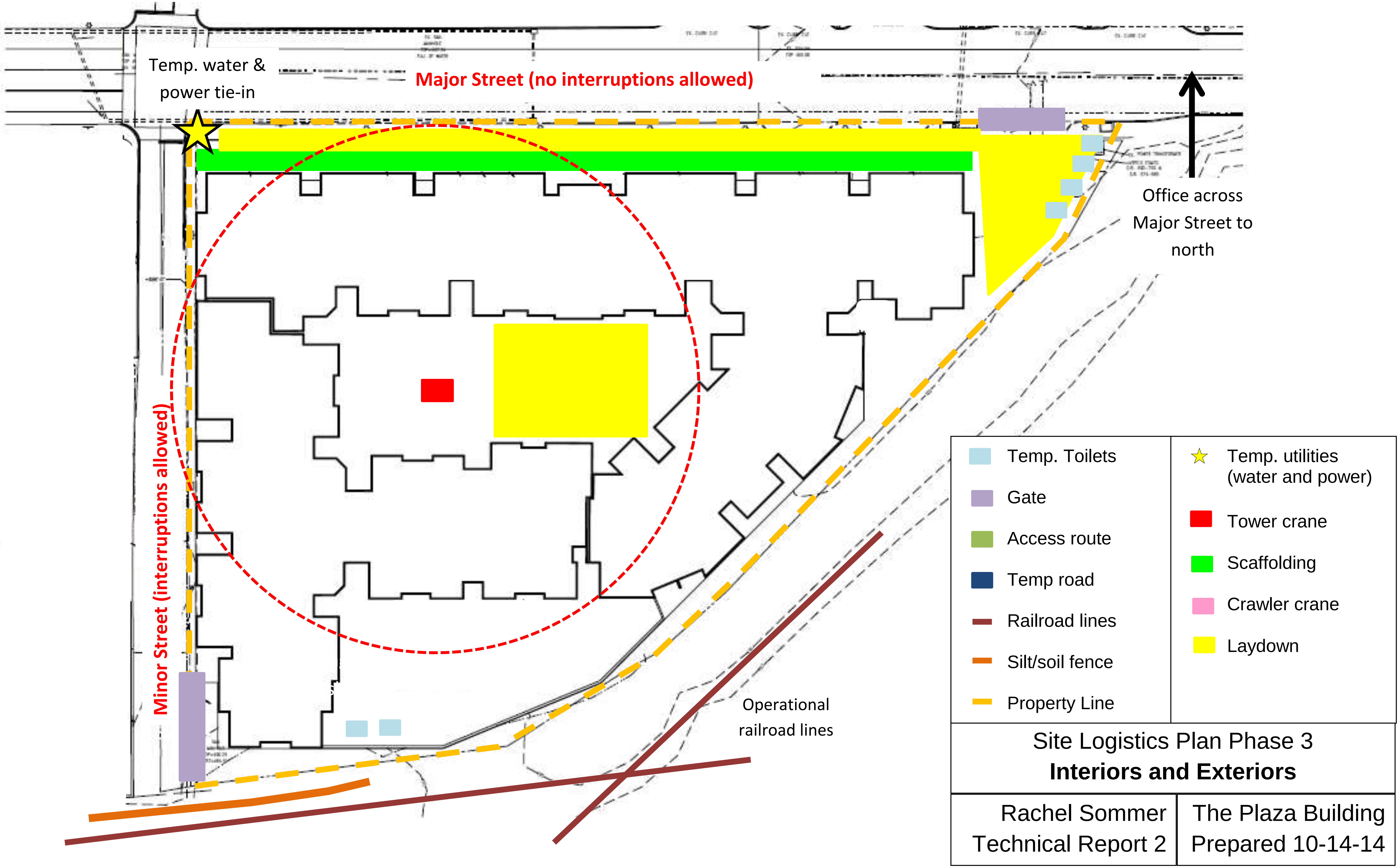
Appendix A

Site Layout Plans


Temp. water & power tie-in
Major Street (no interruptions allowed)
Man gate
Truck gate
Temporary road
Access ramp
Office across Major Street to north
To be excavated, 36' below grade
Minor Street (interruptions allowed)
Existing vegetation and shrubs (to be removed)
Soil erosion/silt fence
Operational railroad lines
Temp. Toilets
Gate
Access route
Temp road
Railroad lines
Silt/soil fence
Property Line
Temp. utilities (water and power)
Tower crane
Scaffolding
Crawler crane
Laydown
Site Logistics Plan Phase 1
Project Start/Excavation
Rachel Sommer
Technical Report 2
The Plaza Building
Prepared 10-14-14



Temp. water & power tie-in
Major Street (no interruptions allowed)
Man gate
Truck gate
Office across Major Street to north
Minor Street (interruptions allowed)
Truck washdown area
Operational railroad lines
Temp. Toilets
Gate
Access route
Temp road
Railroad lines
Silt/soil fence
Property Line
Temp. utilities (water and power)
Tower crane
Scaffolding
Crawler crane
Laydown
Shoring
Site Logistics Plan Phase 2
Foundations and Shoring
Rachel Sommer
Technical Report 2
The Plaza Building
Prepared 10-14-14



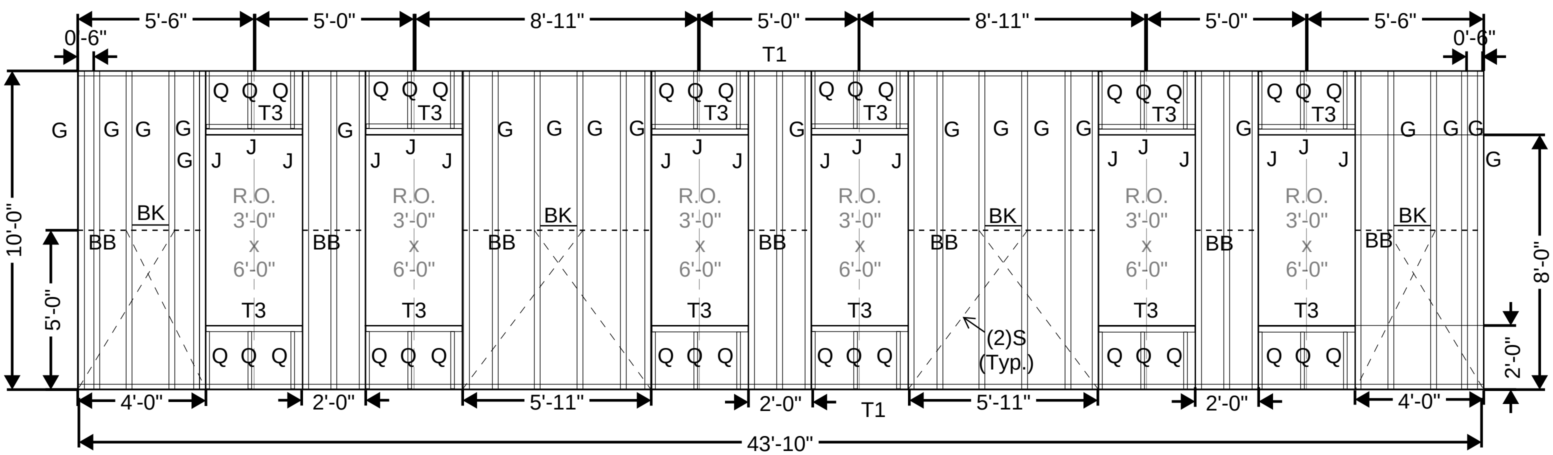
Temp. water &
power tie-in
Major Street (no interruptions allowed)
Minor Street (interruptions allowed)
Office across
Major Street to
north
Operational
railroad lines
Temp. Toilets
Gate
Access route
Temp road
Railroad lines
Silt/soil fence
Property Line
Temp. utilities
(water and power)
Tower crane
Scaffolding
Crawler crane
Laydown
Site Logistics Plan Phase 3
Interiors and Exteriors
Rachel Sommer
Technical Report 2
The Plaza Building
Prepared 10-14-14

Appendix B

Structural Redesign

Structural Redesign Unit Quantites:

Mark	Qty	Item	Length		Length (ft)	Total Length	Unit Weight	Total Weight
	No.		ft	in	ft	ft	lb/ft	lb
BB	2	BB150	4	0	4.00	8.00	0.323	2.58
BB	3	BB150	2	0	2.00	6.00	0.323	1.94
BB	2	BB150	5	11	5.92	11.83	0.323	3.82
BK	4	600T125-43	1	4	1.33	5.33	1.3	6.93
G	20	600SG250-43	10	0	10.00	200.00	2.1	420.00
J	12	600JS250-33	10	0	10.00	120.00	1.49	178.80
J	6	600JS250-33	3	0	3.00	18.00	1.49	26.82
Q	36	600S162-43	1	9.5	1.79	64.50	1.52	98.04
S	8	FS200-43	6	2	6.17	49.33	0.307	15.15
S	8	FS200-43	5	8.5	5.71	45.67	0.307	14.02
T1	2	600SGT200-54	43	10	43.83	87.67	1.944	170.42
T3	12	600T125-43	3	0	3.00	36.00	1.3	46.80



5'-6"
5'-0"
8'-11"
5'-0"
8'-11"
5'-0"
5'-6"
0'-6"
0'-6"
T1
10'-0"
5'-0"
8'-0"
2'-0"
G
J
Q
T3
BK
BB
R.O.
3'-0"
x
6'-0"
(2)S
(Typ.)
4'-0"
2'-0"
5'-11"
2'-0"
T1
5'-11"
2'-0"
4'-0"
43'-10"

				Unit				Total			
	Item	Amnt	Unit	Mtl	Labor	Eqp	Total	Mtl	Labor	Eqp	Total
Steel Studs	18 ga. metal studs, 6" wide at 16" oc	43.83	lf	$ 12.70	$ 10.05	$ -	$ 22.75	$ 556.64	$ 440.49	$ -	$ 997.13
	Metal strap, 18 ga., 2" wide, studs 16" oc	0.95	clf	$ 75.00	$ 52.50	$ -	$ 127.50	$ 71.25	$ 49.88	$ -	$ 121.13
	Continuous bridging, 16 ga. x 1-1/2" channel thru studs 16" oc	0.258	clf	$ 48.00	$ 52.50	$ -	$ 100.50	$ 12.38	$ 13.55	$ -	$ 25.93
	Bridging, solid between studs 16" oc, 18 ga. 6" wide	4	ea	$ 1.90	$ 3.10	$ -	$ 5.00	$ 7.60	$ 12.40	$ -	$ 20.00
	Framing, boxed headers, 18 ga. 10" deep	18	lf	$ 6.90	$ 3.67	$ -	$ 10.57	$ 124.20	$ 66.06	$ -	$ 190.26
								$ 772.08	**$ 582.37**	**$ -**	**$ 1,354.45**
Steel Floor	K-Series open web joists, 40 ton lots, horiz. bridging, 30' to 50' spans	1.31	tons	$ 1,625.00	$ 238.00	$ 107.00	$ 1,970.00	$ 2,127.65	$ 311.62	$ 140.10	$ 2,579.36
	Plain WWF 6x6 W2.9 x W2.9	13.55	csf	$ 22.50	$ 28.00	$ -	$ 50.50	$ 304.88	$ 379.40	$ -	$ 684.28
	Elevated slabs less than 6" thick, pumped	10.46	cy	$ -	$ 18.00	$ 5.55	$ 23.55	$ -	$ 188.28	$ 58.05	$ 246.33
	Normal weight concrete, 3000 psi	10.46	cy	$ 97.00	$ -	$ -	$ 97.00	$ 1,014.62	$ -	$ -	$ 1,014.62
	Floor decking, 1" deep, 24 ga.	1355	sf	$ 1.69	$ 0.43		$ 2.12	$ 2,289.95	$ 582.65	$ -	$ 2,872.60
								$ 5,737.09	**$ 1,461.95**	**$ 198.15**	**$ 7,397.19**

				Unit				Total			
	Item	Amnt	Unit	Mtl	Labor	Eqp	Total	Mtl	Labor	Eqp	Total
Wood Studs	Wood studs, 2" x 6", 10' high wall	0.626	MBF	$ 570.00	$ 640.50	$ -	$ 1,210.50	$ 356.82	$ 400.95	$ -	$ 757.77
	Wall framing, wood studs, headers, 2"x6"	0.036	MBF	$ 570.00	$ 2,050.00	$ -	$ 2,620.00	$ 20.52	$ 73.80	$ -	$ 94.32
	Wood bracing, let-in, with 1"x6" boards, studs at 16" oc	48.3	lf	$ 0.80	$ 2.45	$ -	$ 3.25	$ 38.64	$ 118.34	$ -	$ 156.98
	Blocking, to wood construction, 2"x6"	0.112	MBF	$ 605.00	$ 7,150.00	$ -	$ 7,755.00	$ 67.76	$ 800.80	$ -	$ 868.56
								$ 483.74	**$ 1,393.89**	**$ -**	**$ 1,877.63**
Wood Floor	Open web wood truss joists, 18" deep	657.5	lf	$ 3.99	$ 0.99	$ -	$ 4.98	$ 2,623.43	$ 650.93	$ -	$ 3,274.35
	Plates, 2"x6" (top)	0.088	MBF	$ 570.00	$ 980.00	$ -	$ 1,550.00	$ 50.16	$ 86.24	$ -	$ 136.40
	Plates, 2"x4" (bottom)	0.029	MBF	$ 570.00	$ 1,375.00	$ -	$ 1,945.00	$ 16.53	$ 39.88	$ -	$ 56.41
	Oriented strand board, on walls, 5/8" thick	438.3	sf	$ 0.69	$ 0.56	$ -	$ 1.25	$ 302.43	$ 245.45	$ -	$ 547.88
	3/4" thick plywood subfloor	1355	sf	$ 0.88	$ 0.47	$ -	$ 1.35	$ 1,192.40	$ 636.85	$ -	$ 1,829.25
	Poured gypsum underlayment, 2500 psi, 3/4" thick	1355	sf	$ 0.50	$ 0.11	$ 0.04	$ 0.65	$ 677.50	$ 149.05	$ 54.20	$ 880.75
	TOTALS							**$ 4,862.44**	**$ 1,808.39**	**$ 54.20**	**$ 6,725.03**

Appendix C

Façade Amounts

Material	Area	Bldg	Ht.	Distance		Distance	Area
			ft	ft	in	ft	sf
Fiber Cement	Interior Courtyard	A	69	499	11	499.92	34494.3
Fiber Cement	Interior Courtyard	B	101	298	5	298.42	30140.1
Fiber Cement	All Bldg. B Exterior	B	101	677	7	677.58	68435.9
Fiber Cement	East Angled Exterior	A	69	424	0	424.00	29256.0
							162,326.3
Brick	East Elevation	A	69	74	0	74.00	5106.0
Brick	North Elevation	A	69	475	9	475.75	32826.8
Brick	West Elevation	A	69	69	5	69.42	4789.8
							42,722.5

	No. of Openings					Opening Dimensions (horizontal (ft), vertical (ft), area (sf))															Extended Opening Area (sf)					Tot. SF Open	Tot. SF of Wall	SF Wall Less Open
	A	B	C	D	G	A			B			C			D			G			A	B	C	D	G			
Cement Fiber	252	364	0	81	6	3	6	18	6	6	36	6.5	8	52	6	8	48	9	6	54	4536	13104	0	3888	324	21852	162326	**140,474.3**
Brick- East	8	10	0	0	0																							
Brick-North	146	32	8	10	0																							
Brick- West	8	10	0	0	0																							
Brick Total	162	52	8	10	0	3	6	18	6	6	36	6.5	8	52	6	8	48	9	6	54	2916	1872	416	480	0	5684	42722.5	**37,038.5**

Appendix D

Heat Losses

Façade	Unit	Component	Wall	Wdw	Vol.	UA	Design Loss	Year Loss	Fuel Cost	Cost per Year	No. of Units	Total Cost
			SF	SF	ft^3	BTU/(hr*F)	BTU/hr	MBTU/yr	$/MBTU	$		$
Fiber Cement Panels	Unit A1	Wall	306			34	1864	3.7	$ 15.56	$ 57.57		
		Window		54		25	1394	2.7	$ 15.56	$ 42.01		
		Infiltration			7190	78	4271	8.4	$ 15.56	$ 130.70		
		Total	**306**	**54**	**7190**	**137**	**7529**	**14.8**	**$ 15.56**	**$ 230.29**	**5**	**$ 1,151.44**
	Unit B1	Wall	431.6			48	2629	5.2	$ 15.56	$ 80.91		
		Window		90		42	2324	4.6	$ 15.56	$ 71.58		
		Infiltration			9930	107	5898	11.6	$ 15.56	$ 180.50		
		Total	**431.6**	**90**	**9930**	**197**	**10851**	**21.3**	**$ 15.56**	**$ 331.43**	**84**	**$ 27,839.95**
	Unit C1	Wall	562			62	3423	6.7	$ 15.56	$ 104.25		
		Window		108		51	2789	5.5	$ 15.56	$ 85.58		
		Infiltration			12240	132	7271	14.3	$ 15.56	$ 222.51		
		Total	**562**	**108**	**12240**	**245**	**13482**	**26.5**	**$ 15.56**	**$ 412.34**	**13**	**$ 5,360.42**
	Unit D1	Wall	156			86	4750	9.3	$ 15.56	$ 144.71		
		Window		779.8		73	4028	7.9	$ 15.56	$ 122.92		
		Infiltration			14250	154	8465	16.6	$ 15.56	$ 258.30		
		Total	**156**	**779.8**	**14250**	**313**	**17242**	**33.9**	**$ 15.56**	**$ 527.48**	**62**	**$ 32,704.01**
	Fiber Cement Total											**$ 67,055.82**
Terra Cotta Rain-screen	Unit A1	Wall	306			20	1073	2.1	$ 15.56	$ 32.68		
		Window		54		25	1394	2.7	$ 15.56	$ 42.01		
		Infiltration			7190	45	2491	4.9	$ 15.56	$ 76.24		
		Total	**306**	**54**	**7190**	**90**	**4958**	**9.7**	**$ 15.56**	**$ 150.93**	**5**	**$ 754.66**
	Unit B1	Wall	431.6			28	1513	3	$ 15.56	$ 46.68		
		Window		90		42	2324	4.6	$ 15.56	$ 71.58		
		Infiltration			9930	63	3441	6.8	$ 15.56	$ 105.81		
		Total	**431.6**	**90**	**9930**	**132**	**7278**	**14.3**	**$ 15.56**	**$ 222.51**	**84**	**$ 18,690.67**
	Unit C1	Wall	562			36	1970	3.9	$ 15.56	$ 60.68		
		Window		108		51	2789	5.5	$ 15.56	$ 85.58		
		Infiltration			12240	77	4241	8.3	$ 15.56	$ 129.15		
		Total	**562**	**108**	**12240**	**164**	**9000**	**17.7**	**$ 15.56**	**$ 275.41**	**13**	**$ 3,580.36**
	Unit D1	Wall	156			50	2734	5.4	$ 15.56	$ 84.02		
		Window		779.8		73	4028	7.9	$ 15.56	$ 122.92		
		Infiltration			14250	90	4983	9.7	$ 15.56	$ 150.93		
		Total	**156**	**779.8**	**14250**	**213**	**11699**	**23**	**$ 15.56**	**$ 357.88**	**62**	**$ 22,188.56**
	Terra Cotta Rainscreen Total											**$ 45,214.25**

Appendix E

Payback Calculations

Year	FC Elec.	TC Elec.	FC Eqpmt	TC Eqpmt	Façade FC	Façade TC	FC Yearly Cost	TC Yearly Cost	FC Yearly PV	TC Yearly PV	FC Total PV	TC Total PV
0			$ 246,906.00	$ 235,196.00	$ 3,224,500.00	$ 4,635,642.00	$ 3,471,406.00	$ 4,870,838.00	$ 3,471,406.00	$ 4,870,838.00	$ 3,471,406.00	$ 4,870,838.00
1	$ 67,055.82	$ 45,214.25					$ 67,055.82	$ 45,214.25	$ 65,102.74	$ 43,897.33	$ 3,536,508.74	$ 4,914,735.33
2	$ 68,732.22	$ 46,344.61					$ 68,732.22	$ 46,344.61	$ 64,786.71	$ 43,684.24	$ 3,601,295.44	$ 4,958,419.57
3	$ 70,450.52	$ 47,503.22					$ 70,450.52	$ 47,503.22	$ 64,472.21	$ 43,472.18	$ 3,665,767.65	$ 5,001,891.74
4	$ 72,211.78	$ 48,690.80					$ 72,211.78	$ 48,690.80	$ 64,159.23	$ 43,261.15	$ 3,729,926.88	$ 5,045,152.89
5	$ 74,017.08	$ 49,908.07					$ 74,017.08	$ 49,908.07	$ 63,847.78	$ 43,051.14	$ 3,793,774.67	$ 5,088,204.03
6	$ 75,867.51	$ 51,155.77					$ 75,867.51	$ 51,155.77	$ 63,537.84	$ 42,842.16	$ 3,857,312.51	$ 5,131,046.19
7	$ 77,764.19	$ 52,434.67					$ 77,764.19	$ 52,434.67	$ 63,229.41	$ 42,634.18	$ 3,920,541.91	$ 5,173,680.37
8	$ 79,708.30	$ 53,745.53					$ 79,708.30	$ 53,745.53	$ 62,922.47	$ 42,427.22	$ 3,983,464.38	$ 5,216,107.59
9	$ 81,701.01	$ 55,089.17					$ 81,701.01	$ 55,089.17	$ 62,617.02	$ 42,221.26	$ 4,046,081.40	$ 5,258,328.86
10	$ 83,743.53	$ 56,466.40					$ 83,743.53	$ 56,466.40	$ 62,313.05	$ 42,016.31	$ 4,108,394.45	$ 5,300,345.16
11	$ 85,837.12	$ 57,878.06					$ 85,837.12	$ 57,878.06	$ 62,010.56	$ 41,812.34	$ 4,170,405.01	$ 5,342,157.51
12	$ 87,983.05	$ 59,325.01					$ 87,983.05	$ 59,325.01	$ 61,709.54	$ 41,609.37	$ 4,232,114.55	$ 5,383,766.88
13	$ 90,182.62	$ 60,808.14					$ 90,182.62	$ 60,808.14	$ 61,409.98	$ 41,407.38	$ 4,293,524.53	$ 5,425,174.26
14	$ 92,437.19	$ 62,328.34					$ 92,437.19	$ 62,328.34	$ 61,111.87	$ 41,206.38	$ 4,354,636.40	$ 5,466,380.64
15	$ 94,748.12	$ 63,886.55					$ 94,748.12	$ 63,886.55	$ 60,815.21	$ 41,006.35	$ 4,415,451.61	$ 5,507,386.99
16	$ 97,116.82	$ 65,483.72					$ 97,116.82	$ 65,483.72	$ 60,519.99	$ 40,807.29	$ 4,475,971.60	$ 5,548,194.27
17	$ 99,544.74	$ 67,120.81					$ 99,544.74	$ 67,120.81	$ 60,226.21	$ 40,609.19	$ 4,536,197.81	$ 5,588,803.46
18	$ 102,033.36	$ 68,798.83					$ 102,033.36	$ 68,798.83	$ 59,933.85	$ 40,412.06	$ 4,596,131.65	$ 5,629,215.53
19	$ 104,584.19	$ 70,518.80					$ 104,584.19	$ 70,518.80	$ 59,642.90	$ 40,215.89	$ 4,655,774.56	$ 5,669,431.41
20	$ 107,198.80	$ 72,281.77					$ 107,198.80	$ 72,281.77	$ 59,353.38	$ 40,020.66	$ 4,715,127.93	$ 5,709,452.07
21	$ 109,878.77	$ 74,088.81					$ 109,878.77	$ 74,088.81	$ 59,065.25	$ 39,826.39	$ 4,774,193.19	$ 5,749,278.46
22	$ 112,625.74	$ 75,941.03					$ 112,625.74	$ 75,941.03	$ 58,778.53	$ 39,633.06	$ 4,832,971.71	$ 5,788,911.52
23	$ 115,441.38	$ 77,839.56					$ 115,441.38	$ 77,839.56	$ 58,493.20	$ 39,440.66	$ 4,891,464.91	$ 5,828,352.18
24	$ 118,327.42	$ 79,785.55					$ 118,327.42	$ 79,785.55	$ 58,209.25	$ 39,249.20	$ 4,949,674.16	$ 5,867,601.38
25	$ 121,285.60	$ 81,780.19	$ 405,075.46	$ 385,863.97			$ 526,361.07	$ 467,644.15	$ 251,392.98	$ 223,349.45	$ 5,201,067.13	$ 6,090,950.84
26	$ 124,317.74	$ 83,824.69					$ 124,317.74	$ 83,824.69	$ 57,645.48	$ 38,869.07	$ 5,258,712.62	$ 6,129,819.90
27	$ 127,425.69	$ 85,920.31					$ 127,425.69	$ 85,920.31	$ 57,365.65	$ 38,680.38	$ 5,316,078.26	$ 6,168,500.29
28	$ 130,611.33	$ 88,068.32					$ 130,611.33	$ 88,068.32	$ 57,087.17	$ 38,492.61	$ 5,373,165.44	$ 6,206,992.90
29	$ 133,876.61	$ 90,270.02					$ 133,876.61	$ 90,270.02	$ 56,810.05	$ 38,305.76	$ 5,429,975.49	$ 6,245,298.66
30	$ 137,223.53	$ 92,526.78					$ 137,223.53	$ 92,526.78	$ 56,534.28	$ 38,119.81	$ 5,486,509.77	$ 6,283,418.46
31	$ 140,654.11	$ 94,839.94					$ 140,654.11	$ 94,839.94	$ 56,259.84	$ 37,934.76	$ 5,542,769.61	$ 6,321,353.22
32	$ 144,170.47	$ 97,210.94					$ 144,170.47	$ 97,210.94	$ 55,986.73	$ 37,750.61	$ 5,598,756.34	$ 6,359,103.83
33	$ 147,774.73	$ 99,641.22					$ 147,774.73	$ 99,641.22	$ 55,714.95	$ 37,567.35	$ 5,654,471.29	$ 6,396,671.19
34	$ 151,469.10	$ 102,132.25					$ 151,469.10	$ 102,132.25	$ 55,444.49	$ 37,384.99	$ 5,709,915.78	$ 6,434,056.18
35	$ 155,255.82	$ 104,685.55					$ 155,255.82	$ 104,685.55	$ 55,175.34	$ 37,203.51	$ 5,765,091.12	$ 6,471,259.68
36	$ 159,137.22	$ 107,302.69					$ 159,137.22	$ 107,302.69	$ 54,907.50	$ 37,022.91	$ 5,819,998.62	$ 6,508,282.59
37	$ 163,115.65	$ 109,985.26					$ 163,115.65	$ 109,985.26	$ 54,640.96	$ 36,843.19	$ 5,874,639.58	$ 6,545,125.78
38	$ 167,193.54	$ 112,734.89					$ 167,193.54	$ 112,734.89	$ 54,375.71	$ 36,664.33	$ 5,929,015.29	$ 6,581,790.11
39	$ 171,373.38	$ 115,553.26					$ 171,373.38	$ 115,553.26	$ 54,111.75	$ 36,486.35	$ 5,983,127.05	$ 6,618,276.46
40	$ 175,657.71	$ 118,442.10					$ 175,657.71	$ 118,442.10	$ 53,849.07	$ 36,309.23	$ 6,036,976.12	$ 6,654,585.70
41	$ 180,049.16	$ 121,403.15					$ 180,049.16	$ 121,403.15	$ 53,587.67	$ 36,132.98	$ 6,090,563.79	$ 6,690,718.67
42	$ 184,550.39	$ 124,438.23					$ 184,550.39	$ 124,438.23	$ 53,327.54	$ 35,957.57	$ 6,143,891.33	$ 6,726,676.25
43	$ 189,164.15	$ 127,549.18					$ 189,164.15	$ 127,549.18	$ 53,068.66	$ 35,783.02	$ 6,196,959.99	$ 6,762,459.27
44	$ 193,893.25	$ 130,737.91					$ 193,893.25	$ 130,737.91	$ 52,811.05	$ 35,609.32	$ 6,249,771.04	$ 6,798,068.59
45	$ 198,740.58	$ 134,006.36					$ 198,740.58	$ 134,006.36	$ 52,554.69	$ 35,436.46	$ 6,302,325.73	$ 6,833,505.05
46	$ 203,709.10	$ 137,356.52					$ 203,709.10	$ 137,356.52	$ 52,299.57	$ 35,264.44	$ 6,354,625.29	$ 6,868,769.48
47	$ 208,801.82	$ 140,790.43					$ 208,801.82	$ 140,790.43	$ 52,045.68	$ 35,093.25	$ 6,406,670.98	$ 6,903,862.73
48	$ 214,021.87	$ 144,310.19					$ 214,021.87	$ 144,310.19	$ 51,793.04	$ 34,922.89	$ 6,458,464.01	$ 6,938,785.62
49	$ 219,372.42	$ 147,917.95					$ 219,372.42	$ 147,917.95	$ 51,541.61	$ 34,753.36	$ 6,510,005.63	$ 6,973,538.99
50	$ 224,856.73	$ 151,615.90	$ 664,569.23	$ 633,050.74	$ 5,699,547.73		$ 6,588,973.69	$ 784,666.63	$ 1,502,991.55	$ 178,988.01	$ 8,012,997.17	$ 7,152,527.00
51	$ 230,478.14	$ 155,406.29					$ 230,478.14	$ 155,406.29	$ 51,042.42	$ 34,416.77	$ 8,064,039.60	$ 7,186,943.78
52	$ 236,240.10	$ 159,291.45					$ 236,240.10	$ 159,291.45	$ 50,794.64	$ 34,249.70	$ 8,114,834.24	$ 7,221,193.48
53	$ 242,146.10	$ 163,273.74					$ 242,146.10	$ 163,273.74	$ 50,548.07	$ 34,083.44	$ 8,165,382.31	$ 7,255,276.92
54	$ 248,199.75	$ 167,355.58					$ 248,199.75	$ 167,355.58	$ 50,302.69	$ 33,917.99	$ 8,215,685.00	$ 7,289,194.90
55	$ 254,404.75	$ 171,539.47					$ 254,404.75	$ 171,539.47	$ 50,058.50	$ 33,753.34	$ 8,265,743.50	$ 7,322,948.24
56	$ 260,764.86	$ 175,827.96					$ 260,764.86	$ 175,827.96	$ 49,815.50	$ 33,589.48	$ 8,315,559.00	$ 7,356,537.72
57	$ 267,283.99	$ 180,223.66					$ 267,283.99	$ 180,223.66	$ 49,573.68	$ 33,426.43	$ 8,365,132.68	$ 7,389,964.15
58	$ 273,966.09	$ 184,729.25					$ 273,966.09	$ 184,729.25	$ 49,333.03	$ 33,264.16	$ 8,414,465.71	$ 7,423,228.32
59	$ 280,815.24	$ 189,347.48					$ 280,815.24	$ 189,347.48	$ 49,093.55	$ 33,102.69	$ 8,463,559.25	$ 7,456,331.01
60	$ 287,835.62	$ 194,081.16					$ 287,835.62	$ 194,081.16	$ 48,855.23	$ 32,942.00	$ 8,512,414.48	$ 7,489,273.00
61	$ 295,031.51	$ 198,933.19					$ 295,031.51	$ 198,933.19	$ 48,618.07	$ 32,782.08	$ 8,561,032.55	$ 7,522,055.09
62	$ 302,407.30	$ 203,906.52					$ 302,407.30	$ 203,906.52	$ 48,382.06	$ 32,622.95	$ 8,609,414.61	$ 7,554,678.03
63	$ 309,967.48	$ 209,004.19					$ 309,967.48	$ 209,004.19	$ 48,147.19	$ 32,464.58	$ 8,657,561.80	$ 7,587,142.62
64	$ 317,716.67	$ 214,229.29					$ 317,716.67	$ 214,229.29	$ 47,913.47	$ 32,306.99	$ 8,705,475.27	$ 7,619,449.60
65	$ 325,659.58	$ 219,585.02					$ 325,659.58	$ 219,585.02	$ 47,680.88	$ 32,150.16	$ 8,753,156.15	$ 7,651,599.76
66	$ 333,801.07	$ 225,074.65					$ 333,801.07	$ 225,074.65	$ 47,449.42	$ 31,994.09	$ 8,800,605.57	$ 7,683,593.85
67	$ 342,146.10	$ 230,701.52					$ 342,146.10	$ 230,701.52	$ 47,219.08	$ 31,838.78	$ 8,847,824.65	$ 7,715,432.63
68	$ 350,699.75	$ 236,469.05					$ 350,699.75	$ 236,469.05	$ 46,989.86	$ 31,684.22	$ 8,894,814.51	$ 7,747,116.85
69	$ 359,467.25	$ 242,380.78					$ 359,467.25	$ 242,380.78	$ 46,761.76	$ 31,530.41	$ 8,941,576.27	$ 7,778,647.26
70	$ 368,453.93	$ 248,440.30					$ 368,453.93	$ 248,440.30	$ 46,534.76	$ 31,377.35	$ 8,988,111.03	$ 7,810,024.62
71	$ 377,665.28	$ 254,651.31					$ 377,665.28	$ 254,651.31	$ 46,308.86	$ 31,225.04	$ 9,034,419.89	$ 7,841,249.65
72	$ 387,106.91	$ 261,017.59					$ 387,106.91	$ 261,017.59	$ 46,084.06	$ 31,073.46	$ 9,080,503.95	$ 7,872,323.11
73	$ 396,784.58	$ 267,543.03					$ 396,784.58	$ 267,543.03	$ 45,860.35	$ 30,922.62	$ 9,126,364.30	$ 7,903,245.73
74	$ 406,704.19	$ 274,231.60					$ 406,704.19	$ 274,231.60	$ 45,637.73	$ 30,772.51	$ 9,172,002.03	$ 7,934,018.24
75	$ 416,871.80	$ 281,087.39	$ 1,090,296.27	$ 1,038,586.84			$ 1,507,168.07	$ 1,319,674.23	$ 164,198.74	$ 143,772.19	$ 9,336,200.78	$ 8,077,790.42
76	$ 427,293.59	$ 288,114.58					$ 427,293.59	$ 288,114.58	$ 45,195.72	$ 30,474.47	$ 9,381,396.50	$ 8,108,264.89
77	$ 437,975.93	$ 295,317.44					$ 437,975.93	$ 295,317.44	$ 44,976.32	$ 30,326.54	$ 9,426,372.82	$ 8,138,591.43
78	$ 448,925.33	$ 302,700.38					$ 448,925.33	$ 302,700.38	$ 44,757.99	$ 30,179.32	$ 9,471,130.81	$ 8,168,770.75
79	$ 460,148.47	$ 310,267.89					$ 460,148.47	$ 310,267.89	$ 44,540.72	$ 30,032.82	$ 9,515,671.53	$ 8,198,803.57
80	$ 471,652.18	$ 318,024.59					$ 471,652.18	$ 318,024.59	$ 44,324.50	$ 29,887.03	$ 9,559,996.03	$ 8,228,690.59
81	$ 483,443.48	$ 325,975.20					$ 483,443.48	$ 325,975.20	$ 44,109.33	$ 29,741.94	$ 9,604,105.37	$ 8,258,432.54
82	$ 495,529.57	$ 334,124.58					$ 495,529.57	$ 334,124.58	$ 43,895.21	$ 29,597.57	$ 9,648,000.58	$ 8,288,030.10
83	$ 507,917.81	$ 342,477.70					$ 507,917.81	$ 342,477.70	$ 43,682.13	$ 29,453.89	$ 9,691,682.71	$ 8,317,483.99
84	$ 520,615.75	$ 351,039.64					$ 520,615.75	$ 351,039.64	$ 43,470.08	$ 29,310.91	$ 9,735,152.78	$ 8,346,794.90
85	$ 533,631.15	$ 359,815.63					$ 533,631.15	$ 359,815.63	$ 43,259.06	$ 29,168.62	$ 9,778,411.84	$ 8,375,963.52
86	$ 546,971.93	$ 368,811.02					$ 546,971.93	$ 368,811.02	$ 43,049.06	$ 29,027.03	$ 9,821,460.91	$ 8,404,990.55
87	$ 560,646.22	$ 378,031.30					$ 560,646.22	$ 378,031.30	$ 42,840.09	$ 28,886.12	$ 9,864,301.00	$ 8,433,876.67
88	$ 574,662.38	$ 387,482.08					$ 574,662.38	$ 387,482.08	$ 42,632.13	$ 28,745.90	$ 9,906,933.12	$ 8,462,622.57
89	$ 589,028.94	$ 397,169.13					$ 589,028.94	$ 397,169.13	$ 42,425.17	$ 28,606.35	$ 9,949,358.30	$ 8,491,228.92
90	$ 603,754.66	$ 407,098.36					$ 603,754.66	$ 407,098.36	$ 42,219.23	$ 28,467.49	$ 9,991,577.52	$ 8,519,696.41
91	$ 618,848.53	$ 417,275.82					$ 618,848.53	$ 417,275.82	$ 42,014.28	$ 28,329.30	$ 10,033,591.80	$ 8,548,025.70
92	$ 634,319.74	$ 427,707.71					$ 634,319.74	$ 427,707.71	$ 41,810.33	$ 28,191.77	$ 10,075,402.13	$ 8,576,217.48
93	$ 650,177.74	$ 438,400.41					$ 650,177.74	$ 438,400.41	$ 41,607.36	$ 28,054.92	$ 10,117,009.49	$ 8,604,272.40
94	$ 666,432.18	$ 449,360.42					$ 666,432.18	$ 449,360.42	$ 41,405.39	$ 27,918.73	$ 10,158,414.88	$ 8,632,191.13
95	$ 683,092.98	$ 460,594.43					$ 683,092.98	$ 460,594.43	$ 41,204.39	$ 27,783.20	$ 10,199,619.27	$ 8,659,974.33
96	$ 700,170.31	$ 472,109.29					$ 700,170.31	$ 472,109.29	$ 41,004.37	$ 27,648.33	$ 10,240,623.63	$ 8,687,622.67
97	$ 717,674.57	$ 483,912.02					$ 717,674.57	$ 483,912.02	$ 40,805.32	$ 27,514.12	$ 10,281,428.95	$ 8,715,136.79
98	$ 735,616.43	$ 496,009.82					$ 735,616.43	$ 496,009.82	$ 40,607.23	$ 27,380.56	$ 10,322,036.18	$ 8,742,517.34
99	$ 754,006.84	$ 508,410.06					$ 754,006.84	$ 508,410.06	$ 40,410.11	$ 27,247.64	$ 10,362,446.29	$ 8,769,764.98
100	$ 772,857.01	$ 521,120.32					$ 772,857.01	$ 521,120.32	$ 40,213.95	$ 27,115.37	$ 10,402,660.24	$ 8,796,880.35

Appendix F

Change Order Log

Division and Issues			Rework Changes	Normal Changes	
CONCRETE					
3	1	Quantity of Concrete and Reinforcing		$ 244,735	
3	2	Revisions to Post Tensioning		$ 22,550	
3	4	Formwork Complexity		$ 194,000	
MASONRY					
4	1	Façade change at North elevation insets		$ 24,742	
MISC METALS					
5	1	Stair structure and guardrail		$ 7,400	
5	2	Brick supports		$ 50,549	
5	3	Brick supports for garage elevation		$ 28,769	
5	4	Angle supports for openings below grade		$ 36,090	
5	5	Addition of east elevation canopy		$ 21,400	
5	6	Security at stairs		$ 6,000	
5	7	Misc. guardrails		$ 1,287	
ROOFING					
7	1	Metal coping at openings at parking deck		$ 14,168	
7	2	Add metal coping at pool deck parapet		$ 16,214	
7	3	Add overflow scuppers and downspouts		$ 83,400	
DOORS, FRAMES, HARDWARE					
8	1	Misc. door, frames and hardware adjustments		$ 13,389	
ALUMINUM STOREFRONTS, GLASS & GLAZING					
8	1	Framing for oversized storefront		$ 54,670	
8	2	Add interior glazing		$ 2,000	
8	3	Mullion changes and metal wrap of columns		$ 35,568	
8	4	Hardware Revisions at Storefront Entrance Doors		$ 47,796	
METAL STUDS AND DRYWALL					
9	1	Add decking at stairways and elevator roofs		$ 7,400	
9	2	Canopy framing and decking at pool area		$ 425	
9	3	Wood at door head and jambs for prehung wood doors		$ 45,940	
9	4	Add soffits at roof level at 8-story bldg		$ 4,140	
9	5	Reslope Roof at 8 story		$ 4,050	
9	6	Add wing walls at corridor for magnetic door holds		$ 1,790	
FIRE SUPPRESSION					
21	1	Change of FDC tie-in location from stair 2 to stair 3		$ 5,456	
21	2	Reroute 8” sprinkler main	$ 70,603		
PLUMBING					
22	1	Generator tank and fill station		$ 16,200	
22	2	Reroute of sanitary and storm piping	$ 38,240		
22	3	EWH-1 size change (50 gallon)		$ 3,300	
22	4	Trash Room floor drains		$ 2,070	
22	5	Trash Room hose bibbs		$ 1,200	
22	6	Change to 3” Diesel line		$ 3,850	
22	7	Added 4” floor drain in Generator room		$ 1,035	
22	8	Added 4" FD in bike room & pool pump room		$ 2,070	
22	9	Re-routed 4” water service		$ 18,115	
ELECTRICAL					
26	1	Fire Alarm requirements		$ 28,000	
26	2	Sprinkler line heat trace hook-ups		$ 2,000	
26	3	Add light fixtures		$ 66,850	
26	4	Change wire type		$ 45,925	
26	5	Low Voltage Budget True-up		$ 282,229	
CIVIL					
31	1	Change tap and vault type for water		$ 24,620	
31	2	Reroute sewer tie-in	$ 27,330		
31	3	Add Storm Sewer drains at east plaza		$ 6,990	
31	4	Additional asphalt paving		$ 50,013	
31	5	Additional shoring due to footprint changes		$ 45,600	
MISCELLANEOUS					
	1	Add bike racks		$ 20,940	
	2	Add guardrails at parking deck openings		$ 26,419	
		Totals	$ 136,173	$ 1,621,354	$ 1,757,527
		Markup		$ 162,135	

Appendix G

Informed Consent Form

Informed Consent Form for Social Science Research
The Pennsylvania State University

Title of Project: Determining the Effects of Facilitated Collaboration on Team Performance and Project Outcomes on Penn State Construction Projects

Principal Investigator: Dr. Robert M. Leicht
Address: 104 Engineering Unit A, The Pennsylvania State University, University Park, PA 16802
Phone: (814) 863-2080; Email: rmleicht@engr.psu.edu

1. **Purpose of the Study:** This research aims at understanding the role of individuals and interactions amongst team members in the development of collaborative team behaviors, processes, models of leadership, and ultimately successful project outcomes for the facility owner. There is a need to better understand the means for rapidly assembling collaborative and effective teams within the organizational and governance constraints of the current contracts and policies.

2. **Procedures to be followed:** You will be asked to participate in surveys related to team, and personal aspects that may contribute to team interactions, in the context of the project. In addition, you may be asked to participate in interviews to align your point of view and personal experience with the aggregated findings of the team.

3. **Benefits:** This research will be shared with the team in the context of transparency and team building, to support an open and collaborative environment for the project.

   The participants will have an opportunity to gain more knowledge related to the value of different processes and collaborative behaviors in the construction process.

4. **Risks:** This research will have minimum risk. Loss of confidentiality is likely to be the only risk. The data collection is to maintained as anonymous, even amongst the team, with only aggregate information shared back by the researcher. The team may choose to share their individual results or responses, at their own discretion, with the rest of the team.

5. **Duration/Time:** The surveys are expected to take less than 10 minutes and any interviews will likely take less than 15-20 minutes to conduct.

6. **Statement of Confidentiality:** Your participation in this research is confidential. Only the person in charge, and his/her assistants, will know your identity in the context of the aggregate data. The data will be stored and secured at Primary Investigator's office and any electronic files in a locked/password protected file. In the event of a publication or presentation resulting from the research, no personally identifiable information will be shared.

   The Pennsylvania State University's Office for Research Protections, the Institutional Review Board and the Office for Human Research Protections in the Department of Health and Human Services may review records related to this research study.

7. **Right to Ask Questions:** Please contact Dr. Robert M. Leicht at (814) 863-2080 with questions, complaints or concerns about this research. You can also call this number if you

feel this study has harmed you. If you have any questions, concerns, problems about your rights as a research participant or would like to offer input, please contact The Pennsylvania State University's Office for Research Protections (ORP) at (814) 865-1775. The ORP cannot answer questions about research procedures. All questions about research procedures can only be answered by the research team.

8. **Voluntary Participation:** Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this study will involve no penalty or loss of benefits you would receive otherwise.

You must be 18 years of age or older to consent to take part in this research study. By returning the your questionnaire or participating in any interviews with the researchers, you are providing consent to use the data provided in this study.

Robert M. Leicht, Ph.D.
Assistant Professor of Architectural Engineering
The Pennsylvania State University
104 Engineering Unit A
University Park, PA 16802
Tel: 814-863-2080
Email: rmleicht@engr.psu.edu

Appendix H

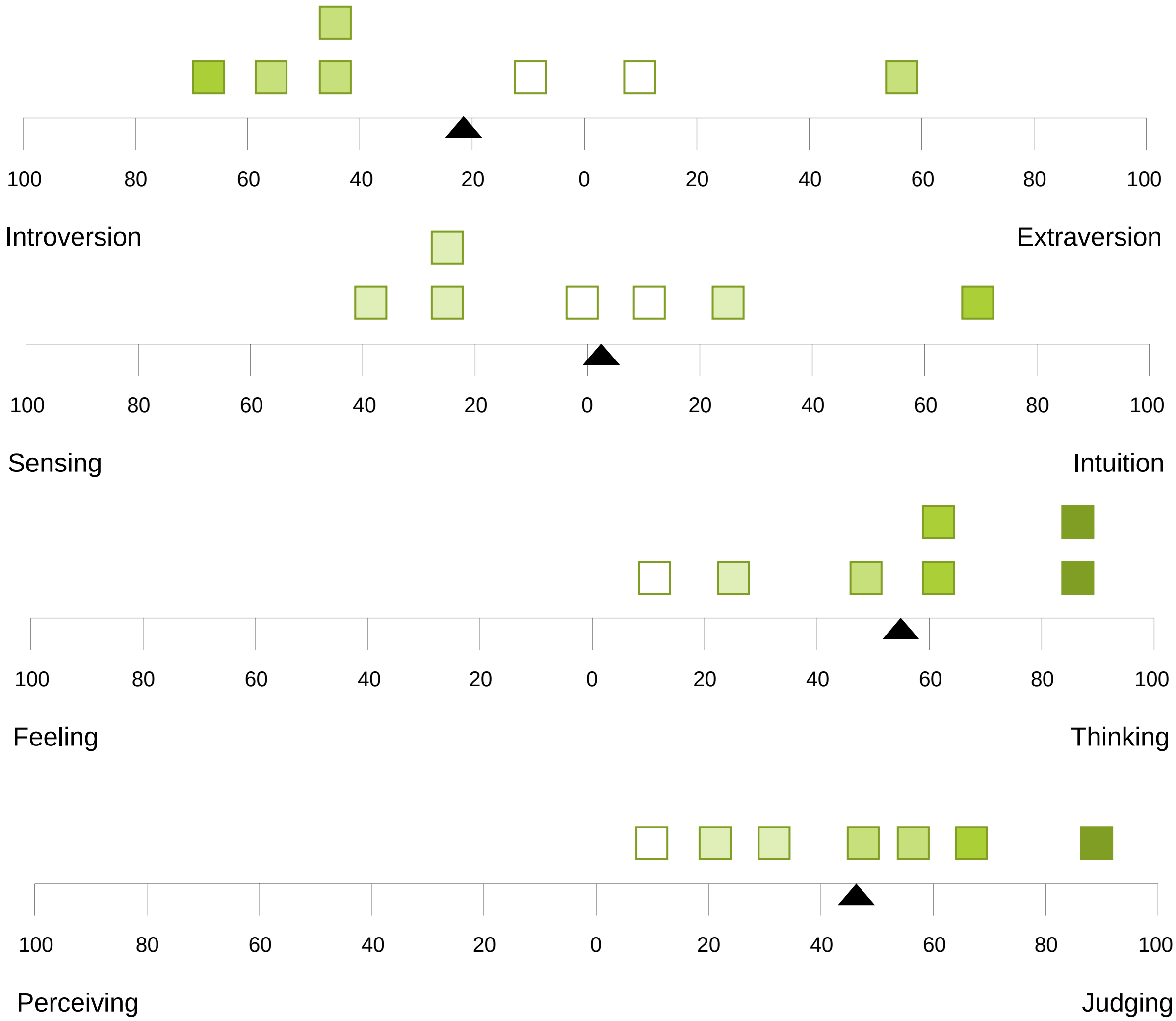
Survey Results

Plaza Results:

Title	MBTI								Type
	E	I	S	N	T	F	J	P	
PM	56	0	25	0	62	0	56	0	ESTJ
PE	0	56	25	0	88	0	33	0	ISTJ
Super	0	67	38	0	88	0	67	0	ISTJ
FOC	0	11	1	0	25	0	22	0	ISTJ
PX	0	44	0	12	62	0	89	0	INTJ
PX	0	44	0	69	12	0	11	0	INTJ
Super	12	0	0	25	48	0	48	0	ENTJ
TOTALS	9.71	31.7	12.7	15.1	55	0	46.6	0	**INTJ**
		22		2.4	55		46.6		

IPD Results:

Title	Org	MBTI								Type	Avg. Type
		E	I	S	N	T	F	J	P		
EU	ABE	11	0	0	38	12	0	67	0	ENTJ	INFJ
EU	ABE	0	56	0	44	0	38	44	0	INFJ	
PE	DPR	33	0	1	0	0	38	44	0	ESFJ	ENTJ
PX	DPR	78	0	0	62	0	12	22	0	ENFJ	
PM	DPR	11	0	0	50	88	0	44	0	ENTJ	
PR	DPR	67	0	0	75	0	12	78	0	ENFJ	
SU	DPR	56	0	0	25	0	38	78	0	ENFJ	
IC	DPR	0	22	0	38	38	0	67	0	INTJ	
PD	EYP	22	0	38	0	75	0	78	0	ESTJ	ESTJ
MD	EYP	1	0	25	0	19	0	33	0	ESTJ	
PM	EYP	1	0	0	50	0	12	0	11	ENFP	
PX	OPP	44	0	0	50	50	0	33	0	ENTJ	INTJ
PM	OPP	0	33	12	0	62	0	78	0	ISTJ	
FM	OPP	0	11	0	25	50	0	78	0	INTJ	
IC	OPP	0	11	0	38	1	0	33	0	INTJ	
TOTALS		21.6	8.87	5.07	33	26.3	10	51.8	0.73	ENTJ	
		12.7			27.9	16.3		51.1			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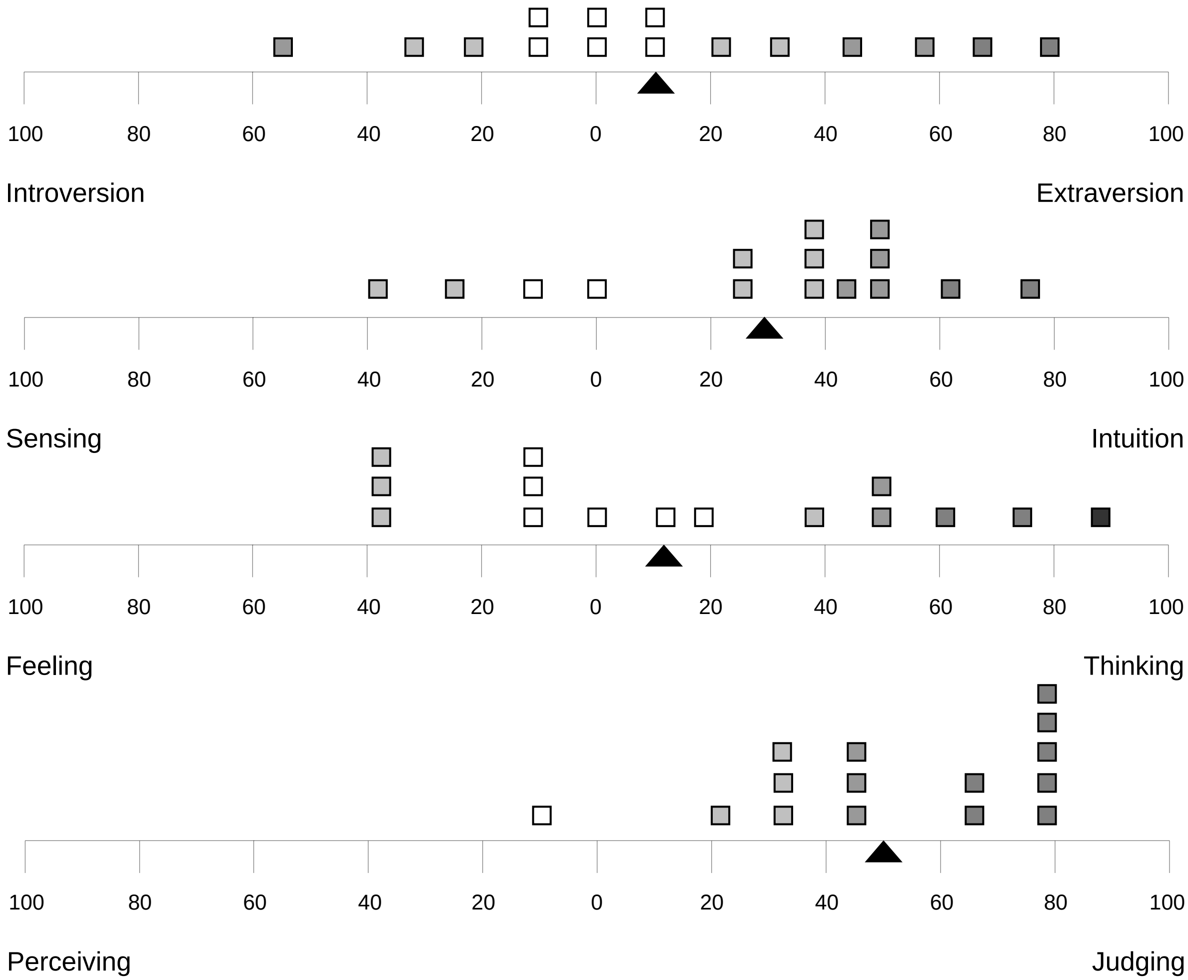
Perceiving
Judging

Plaza Scale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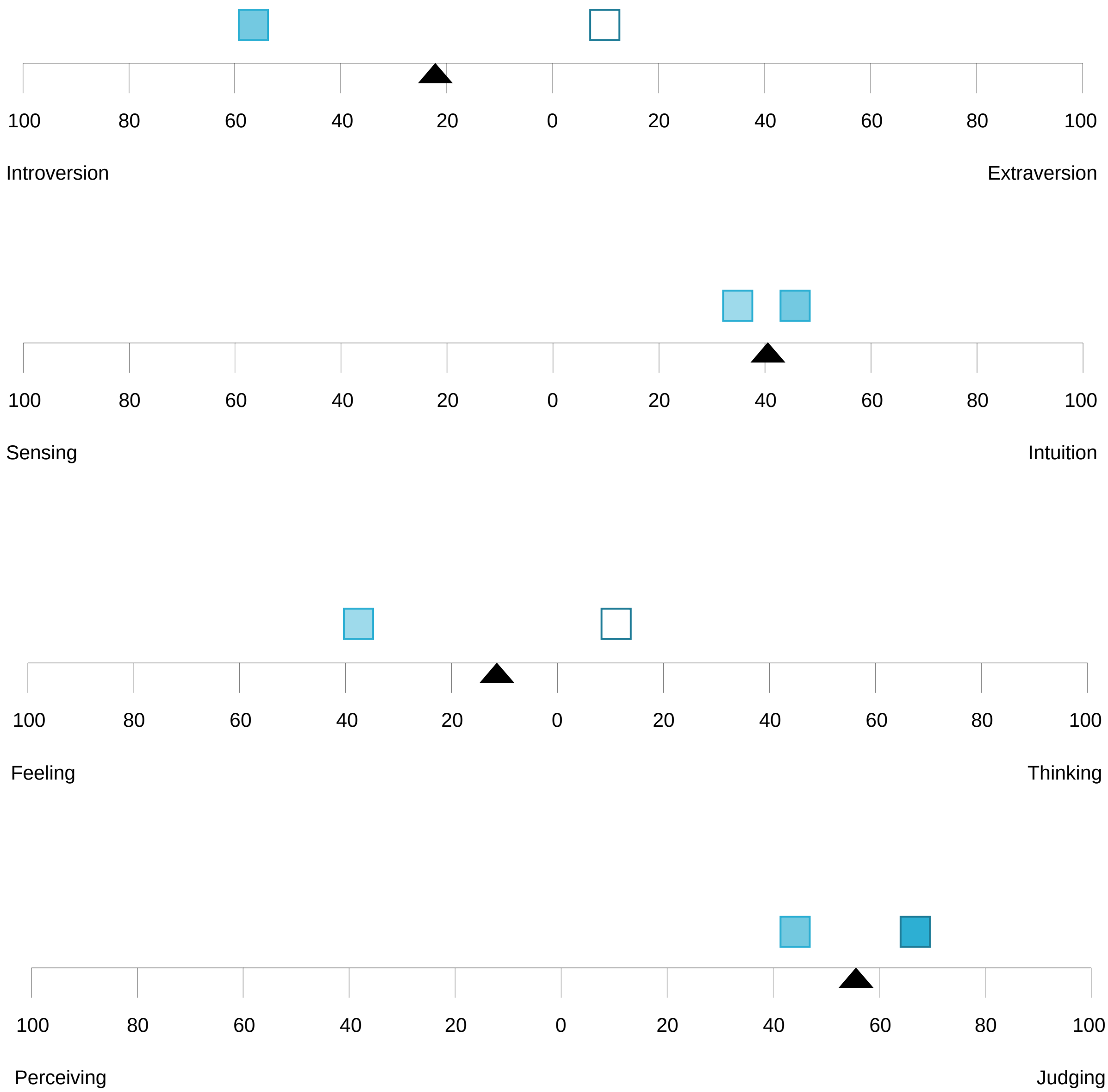
IPD Scales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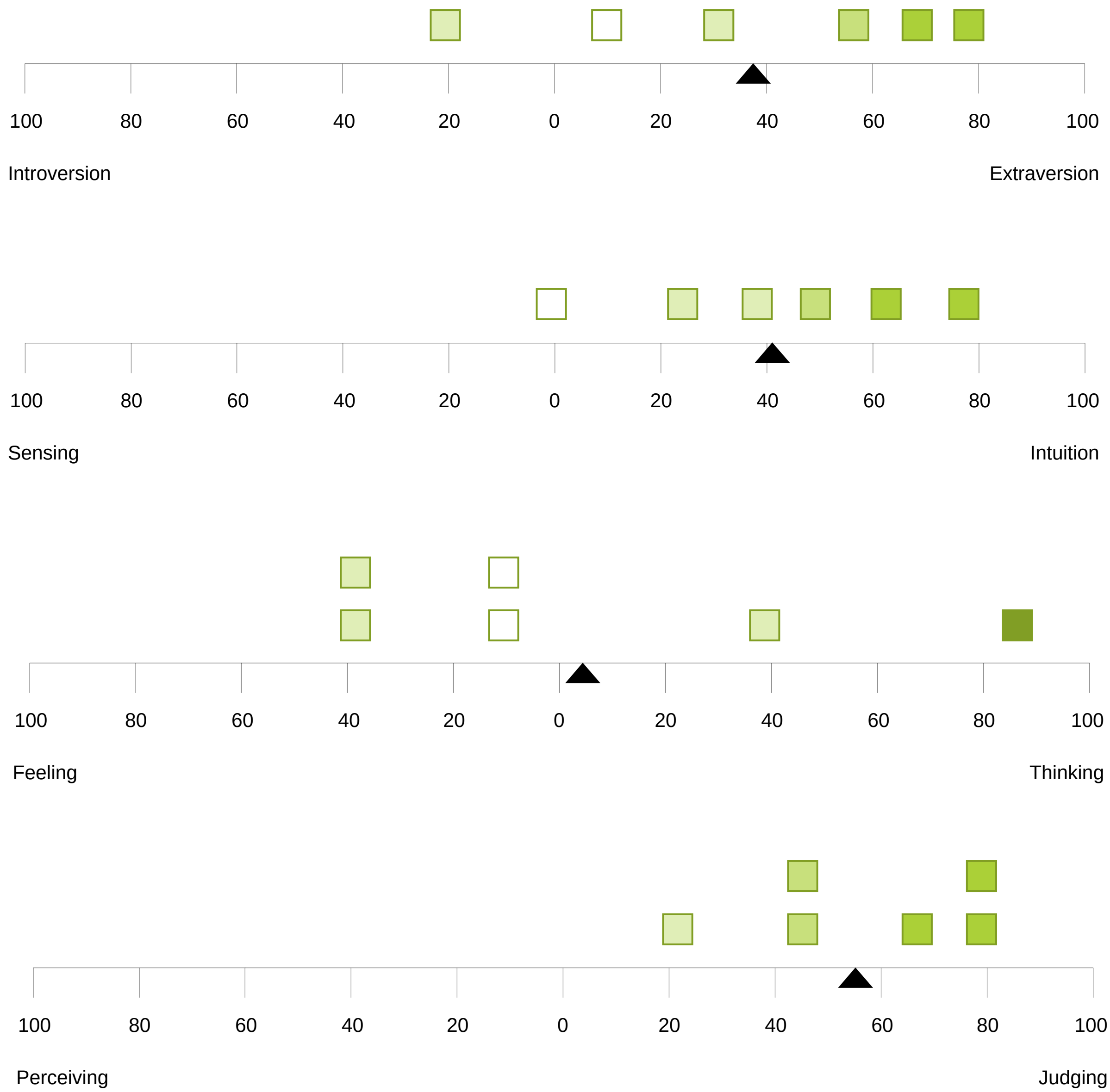
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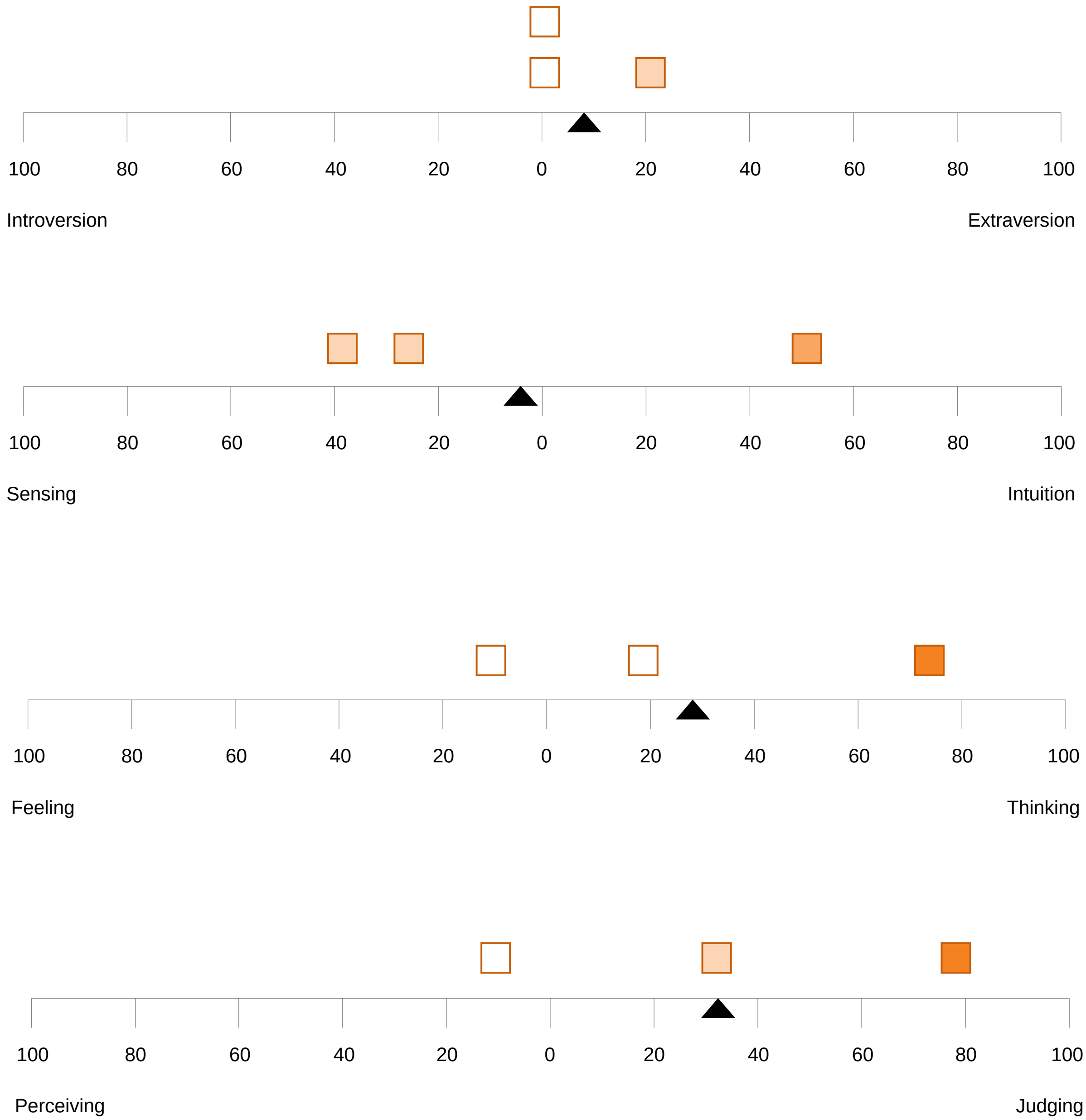
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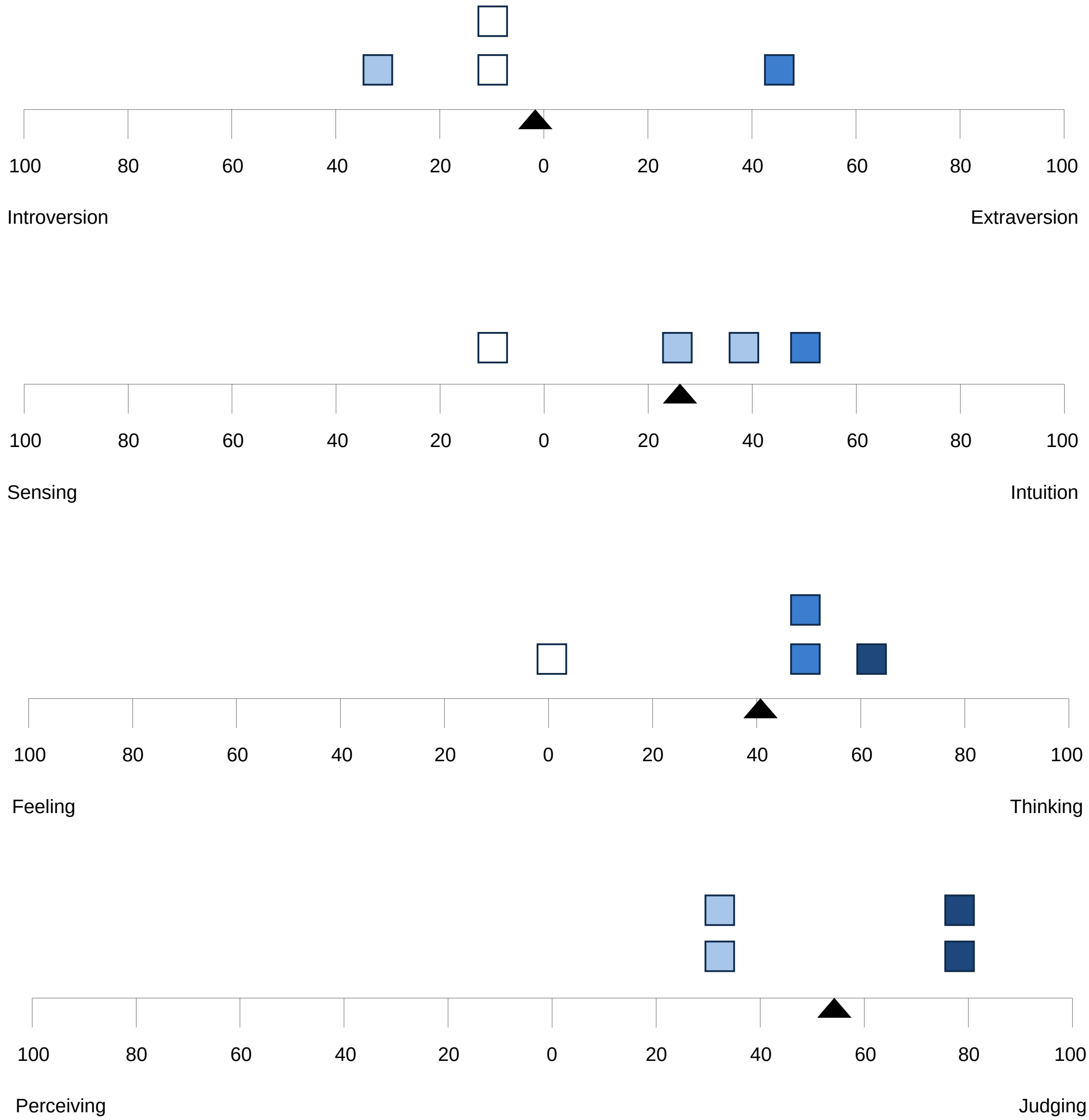
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ACADEMIC VITA

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Email: rms5477@psu.edu

EDUCATION

Bachelor and Master of Architectural Engineering May 2015
The Pennsylvania State University, Schreyer Honors College, University Park, PA

WORK EXPERIENCE

DPR Construction

Project Engineer Intern- (Los Angeles, CA) **Summer 2014**

- Managed all PE duties for a Hybrid OR renovation at Cedars-Sinai Hospital. This included creation and maintenance of a Rolling Completion List and directing subs on scope, field issues, and RFI's.

Project Engineer Intern- (Richmond, VA) **Summer 2013**

- Provided startup and operational support for a $50 million apartment project, including Last Planner tracking, RFI documentation, drawing change tracking, and production of formal OAC reports.

Penn State University- Office of Physical Plant (University Park, PA)

Contract Administration (CA) Intern **Fall 2013 – Present**

- Support CA in project startup and management, including IPD development and CM selection. Also restructured the intern hiring process. Worked approximately 10-20 hour/week each semester.

Project Management Intern **Summer 2012 - Spring 2013**

- Office and field experience organizing and inspecting contractor work as an owner representative.

SKILLS

Bluebeam | CMiC PM | Microsoft Office Suite | First Aid and CPR Certification | Microsoft Project

DISTINCTIONS

- Presidential Leadership Academy Graduate
- The President's Freshman Award
- Construction Owners Association of America (COAA) National Albert E. Phillips Scholarship
- Outstanding Performance in Construction Management, 4^{th} Year Class Award
- *Engineering Scholarships:* The Paul Morrow Endowed Scholarship, The Diefenderfer Scholarship