Kaiser Permanente Largo Medical Office Building – Largo, MD

Christopher Pozza - CM

Final Thesis Report

April 3, 2013

Advisor – Rob Leicht

Kaiser Permanente Largo Medical Office Building

Largo, MD


Image courtesy of DPR Construction.

KAISER PERMANENTE | DPR Construction Inc. | ELLERBE BECKET

Project Overview

Owner:	Kaiser Permanente
Contractor:	DPR Construction
A/E Firm:	Ellerbe Becket
Contract Type:	GMP
Delivery Method:	CM at Risk
Total Cost:	$40,000,000
Size:	106, 700 SF (Addition)
	129,000 SF (Renovation)
Height:	3 Stories (Addition)

Architecture

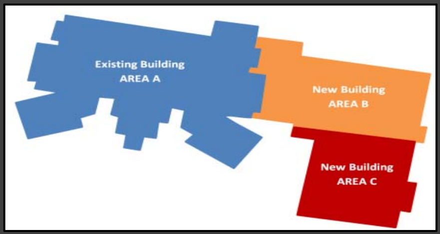
- Masonry façade to match existing structure
- Clear glass curtain wall extending west elevation
- Clerestory spanning 3rd floor (see below right)
- Accent brick ties two structures on east elevation


West Elevation Glass Curtain Wall.


Clerestory spanning 3rd floor addition.

Construction

- Work flows from Area B to Area C, see below
- Notice to Proceed: June 10, 2011
- First Patient: July 17, 2013
- Renovation – 1 year duration after First Patient



Building footprint divided into phasing areas. Area A consists of the existing building to be renovated upon completion of the addition.

Mechanical System

- Air conditioning provided by 4 packaged rooftop units
- Direct expansion rooftop AC units with supply/return
  - Equipped with variable frequency drives
- New terminal units provided with electric reheat coils to each variable air volume and constant air volume unit

Structural System

- Cast-in-place spread footings and slab on grade
- Wide flange beams, columns and girders
- Sideplate Frame Systems consisting of beam-to-column moment connections.


Sideplate moment connection.


Column-to-beam moment connection.

Electrical System

- 4,000 Amp, 480/277V 3-phase Switchboards
- 208/120 V Dry-type transformers ranging from 45 to 150 KVA are found in electric rooms throughout building
- New 60 KVA uninterruptible power supply for addition
- Two 1,250 KW Diesel emergency generators

Executive Summary

Analysis 1: Change Order Management – Change order management was chosen for research because of the extensive volume and costs associated with changes, accounting for nearly a 40% increase in the original contract value. A process map was created and durations of specific change orders were investigated to determine where issues and bottlenecks were developing in this process. A significant amount of time was spent by management dealing with changes and productivity was hindered as the volume continued to accumulate throughout construction. This research has led to three key recommendations. It is suggested to give the construction manager the authority to approve small-scale changes as that potentially has the largest impact, the owner should consider purchasing preconstruction services, and finally to transition to an alternative change review process.

Analysis 2: Implementation of Precast Panels – With schedule being the driving factor, implementing precast panels was considered as challenges arose hindering progress and delaying the project schedule. A complete analysis of the building façade was performed and showed that the mechanical system will not be affected as long as proper measures are taken to prevent thermal bridging while the structural steel will not need to be upgraded for the additional loading. Precast panels will have a much higher unit cost than using brick due to the irregularity of the façade and limited amount of repetition allowed by the current design, but the schedule savings would be the largest benefit for the project. With the watertight milestone advancing two months, major interior finishes work and construction of the elevator could begin much sooner. The estimated $125,371.56 savings make use of precast panels a logical alternative.

Analysis 3: Use of Virtual Mock-ups and Implementation to SIPS – Constructability issues at building connections led to the study of implementing virtual mock-ups. The Tyson's Corner case study revealed benefits for the owner but little use for those in the field while more changes were created requiring additional costs. This analysis focused more on ways to benefit field personnel and increase efficiency. Because of this, a Short Interval Production Schedule (SIPS) was created as a potential opportunity to save labor time and using a mock-up could help reach the level of detail needed. Use of the single mock-up analyzed can produce over $1,700 worth of possible savings. Savings are expected to be greater if the same measures were taken for other areas of the building. It is recommended to use virtual mock-ups for building interface and tie-ins, and implement the use of SIPS. Although these activities did not affect the critical path, time savings can help offset the cost of additional upfront coordination.

Analysis 4: Complete Headwall Modularization vs. Partial Modularization – The final analysis was intended to further increase productivity and decrease the overall project schedule. Modular headwalls were used; however, productivity was still an issue as in-wall rough-ins were very labor intensive. Full-size wall assembly modules would have been an ideal opportunity for increasing labor productivity and better streamlining the MEP rough-in sequence. Also, changes had such a large impact on rough-ins that resulted in significant delays. Floor-to-ceiling modules were proposed to eliminate any productivity issues. Utilizing the proposed system could have better eliminated a total of 563 man-hours, but a 0.49% increase to the original contract was estimated due to the high unit cost. If changes did not set back MEP rough-ins enough to prevent any critical path savings associated with the proposed system, reduced general conditions costs could further offset the higher unit cost. Although it appears that costs could not be justified in this case; it is recommended to incorporate more modularization in future projects because of the better opportunity to provide schedule savings and reduce the amount of labor needed, especially for systems that are the same from facility to facility.

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Industry Acknowledgements

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Mark Taylor of Nitterhouse

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Andy Rhodes & Nate Patrick of Southland Industries

Cory Trent of Modular Services

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PACE Industry Members

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Project Introduction

Kaiser Permanente's (KP) Largo project includes expansion of its existing medical office building. The 106,700 square foot addition will consist of three-stories and include everything from a pharmacy, an MRI suite, orthopedics, medical pulmonary, a staff lounge, operating rooms, surgical center and several other departments. Following the addition, a phased renovation of the existing building, which will remain occupied, will take place.

The goal of this project is to implement requirements of the KP functional program to meet the current and future patient healthcare demand as well as create a healthier experience for patients and staff. The three-story addition footprint is replacing a large amount of parking space, so a four-level parking garage was built before construction of this addition began. The project schedule provided very little room for delay from the very beginning. DPR was awarded the construction contract on December 27, 2010. Notice to proceed was issued June 10, 2011 and the first patient milestone is expected to be reached on July 8, 2013 for the addition

This thesis goes into more detail about the project issues that were revealed through research conducted during the fall semester. The analyses selected revolve around the driving schedule. Each topic investigates possible ways to accelerate the schedule and deal with constructability issues that were experienced on the project.

Industry members from multiple states attended the PACE Roundtable to discuss critical industry issues. "Improving Efficiency through Innovation" was the theme, with discussions playing a key role in the specific areas chosen to study. Each analysis can be related back to these dialogues as ways to improve efficiency for the driving schedule have been investigated.

Figure 1 - Progress photo of the addition taken in September 2012. Image courtesy of DPR.

Existing Conditions

The Kaiser Permanente Largo Medical Office Building is located in Largo, Prince George's County, Maryland. This building is less than two miles away from FedEx Field, home of the Washington Redskins. Between the football stadium and site is Interstate 495. Directly to the west of the site is Landover Road, Route 202. These major roadways allow for several means of access to the site.

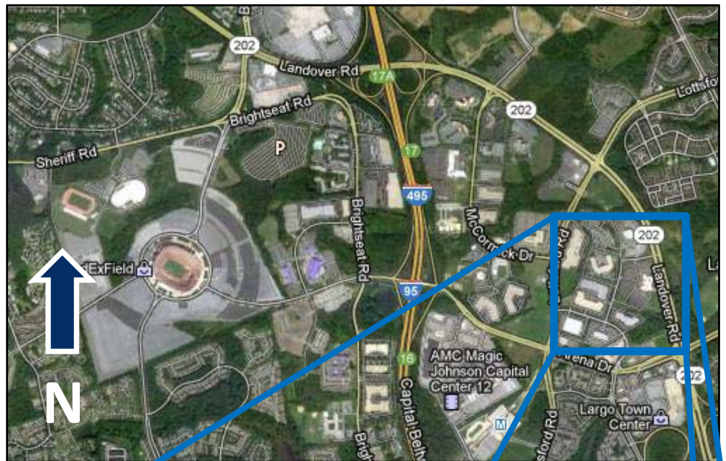


Figure 2, *right* – Zoomed out site view highlighted in blue showing major nearby access routes such as Interstate 495 and Route 202. Image taken from maps.google.com.

The site is surrounded almost entirely by roads. Technology Way is to the north, Mercantile Lane to the west, and Landover Road to the east. Directly to the south is the only area where commercial property can be accessed directly. The terrain is flat and relatively level as the majority of the space was previously a parking lot for the existing building.

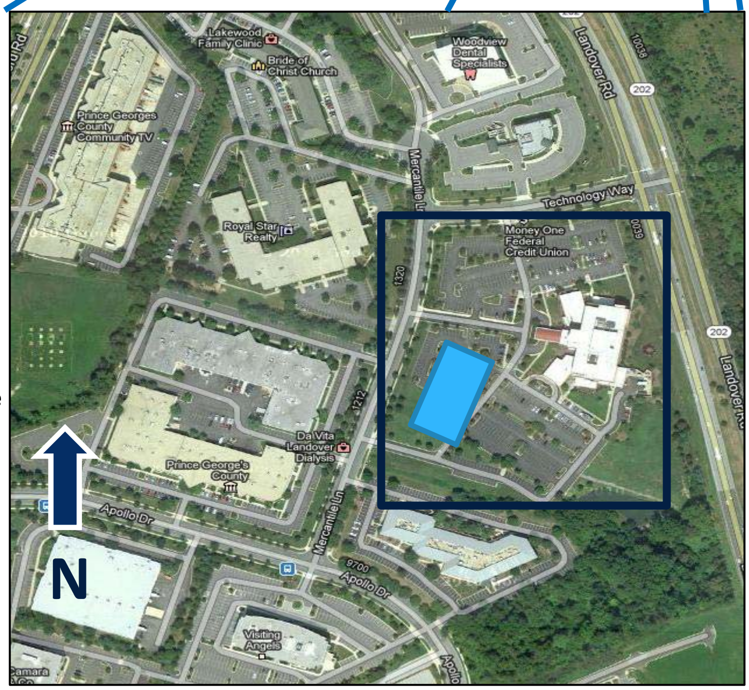


Figure 3, *right* – Zoomed in site view of the existing medical office building. The majority of the site surface is hardscape for vehicle and pedestrian traffic. Due to the outdated image, the existing parking garage was drawn in blue. Neighboring low-rise buildings can be seen a large distance away, thus construction had little to no impact on neighboring properties. Image taken from maps.google.com.

It can be seen that most buildings in this area have a large footprint and are relatively low, ranging from two to four stories. KP's medical office building is no different, with the existing building standing as one of the tallest at four stories and 51' 4". It can be seen in Figure 3 that the majority of the site is parking lot, even though the image is outdated due to the current parking garage that has been added, which is highlighted in blue.

A more detailed site plan showing the existing conditions can be seen in **Appendix A**. Underground electric below the existing parking lot to be removed is included. One unique thing is that many of the existing utilities near the new building footprint have been added during the construction of the parking garage in preparation for this project. Once excavation began for the addition, trenches and utility work had minimal impact on the overall site work.

Project Delivery System

Kaiser Permanente (KP) has chosen a CM at Risk project delivery for the construction of this 3-story addition and renovation work. Although DPR would have liked to be more involved in preconstruction activities, there is a clear overlap between design and construction, eliminating the possibility of a design-bid-build delivery. An organizational chart including contract types listed with appropriate project team members has been created, which is included on the following page.

DPR has been awarded a guaranteed maximum price (GMP) contract as the general contractor; therefore, DPR takes on risk for all subcontractors on site. Drywall and framing is the only activity that DPR self-performs. All contracts DPR holds with subcontractors are lump sum. DPR is not contractually tied to the construction manager, Jacobs, or the architect, Ellerbe Becket; which is not practicing as AECOM. Essex Construction, a minority business enterprise (MBE), has a lump sum contract agreement with DPR. Team members help with project management; including directly managing the electric/fire alarm sub. Pro-Air is the only subcontractor to hold another contract; CMC placed the ductwork.

Ellerbe Becket has a term contract with KP. This contractually ties Ellerbe Becket with KP for a fixed period of time. More information regarding this specific contract was not deemed necessary for this report. Also, Ellerbe Becket performs more than just the aesthetic design. Structural, mechanical, electrical, plumbing, and interiors are all engineered and designed within the organization. The only outside assistance is required from a civil engineering firm and landscape architect, both of which are lump sum contracts.

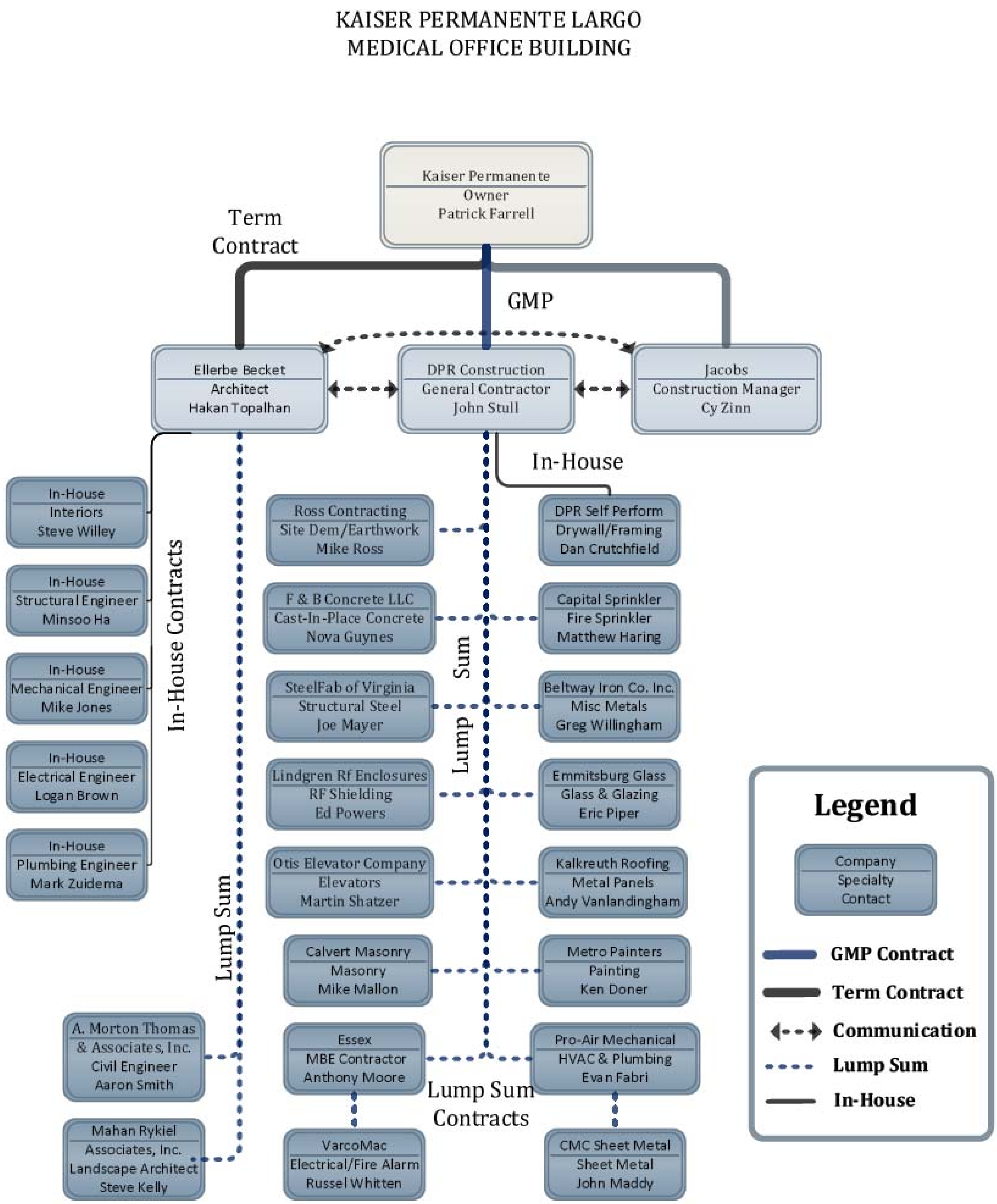
Jacobs is the Construction Manager for the project. Jacobs Project Management Company has been brought on early as a program manager consultant. Other early involvement activities performed by Jacobs include a schematic design cost estimate based on the overall project scope. Kaiser Permanente holds a GMP contract with Jacobs as well as DPR. Kaiser Permanente had three major construction projects all taking place around the same time in the Virginia/Washington DC Metro Area. This will be important to note in Analysis 1 as change was a concern on the project and is analyzed in more detail.

Client Information

Kaiser Permanente was founded in 1945 and has become one of the largest national healthcare organizations in the country with almost nine million customers. Today, the organization continues to grow, providing both for-profit and not-for-profit health plans. Kaiser has hospitals and medical office buildings providing outpatient services at many locations, including Largo's medical office building. Outpatient services include almost everything a hospital does, but without overnight stay.

The purpose of this project is to expand and improve existing facilities to meet future healthcare demands and create an environment that improves the overall experience for the people in this facility. With a growing population in the region, the demand for healthcare facilities is on the rise and this additional space has been determined critical. The real driver on this project has been schedule. First Patient is the most critical milestone, scheduled for July 8, 2013, and cannot be missed. Construction in the renovation began its initial phase on the fourth floor, which started earlier this year.

Project Delivery



Staffing Plan

A staffing chart making up DPR's project team can be seen below. DPR site trailers utilize an open concept which promotes collaboration and the overlap of responsibilities. The project executive, John Anania, was on site as required. The original field office staff consisted of the field coordinator (FOC), two superintendents, Jeff Busch and Tim Miner; and the project managers, John Stull and Michael Hudak. Blake Haldeman and Emily Price were project engineers. After BIM coordination finished, Matt Hedrick transitioned into a project engineer. The regional safety leader, Stephen Cloutier, was on site once week. Two members from Essex Construction were also in the trailer; Joe Brito, whose responsibility was for quality control and Anthony Moore who managed the electric subcontractor and assisted DPR's management staff.

Throughout construction, additional team members were brought on the project as needed. The project ended with three people dedicated to working full time on change management; Michael Hudak, Anthony Moore, and Emily Price. Also, an additional superintendent, Tony Gill, and project engineer were assigned to the team to help reduce the workload and also oversee work starting on the renovation.

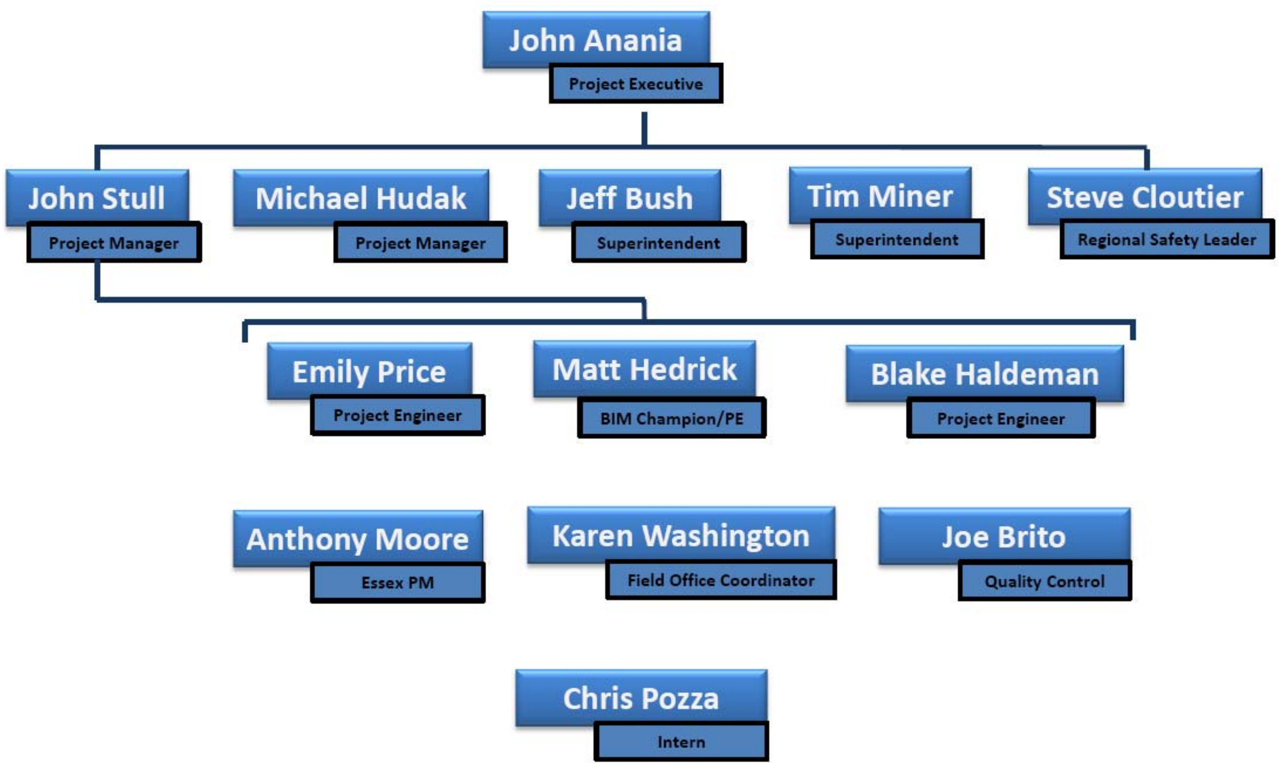


Figure 4 - Project staffing chart. Additional team members were brought on later in construction to deal with changes and to begin working on the renovation.

Project Schedule

Schedule has been the key driver on this project, and has evolved into the reoccurring theme of this thesis. Kaiser Permanente has developed a well-planned execution of expanding its current facilities in Largo, MD. Because the new addition will take up critical parking areas, a new four-story parking garage was completed before the construction of the addition could start. Upon completion of the parking garage, DPR was awarded the construction contract to be the general contractor on December 27, 2010. Kaiser Permanente issued the Notice to Proceed on June 10, 2011. A detailed project schedule can be found in **Appendix B.** DPR is responsible for construction of the addition along with the renovation of the existing medical office building. The detailed schedule does not include any renovation work as the addition is the focus of this report.

Because of the site layout, it has been determined that major work would flow best from the area closest to the existing building and proceed south to the rest of the L-shaped addition, as seen in Figure 5. Major activities are sequenced to start near the existing building in Area B and proceed to Area C. After completion of the addition, the renovation will be phased while occupied night work will take place in 10-hour shifts.

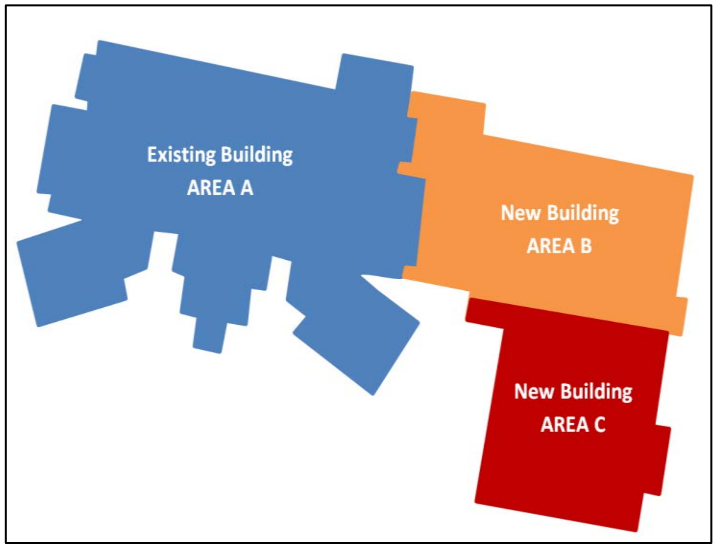


Figure 5 - Footprint of the existing building and addition, separated into different areas based off construction. These references will be used throughout the report. Image created by Chris Pozza.

Construction was initially delayed to late attainment of the owner provided building permit. Construction included a fairly traditional route with a few variations; a specific example includes interior finishes going in place before the building was watertight. As of fall 2012, Substantial Completion was set for February 11, 2013. This has since been schedule for March 1, 2013, and Final Completion March 29, 2013. There is an activation period of a few months before the first patient can receive treatment on July 8, 2013. The goal for the renovation is to be complete one year from time of the first patient of the addition.

Foundation

Spread footings and perimeter walls were used for the building's foundation. The sequence began with the framing, reinforcing, and placement of the footings followed by perimeter foundations. The sequence began in Area B, quickly moving to Area C. Footings are normal weight, 3,000 PSI concrete extending at least 2.5' below the final exterior grade, safely below the frost line. The slab on grade is 5" thick, 3,000 PSI normal weight concrete reinforced with W2.9xW2.9 welded wire fabric. Dewatering systems were unnecessary as the closest level groundwater was encountered was 12' below the surface.

Structure

The new footprint is an L shape; steel began near the existing building, referred to as Area A. The structure itself is comprised of wide flange columns, girders, and beams. Sequencing repeated the same direction as foundations; moving south to Area B and finishing steel erection with Area C. It should be noted that the steel sequence was changed near scheduled time of erection as described below.

Figure 6 – Photograph of a SidePlate system which is a moment frame that connects columns to beams and girders and can be a single- or double-sided connection. Spray-on fireproofing has already been applied to the structural steel at this point of construction. Personal photograph taken by Chris Pozza.

Originally, the steel erection plan was to place all columns on the first level, which are two-story columns, followed by the entire top level; again moving from Area B to Area C. Opportunity to enhance efficiency was discovered and quickly re-sequenced to save valuable time. Slabs and floor deck would not have been able to begin in areas where crane lifts were going to be overhead, so the sequence was changed to do entire areas of the building instead of entire floors. Slab-on-grade construction was able to start roughly one week after steel erection began.

A unique aspect of this project is the structural steel connections. A Sideplate Frame System, seen in Figure 6, has been selected. This is much more common on the west coast to deal with seismic loading.

MEP Rough-Ins

Rough-ins for systems began March 5, 2012 and were expected to be completed on October 24, 2012, but were actually finished February 5, 2013. The actual rough-in date was significantly later than originally anticipated largely due to change orders, which will be described in Analysis 1. Rough-ins started on the first floor and proceeded along the same path as the foundation, with a large overlap between floors. After the first floor began, it would take about two and a half weeks for the floor above to begin.

Each area had overhead plumbing, electric, tele/data, and mechanical rough-ins after walls were laid out; followed by in-wall rough-ins of each system. Each floor took about ten months to complete, even though upper floors were both expected to take 6.5 months to complete and the first floor only eight months. Again, the reason for the significant delays has been linked to change order impacts.

Finishes

There are a few things to point out regarding the sequencing of events during construction and how they affected finishes. The exterior enclosure was behind schedule from early on due to obtaining the owner provided building permit late and weather delays. Along with this, complicated details for the vapor barrier further hindered the façade construction about one month. These are two main reasons why the feasibility of using a precast façade was analyzed. This combination delayed the Building Watertight milestone and major elevator work, which were both critical path activities.

Project Cost

Cost of the KP Largo Medical Office Building project can be seen in Table 1, which focuses on the addition. The original guaranteed maximum price is $39,558,519. The total cost per square foot is very low for such a project, but that is due to renovation work typically being lower and only certain areas in the existing building being renovated. The addition costs roughly $305 per square foot. Throughout construction, these quantities have changed. As of early March, the revised contract amount has reached over $45,900,000, for a 16% total project cost increase. These costs will be discussed more in **Analysis 1.** The costs breakdown by building system can be seen in Table 3.

Project Cost	Size (Square Feet)	Cost ($)	Cost per Square Foot ($)
Total Project Cost	236,200	$39,558,519	$167.47
Addition	106,700	$32,504,687	$304.64

Table 1 - Total project cost and size information for the Kaiser Permanente Largo Medical Office Building.

Actual Construction Cost	Size (Square Feet)	Cost ($)	Cost per Square Foot ($)
Total Actual Const. Cost	236,200	$30,018,866	$127.09
Addition	106,700	$24,625,461	$230.79

Table 2 - Actual construction cost and size information for the Kaiser Permanente Largo Medical Office Building.

Table 2 summarizes the actual cost of construction, excluding the following:

- Contingency
- Bonds, Insurance, and Taxes
- Performance and Payment Bond
- Commercial General Liability
- Subcontractor Default Insurance
- Contractor's Fee and General Conditions Costs
- Project General Requirements Costs

Division	Building System	Total Cost ($)	Cost per Square Foot ($)	% of Building Cost
03	Concrete	$870,118	$8.15	3.5
04	Masonry	$1,131,376	$10.60	4.6
05	Metals	$2,252,965	$21.11	9.1
06	Woods and Plastics	$726,303	$6.81	2.9
07	Thermal Moisture Protection	$1,289,192	$12.08	5.2
08	Doors and Windows	$1,882,838	$17.65	7.6
09	Finishes	$4,041,341	$37.88	16.4
10	Specialties	$328,331	$3.08	1.3
11	Equipment	$133,992	$1.26	0.5
12	Furnishings	$76,450	$0.72	0.3
13	Special Construction	$74,665	$$0.70	0.3
14	Conveying System	$350,654	$3.29	1.4
21	Water Suppression	$299,670	$2.81	1.2
23	HVAC	$5,158,880	$48.35	20.9
26	Electrical	$6,008,686	$56.31	24.4

Table 3 - Major building systems and cost per square foot for the addition.

Building Systems Summary

Building systems that are of significant importance for analyses have been focused on in this report, but Table 4 lists all of the systems included on this project. Systems primarily focused on include the structural steel frame, mechanical system, masonry, and curtain wall systems. The structural steel frame has unique connections while the majority of the exterior façade covered in brick veneer and a prefabricated aluminum curtain wall.

Yes	No	Work Scope
X		Demolition
X		Structural Steel Frame
X		Cast-In-Place Concrete
X		Precast Concrete
X		Mechanical System
X		Electrical System
X		Masonry
X		Curtain Wall
	X	Support of Excavation

Table 4 - Building Systems Summary table created by Chris Pozza.

Demolition

There are a few locations where the addition connects to the existing building. These connections will involve removing large portions of existing façade to create new doorways for access between the adjacent structures. The original plans were not specific and required seeking additional information to determine the best solution for the connections. Before penetrations through the façade of the existing building could begin; fire-rated partitions needed to be put in place. The full procedure has been investigated and is included in Analysis 3.

Prior to start of construction, the existing surfaces, structures, paving, and hardscape making up what was once a parking lot, needed to be removed. Also, a vestibule connected to the existing pharmacy needed to be demolished as well as a canopy at the loading dock. Once the renovation begins, there will be large amounts of demolition in the existing building as entire departments are being redone. Zip walls will be required in areas during renovation work in order to limit the amount of dust and debris reaching neighboring areas. Being that this building was constructed in 1998, asbestos and lead aren't a concern.

Excavation

There is no major excavation that required an additional form of support as this three-story addition's first floor is a slab on grade with no basement. Minor excavation is required for the footings, foundations, and underground utilities. Utility trenches have been dug four inches deeper than the required bottom-of-pipe elevation to allow for a layer of aggregate bedding. Because the water level was well below foundations with only shallow excavations being done, no dewatering systems were necessary.

Structural Steel Frame

The main superstructure consists of wide flange beams, columns, and girders. The first floor is a 5" thick concrete slab on grade. The rest of the building's floor deck is 3" deep, 18 gage, composite metal deck with a 2.5" topping thickness. Most columns are either W10x39's or W21x111's. Typical floor beams range from W16x26 to W16x31 with girders ranging from W21x57 to W21x73.

Typical roof construction consists of 3" deep 20 gage steel roof deck. Decking has been specified based on a three span condition. Wide flange beams are used on the roof that primarily consists of W14x22, but W21x44 are required where supporting rooftop mechanical units. Roof girders mostly range from W21x44 to W21x62 with W18x40 and W18x50 spanning the perimeter. Hollow Structural Steel (HSS6x6x1/4) is used near the clerestory roof. Steel is sloped toward roof drains.

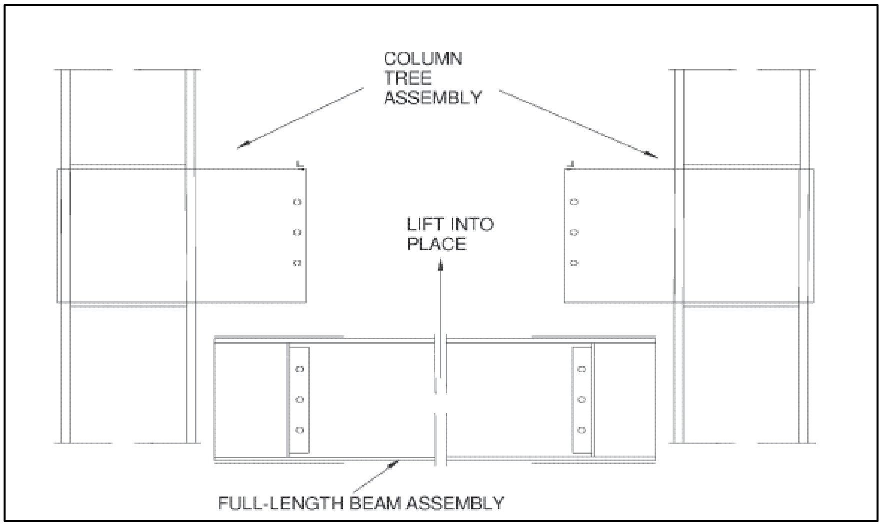


Figure 7 - Field erection method of a SidePlate Frame System. Image courtesy of Ellerbe Becket.

This structure uses a unique moment connection, a SidePlate Frame System, which is shown in Figure 7 and Figure 8, and has previously been used on west coast KP facilities. SidePlate connections were chosen over braced frames because they allow lateral framing to be located more conveniently and offer a greater cost economy. Smaller members were able to be used; allowing for more space above ceilings and quicker steel erection. The building weighs less with smaller members; therefore, smaller foundations can be utilized.

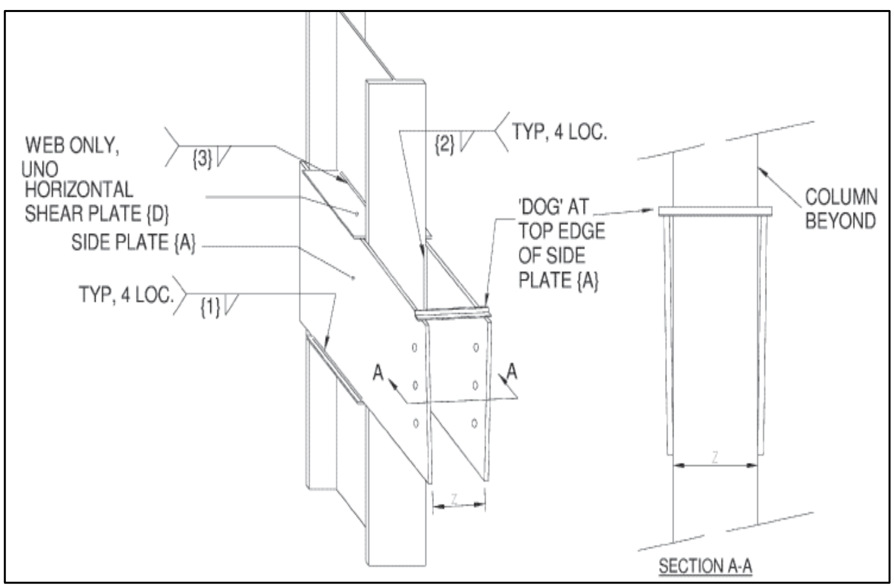


Figure 8 - 3D drawing of a Sideplate Frame System. Image courtesy of Ellerbe Becket.

Connections are prefabricated and require minor field work to bolt and weld members. The system itself is a beam-to-column moment connection. This can be a one- or two-sided connection that saves space and construction time. A shear plate is welded to the web of the column above and below the physical side plate with one on each side. The side plate itself extends beyond the column where the beam is then placed and bolted. Figure 9 is an elevation and plan view of the SidePlate Frame System.

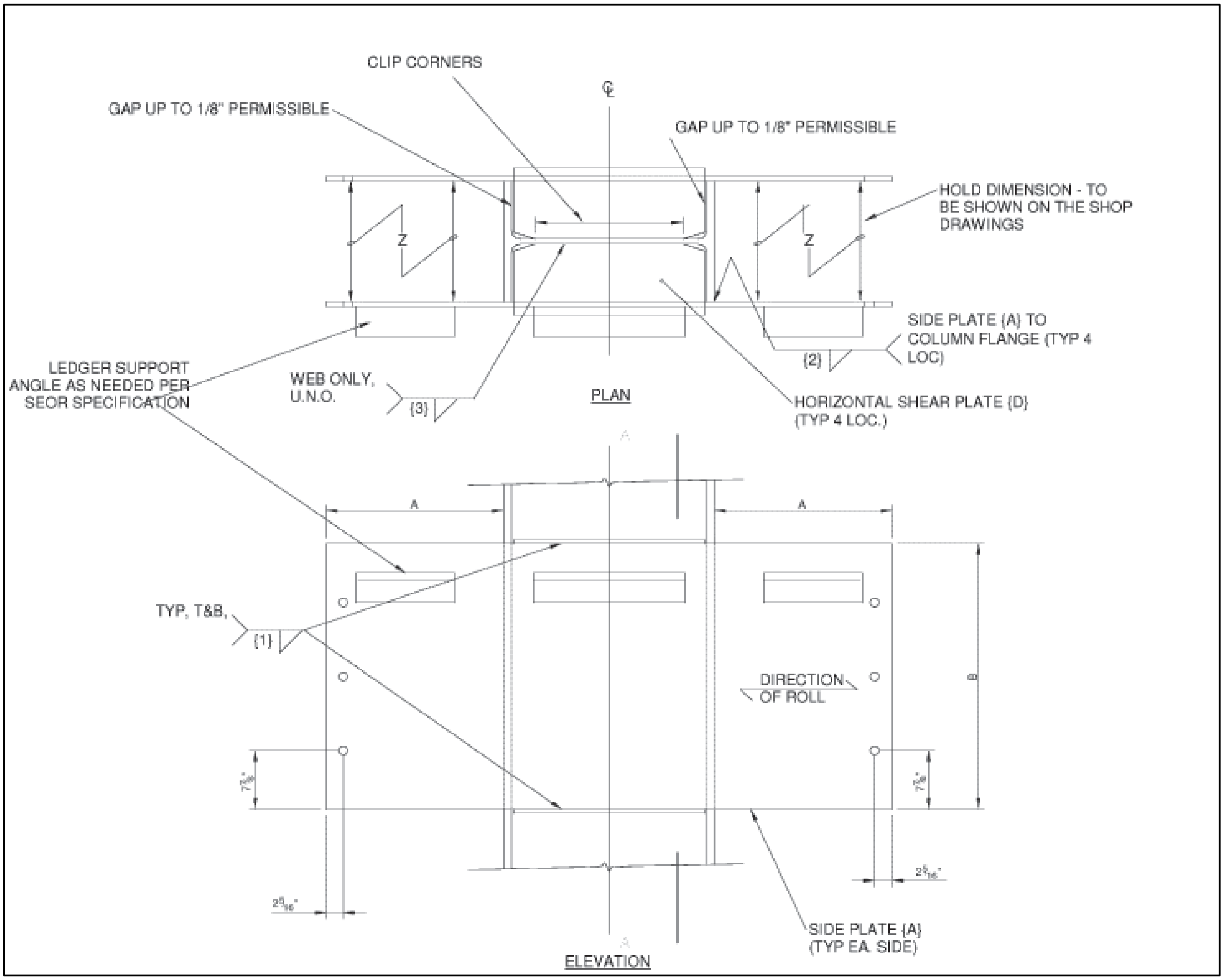


Figure 9 - Elevation and plan view of a SidePlate Frame System. Image courtesy of Ellerbe Becket.

Cast-In-Place Concrete

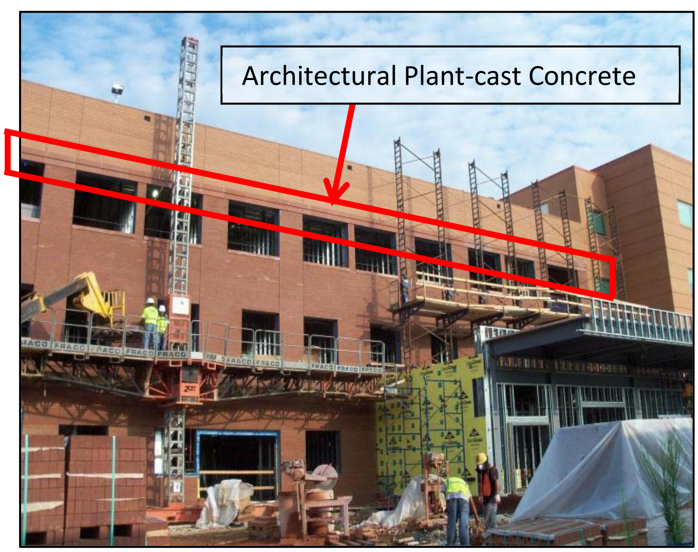
Cast-in-place concrete serves several purposes for this structure. Shallow spread footings make up the foundation. The floor systems, including the 5" thick slab on grade, are all cast-in-place that are reinforced with welded wire fabric. Housekeeping pads are also required for all mechanical, electrical and plumbing equipment. The screen wall at the west loading dock was cast-in-place concrete as well. A concrete pump truck was utilized for the majority of concrete placement. Buggies were necessary for small placements such as housekeeping pads.

Precast Concrete

The neighboring parking deck is predominantly brick-clad architectural precast. The addition uses very little precast; however, precast concrete was used as an architectural feature to make a smooth transition from the existing to new structure. This accent band can be seen under construction in Figure 10; along with the vapor barrier, insulation, and necessary steel tie-backs. The band itself is called out in red below in Figure 11. It can be seen that a color near that of the brick used blends nicely with the window sills and accent bands. An all-terrain forklift was used to lift precast to Fraco Lifts from which pieces were placed.

Figure 10 - Precast concrete can be seen above which make up the accent band along with east elevation. Personal photograph taken by Chris Pozza.

Figure 11, *Below* - Architectural precast concrete is seen under window sills and spanning the addition on the left above the third story windows. Personal Photograph taken by Chris Pozza.



Use of solid precast panels with an architectural thin brick finish has been investigated with the primary intention of saving construction schedule time. Please refer to **Analysis 2** to for more details of the findings that have been discovered. Both structural and mechanical breadths can be found in the same analysis as a complete investigation was performed to determine whether an alternate system would be practical for this project.

Mechanical System

Four rooftop air conditioning units resting on 30" high roof curbs are responsible for the building's air conditioning. Rooftop units one, two, and three (RTU-1, -2, -3) serve spaces on each floor, with output capacity ranging from 26,000 to 34,000 cubic feet per minute (CFM). The fourth (RTU-4) is dedicated to the third floor operating rooms, with a capacity of 21,600 CFM. Each supply and return fan is equipped with a variable frequency drive (VFD). Each unit includes a fan inlet airflow measuring station, two banks of filters, along with economizing dampers and controls to provide free cooling when outdoor conditions are suitable. A few other energy conservation measures have been taken for this system. Operating suites have setback controls for unoccupied periods and the mechanical system controls will optimize energy efficiency. A direct digital Energy Management System (EMS) also optimizes units' operation.

Imaging and MRI suites have smaller dedicated split air conditioning units. New terminal units with electric reheat coils also include variable air volume (VAV) and constant air volume (CAV) units, which are the primary source of heating. The majority of the building's air terminal units are CAV units. Both operate through a direct digital control (DDC) system with an adjustable temperature set point. When VAV boxes are supplying occupied spaces, a space thermostat controls the damper to maintain temperature. When heating is required, the damper will close to a minimal position, while the reheat coil valve opens in raise room temperature. The opposite takes place for cooling. For occupied spaces controlled by CAV units, air dampers are fixed at modes defined for each specific space on plans. The big difference between the VAV and CAV units is that CAV's include humidity isolation valves to control and maintain humidity levels.

A closed-loop chiller system uses non-CFC/HCFC R404a refrigerant. Each chiller has a cooling capacity of 118.8 thousand BTU per hour (MBH), 15 horsepower (HP) compressor, operating weight of 3,500 pounds, and is three-phase running on 460 volts. Chillers are located on the rooftop of Area B, as seen below in Figure 12.

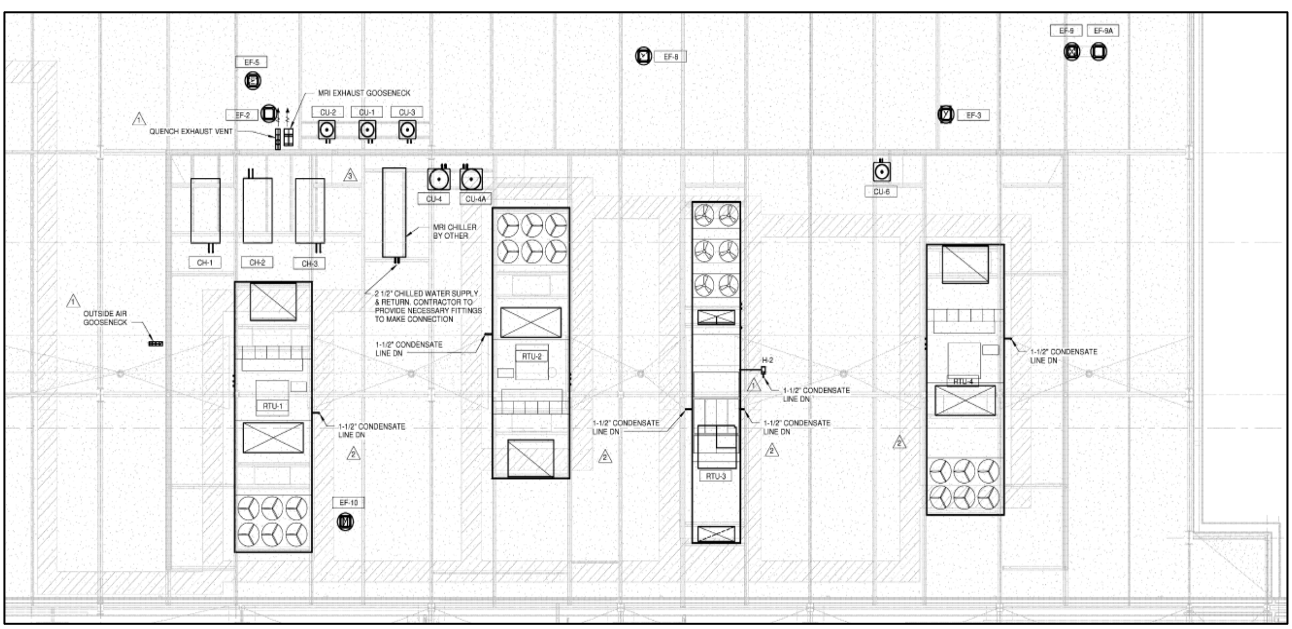


Figure 12 - Plan view of Area B's rooftop and the location of the building's major mechanical components. Rooftop units, chillers, exhaust fans, and even the cryogen vent exhaust vent. Image courtesy of Ellerbe Becket.

A unique feature is the cryogen vent which is required for the MRI equipment. This vent allows the superconducting liquid, used to keep magnets from overheating, to be dissipated from the building in the event of an unexpected shutdown, also known as a quench. The cryogen vent runs from the MRI suite through the building's partition walls until exiting the building on the roof.

Medical gas wall outlets and piping were color coded and labeled for easy identification during construction or future maintenance. From the first floor, piping rises to serve outlets in second and third floors rooms, including operating suites, pre-operation areas, and procedure rooms. Medical gas includes oxygen, nitrous oxide, carbon dioxide, and nitrogen. The entire med gas system is linked to the Building Automation System (BAS).

Masonry

Non-load bearing brick veneer over steel studs is the primary building façade. There are two colors of brick used that match the existing building's colors. Mortar color presented a challenge as it was difficult to produce a color matching that of the existing building.

Fraco Lifts were set up around the perimeter of areas placing brick. MasonKing lifts were required in areas where veneer work was done above rooftops, which are shown and described below in Figures 14 and 15. Several challenges were presented due to the masonry façade; therefore, use of precast panels was chosen as an analysis. See **Analysis 2** for more detail of challenges on the project.

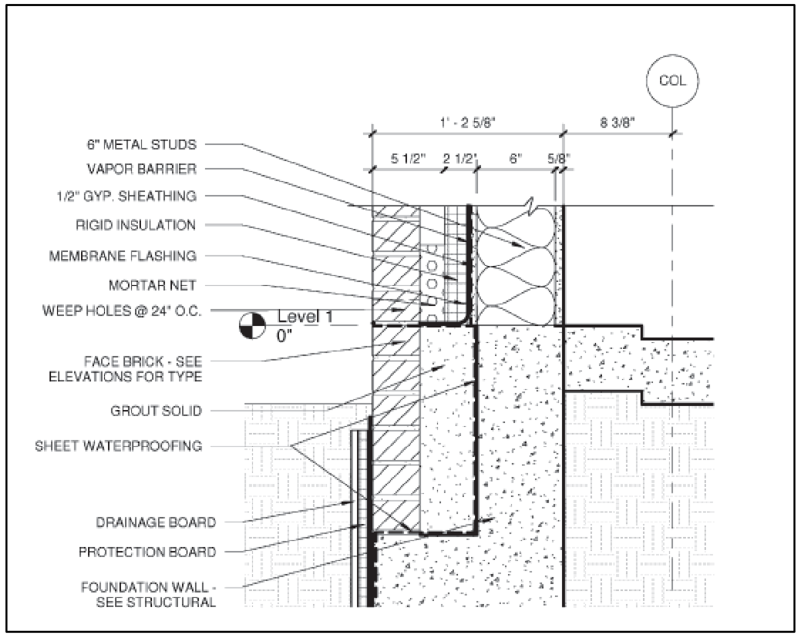


Figure 13 - Detail of exterior masonry wall at foundation. Image courtesy of Ellerbe Becket.

Figure 14 - View looking at southwest elevation. A MasonKing lift is required in areas where work is done above rooftops. These lifts have to be simultaneously cranked by hand on each side to be lowered or raised. Personal photograph taken by Chris Pozza.

Figure 15 - View looking at east elevation. Fraco Lifts are used around the exterior to provide an efficient workflow along a large percentage of elevation at a time. Materials are lifted into place with a boom lift. Personal photograph taken by Chris Pozza.

Curtain Wall

Prefabricated aluminum curtain wall systems are used mostly on the west and south elevations. This wall system consists of 2.5" wide by 8" deep exposed mullions and caps at multistory locations. At low rise locations, 2.5" wide by 6" deep exposed mullions and caps are used. There are horizontal and vertical expressed caps along with the two main types of glass; 1" clear low-E coated insulated glass and 1" spandrel glass. The system is thermally broken and designed to accommodate horizontal and vertical movement. Glass is lifted into place and sealed by two workers using a using JLG lift. Details how the curtain wall ties into the existing building are discussed in **Analysis 3.**

Figure 16 - View of west elevation curtain wall system under construction. The boom lift used during construction of the façade system can be seen at the bottom of the photo. Personal photograph taken by Chris Pozza.

An exterior view of glass curtain wall going in place is shown above in Figure 16. To the left, Figure 17, an interior view looking at the same area on the second floor is seen. This area is a corridor into the existing building (straight ahead) with waiting areas to the right, that will get plenty of natural daylight. Issues with building connection details and constructability were discovered during construction; therefore, that is a key area of focus for using virtual mock-ups and creating a short interval production schedule.

Figure 17, *left* – Interior view of west elevation curtain wall system under construction. Personal photograph taken by Chris Pozza.

Sustainability Features

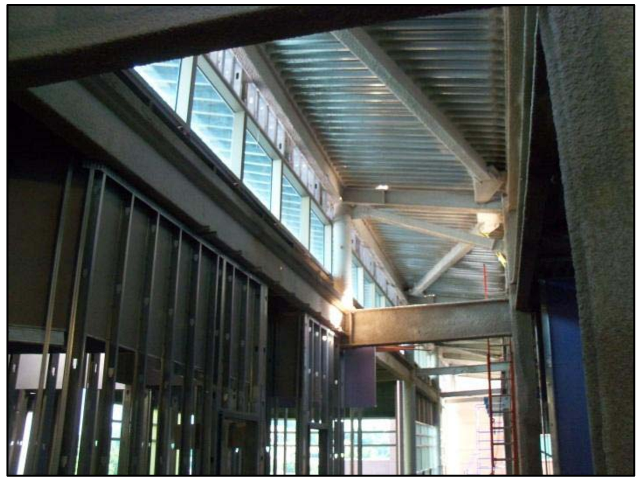


Figure 18 - Shown above is the clerestory that stretches over 200 feet long and bringing in natural light. Personal photograph taken by Chris Pozza.

Although it was not a project goal to reach LEED certification, there are many sustainable features in this medical office building. Construction is guided by the Green Guide for Health Care, although contracts are not tied to it. Throughout construction, material was separated and recycled. A major passive feature of this building is the large clerestory roof on the third floor of the addition which spans over 200 feet in length, shown in Figure 18. This brings in large amounts of natural daylight without overheating the space. The top layer of roofing consists of a thermoplastic membrane. This is a durable material that, because of its white color, helps the roof reflect light and absorb as little heat as possible, preventing the heat island effect.

A drainage pond located between the Area C and the existing south wing. The pond manages storm water runoff and helps improve the water quality of nearby sources. Another sustainable feature incorporated into the landscape design is the natural vegetation that surrounds the building. There is a lot less macadam and concrete around the perimeter of the building, allowing plenty of space for grass, shrubs, and small trees that are all native to the area. The landscaping includes new pathways guided through a variety of vegetation. The plantings have been chosen specifically for their indigenous characteristics and do not require more water than the natural environment provides; therefore, no irrigation system is required.

Local Conditions

The geotechnical analysis required further investigation for carrying out the Structural Breadth which can be found in **Analysis 2.** It is important to point out that the allowable soil bearing strength (q_a) is 5,000 pounds per square foot. This was used for determining if the proposed precast façade is going to require any foundation resizing. The geotechnical analysis and study was conducted by Hills-Carnes Engineering Associates, Inc. Their work was reported on August 27, 2010. This date was prior to even the new parking garage on site which was complete before the addition started, so the soil analysis was done on a much larger area than just the surrounding footprint of the addition. In total, 28 Standard Penetration Test soil borings were drilled throughout this area.

Findings included combinations of man-placed fill and natural soils; both of which were found in the majority of borings taken from this site. The man-made fill materials appeared to be materials placed during the construction of the existing building in 1998, but was not determined to have an effect on construction because the fill is similar to the on-site natural soils. The natural soils found were classified as silty sand (SM), clayey sand (SC), sandy silt (ML) and combinations of the three. The maximum column loads expected were calculated to be near 400 kips for the proposed addition. A 1” settlement has been assumed to be tolerable for this structure. Groundwater in the site was encountered at its highest level was well below grade, roughly 12’ below the lowest finished floor elevation.

Analysis 1 – Change Order Management

Problem Identification

Schedule has been the major driver throughout construction of the Kaiser Permanente Largo Medical Office Building. Managing change orders has proved to be a major challenge, especially as time plays such a critical role in this process. Research impacts due to change order management have been investigated in order to document their effects on the project.

Research Purpose

After interviewing team members, it has been established that the current process has negatively impacted the project in terms of cost and critical schedule time. These effects have been severe enough that a full-time crew has been established on site dedicated to performing change order work. The study of this process is also the critical industry issue.

The entire process, from the time an RFI is created until work can be billed and paid for; has been investigated. This was done to identify specific parts of the process that have affected the project. Specific owner issued change orders have been selected to study in more detail. Labor costs associated with change orders have been tracked on the project and used for research. Overtime and trade stacking will be investigated to look into impacts on productivity. For an extended period during construction, a crew intentionally wore blue vests to differentiate laborers from those performing work as originally anticipated. All information that could be gathered for analysis in search for possible proposals to assuage the effects on future projects has been investigated.

Background Investigation & Case Study

Change orders are brought about several different ways and serve several key purposes. Design changes, project scope modification, unfavorable weather, or unforeseen conditions are a few causes. For these changes, contractors are entitled to an adjusted contract price and time extension that is equivalent to any additional cost and fair for any schedule impacts due to each specific change.

Several case studies have been conducted to investigate the ways construction projects are impacted by change orders and how these impacts can be quantified. A study done by Osama Moselhi, *Change Orders Impact on Labor Productivity,* lists and describes six key change order characteristics that can affect productivity (Moselhi 2005):

1. Timing in relation to project duration – the impact of timing increases from the project's initiation to completion in a linear manner. More time is lost in later stages of construction. A ripple effect is typically caused from change orders in remaining and unchanged work
2. Intensity – this can be represented either as a number of total change orders, their frequency, and/or the ratio of change orders to contract hours
3. Type of work – different skill levels are required for different work types while some work is affected by sequencing and supplementary trades
4. Impact type – variable impacts can be linked to specific changes. Additional factors can be combined to further impact productivity; including site congestion and overtime
5. Project phase – changes brought about during the design phase differs from those during the construction phase. Changes during design phase are typically easier and less costly than those implemented during construction
6. Management On-site – experience of project team members on-site can impact the project's productivity

This list can be investigated in much more detail for the Kaiser Permanente Largo Medical Office Building; however, only a limited amount of information was available for research purposes so not all factors were explored. Response times, and time in relation to the project duration coupled with the types of work and impacts have been investigated in relation to this thesis.

Similar research was carried out by Awad S. Hanna as change order impacts on labor efficiency for both electrical and mechanical construction were investigated. Although these studies each focused on a specific part of the construction industry, the findings appear to be in line with feedback received from interviews of project team members working on the focus of this thesis. Four main problems have been revealed in correlation to change orders (Hanna and Russell 1999):

1. Trade stacking – overcrowding due to different trades being forced to work in the same area as changes require planned sequences to instead take place concurrently.
2. Schedule compression – schedule has been the key driver on this project. When work has been affected is required to be done at an accelerated rate; out-of-sequence work, stacking of trades, site congestion, and multiple-shift work are normally side-effects that follow, or what has been described as the ripple effect
3. Multiple-Shift work/Overmanning – additional workforce is required while extended or extra shifts are required to meet schedule milestones. Coordination between shifts can also become a problem
4. Morale issues – laborers and project team members can be impacted by change orders simultaneously. Work interruptions, crew adjustments, and rework are a few examples of labor-related morale issues. Stress is added for the project team, who is responsible for scheduling activities, managing finances, and monitoring quality, due to a buildup of change orders

Current Change Order Management Process

Before any project impacts caused by change orders could be determined, the entire process first had to be understood. A process map, Figure 19 on the following page, was created after conducting interviews with two project managers on site. Each step necessary to take place, from the time a change is established until the change order is approved and work can be billed against it, has been summarized.

There are three possible ways that a change order is brought about by only the owner or contractor:

1. A request for information (RFI) is issued that has cost implications
2. The owner issues architectural supplemental information
3. The owner issues a change in the form of a bulletin or construction change directive consisting of additions, or other revisions, with or without adjusting the contract sum or time.

Any RFI's or changes that are initiated by DPR are first entered into the project database CMiC and require a change proposal request (CPR). These requests are given a designated change quotation (CQ) number. DPR next creates a rough order of magnitude (ROM) estimate, documents it electronically, and submits it to Jacobs; the construction manager. At this time, DPR determines if the work is schedule critical. If not, the cost of work is finalized and submitted to Jacobs again for evaluation. If work is critical, DPR proceeds with the work without a formal Change Directive (CD) and takes on the risk, but only up to a certain point. Notice is given to Jacobs along with the change quote and intent to be paid for the work. If this work is too large, typically anything above $10,000, DPR will not proceed without a formal CD.

Once the cost information is approved by Jacobs, the information is submitted to Kaiser Permanente. It is important to note that although the change order is reviewed by the construction manager, Jacobs does not have authority to approve a change order regardless of the associated size, impact, or cost of work. If the total amount for the work submitted costs over $250,000, the decision to proceed with the work rests on Kaiser Permanente's management at headquarters in California and is reviewed internally before being processed. When the amount is under that total, the KP job-specific representative can approve and signoff for work to proceed. Regardless of the cost of the change, upon approval, DPR is notified and can issue the change order to the subcontractor. Two things need to take place before DPR can bill for work involved in a change order. First, the change order needs to be approved and received from KP. Second, the work needs to be verified by Jacobs the work is complete and put in place accurately. Finally, the work for which the change order has been issued can be billed against (Stull).

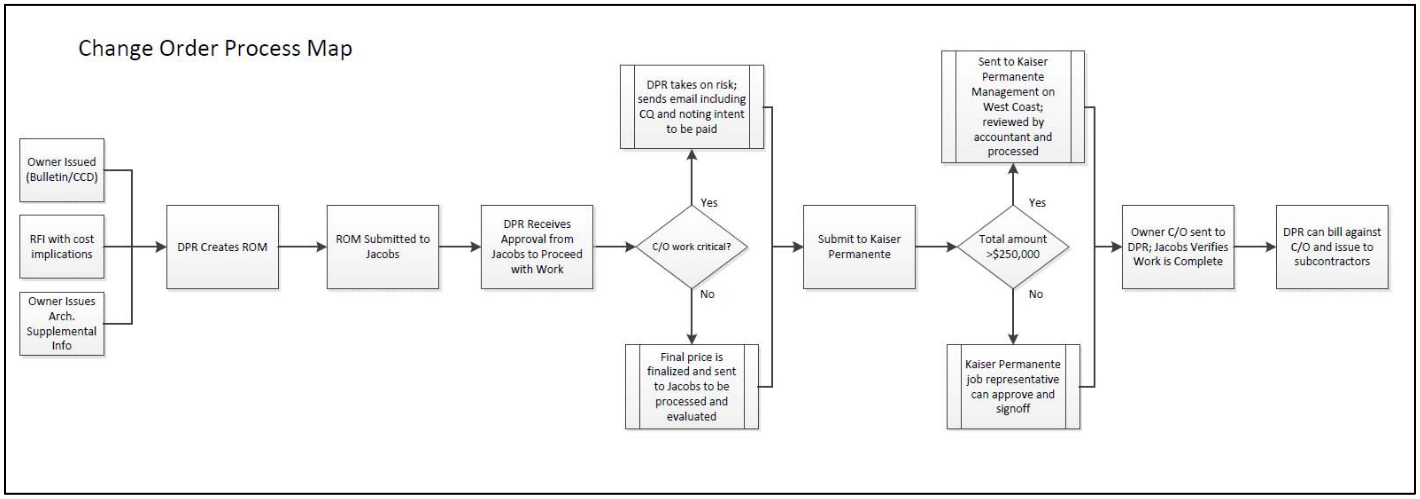


Figure 19 - Change order process summary. See Appendix C for enlarged detail. Process map created by Chris Pozza.

As previously mentioned, all changes under $250,000 must be approved by KP's Mid-Atlantic representative. With the responsibility of this project, along with all changes on other projects occurring simultaneously in the region, receiving approval can take longer than what is ideal for construction. Although KP's internal review process will not be discussed in more detail, this process can be equally, if not more, time consuming. Due to the fact that no change order could be approved by Jacobs, the amount of work needing approval has built up on occasion for this specific project.

Table 5 on the next page shows four specific owner approved change orders. The four were chosen for a few specific reasons. They each have a different amount of change items included with each one. Whenever a change is established, a change quotation (CQ) is created. There is a wide variety of durations from when the CQ's were initiated until each respective ROM estimate was submitted and also from the time each final pricing was submitted until receiving KP's approval in a combined change order. Prices of each change order varied, as one was a relatively smaller dollar value, two were about average, and one was significantly higher than the other examples.

Owner Change Order 10										
CQ Included	Date Initiated	Date ROM Submitted	Calendar Days from Initiation until ROM Submitted	Date Final Pricing Submitted	Calendar Days from ROM Submitted until Final Pricing Submission	Total Price	Date Closed	Calendar Days from Final Pricing Submission until KP Approval	Total Weeks	Total Months
1.1	7/28/2011	3/12/2012	163	3/12/2012	1	9,520.28	6/28/2012	79	11.3	2.6
42	2/13/2012	5/2/2012	58	5/2/2012	1	-42,077.08	6/28/2012	42	6.0	1.4
58	11/2/2011	1/16/2012	54	1/16/2012	1	30,630.51	6/28/2012	119	17.0	3.9
133	3/21/2012	4/25/2012	26	5/10/2012	12	1,711.10	6/28/2012	36	5.1	1.2
155	4/30/2012	5/2/2012	3	5/2/2012	1	2,050.78	6/28/2012	42	6.0	1.4
		Average	61	Average	3		Average	63.6	9.1	2.1
					Total Cost	$1,835.59				

Owner Change Order 24										
CQ Included	Date Initiated	Date ROM Submitted	Calendar Days from Initiation until ROM Submitted	Date Final Pricing Submitted	Calendar Days from ROM Submitted until Final Pricing Submission	Total Price	Date Closed	Calendar Days from Final Pricing Submission until KP Approval	Total Weeks	Total Months
099Rev	10/9/2012	10/17/2012	7	10/17/2012	1	7,498.99	2/5/2013	80	11.4	2.6
127	3/8/2012	11/6/2012	174	11/7/2012	2	4,654.44	2/5/2013	65	9.3	2.1
157	5/1/2012	10/12/2012	119	10/12/2012	1	5,863.40	2/5/2013	83	11.9	2.7
182	6/11/2012	6/11/2012	1	11/5/2012	106	36,182.22	2/5/2013	67	9.6	2.2
188	6/15/2012	11/2/2012	101	11/2/2012	1	4,232.14	2/5/2013	68	9.7	2.2
196	7/9/2012	10/15/2012	71	10/15/2012	1	14,529.92	2/5/2013	82	11.7	2.7
203	7/25/2012	11/2/2012	73	11/2/2012	1	2,229.03	2/5/2013	68	9.7	2.2
240	8/22/2012	9/20/2012	22	9/20/2012	1	3,922.45	2/5/2013	99	14.1	3.3
261	9/19/2012	10/11/2012	17	11/20/2012	29	9,466.81	2/5/2013	56	8.0	1.8
276	10/12/2012	11/14/2012	24	11/14/2012	1	2,578.74	2/5/2013	60	8.6	2.0
298	11/13/2012	11/20/2012	6	11/20/2012	1	12,668.06	2/5/2013	56	8.0	1.8
		Average	56	Average	13		Average	71.3	10.2	2.4
					Total Cost	$103,826.20				

Owner Change Order 21										
CQ Included	Date Initiated	Date ROM Submitted	Calendar Days from Initiation until ROM Submitted	Date Final Pricing Submitted	Calendar Days from ROM Submitted until Final Pricing Submission	Total Price	Date Closed	Calendar Days from Final Pricing Submission until KP Approval	Total Weeks	Total Months
105	2/29/2012	4/24/2012	40	5/16/2012	17	108,713.45	1/29/2013	185	26.4	6.1
236	8/22/2012	11/5/2012	54	11/5/2012	1	7,407.97	1/29/2013	62	8.9	2.0
247	8/31/2012	10/17/2012	34	10/17/2012	1	553.23	1/29/2013	75	10.7	2.5
248	8/31/2012	10/17/2012	34	10/17/2012	1	553.23	1/29/2013	75	10.7	2.5
251	9/10/2012	10/17/2012	28	10/17/2012	1	1,758.05	1/29/2013	75	10.7	2.5
		Average	38	Average	4		Average	94.4	13.5	3.1
					Total Cost	$118,985.93				

Owner Change Order 012										
CQ Included	Date Initiated	Date ROM Submitted	Calendar Days from Initiation until ROM Submitted	Date Final Pricing Submitted	Calendar Days from ROM Submitted until Final Pricing Submission	Total Price	Date Closed	Calendar Days from Final Pricing Submission until KP Approval	Total Weeks	Total Months
2.1	5/6/2011	3/12/2012	222	3/12/2012	1	43,523.06	8/6/2012	106	15.1	3.5
17	6/12/2012	6/22/2012	9	6/22/2012	1	199,054.24	8/6/2012	32	4.6	1.1
103	2/1/2012	3/12/2012	29	3/12/2012	1	807.48	8/6/2012	106	15.1	3.5
115	2/27/2012	3/12/2012	11	3/12/2012	1	2,317.61	8/6/2012	106	15.1	3.5
156	4/30/2012	6/11/2012	31	6/11/2012	1	6,387.01	8/6/2012	41	5.9	1.4
170	5/15/2012	5/21/2012	5	5/21/2012	1	5,253.11	8/6/2012	56	8.0	1.8
		Average	51	Average	1		Average	74.5	10.6	2.5
					Total Cost	$257,342.51				

Table 5 - Four specific change orders have been selected for investigation. The total number of changes associated with owner issued change orders varies, but each change quotation (CQ) provided for work has been included with each change order. The date each change is initiated has been included along with its respective ROM, Final Pricing, and Approval Date. Calendar days have been included for each exchange to best try to pinpoint potential problems described in the process map, Figure 19.

First the dates were compared in each table and category. It was determined that most issues taking extremely long to create and submit a ROM were due to one of three options:

1. A solution for a problem could not be determined in a timely manner
2. Formatting and/or pricing errors were found in subcontractor ROM's
3. Work was not deemed critical so providing a response was not urgent

Jacobs was timely in approving DPR's ROM estimates in the examples chosen, which allows the opportunity for DPR to receive a directive to proceed faster. This was not always the case as a few construction change directives (CCD's) were not received in a timely manner for various reasons such as design decisions, pricing issues, and other reasons. It was noted that CCD 14, 15, 17, and 19 caused issues with delays; however, the exact scope and involved with each could not be determined for further investigation to the same level of detail as official owner change orders that have been analyzed.

One thing that seemed to remain consistent for each change order was the total time from the final pricing submission until receiving an approved change order. It was originally expected that the costs associated with each would roughly determine which change orders would have longer responses, but that was not the case. Although the smallest change order used in the example was the shortest in duration, the amount of time is very close compared to the other examples' durations, while the price of the CO is less than $1/10^{th}$ of the next smallest example. Another interesting fact is the largest example CO did not take the longest, although the price is more than double the cost involved with the next highest change order value. No conclusive evidence could be determined as to why responses for certain CQ's and CO's took longer than others.

Data Collection

Interviews conducted revealed some interesting project facts. Specifically relating to subcontractor payments described in the previous paragraph, in some cases subcontractors have financed their own work in excess of tens of thousands of dollars or more, with payment for that work still not having been received for up to six months after it was been put in place. Such a large amount of money can quickly put subcontractors in a financial bind, which could only further hurt the project.

Other facts that have been revealed include for the project with the original contract for the addition worth $32,504,687 (Hudak):

- 33%+ rate of change
- Nearly $13,000,000 in change-related cost (See Table 6)
- 1000+ RFI's have been issued since the start of project
- 370+ change quotations, also referred to as change proposal requests
- Three DPR employees are dedicated to working full-time on changes

DPR began tracking where each CCD and change order was in the process described in Figure 19. This was helpful for team members to not only manage them, but tracking also helped prioritize work, determine critical work, and to find bottlenecks in the process. Information has been organized such as the format of Table 6. Each dollar amount and quantity of CQ's can be summarized quickly to keep the project team informed and continuously updated, which has proved to be very effective.

Change Order Tracking Table			
Description	**Sum of Amount**	**Total Count No.**	**Average**
Approved	$6,249,917.07	148	$42,229.17
Pending Do Not Proceed	$498,568.82	8	$62,321.10
Pending Proceeding	$176,653.59	24	$7,360.57
Pending Proceeding with Authorization	$1,616,746.32	49	$32,994.82
ROM Do Not Forecast - Non-Proceeding	$593,500.00	5	$118,700.00
ROM Proceeding	$224,522.85	30	$7,484.10
ROM Proceeding with Authorization	$2,664,823.18	58	$45,945.23
ROM Do Not Proceed	$671,558.91	22	$30,525.41
In Dispute - Proceeding	$286,834.72	28	$10,244.10
Total	**$12,983,125.46**	**372**	

Table 6 - Summary of change order work as of February 2013. Information provided by DPR Construction.

Investigation of change orders has revealed intriguing facts about the project. The information included in Table 6 has been tracked throughout the project. Information regarding change orders and impacts has been researched for the previous nine months, with the earliest data dating back to July 2012. Changes that have been submitted and are pending in review have been documented in Figure 20. The different colors specify the duration that the change order has been in review. The bottom values, dark blue, represent the most recent change orders that were submitted less than 30 days ago from the time the update was created. The lighter blue represents changes that have been in review between 31 and 60 days, while the red are open changes submitted over 61 days prior to the update.

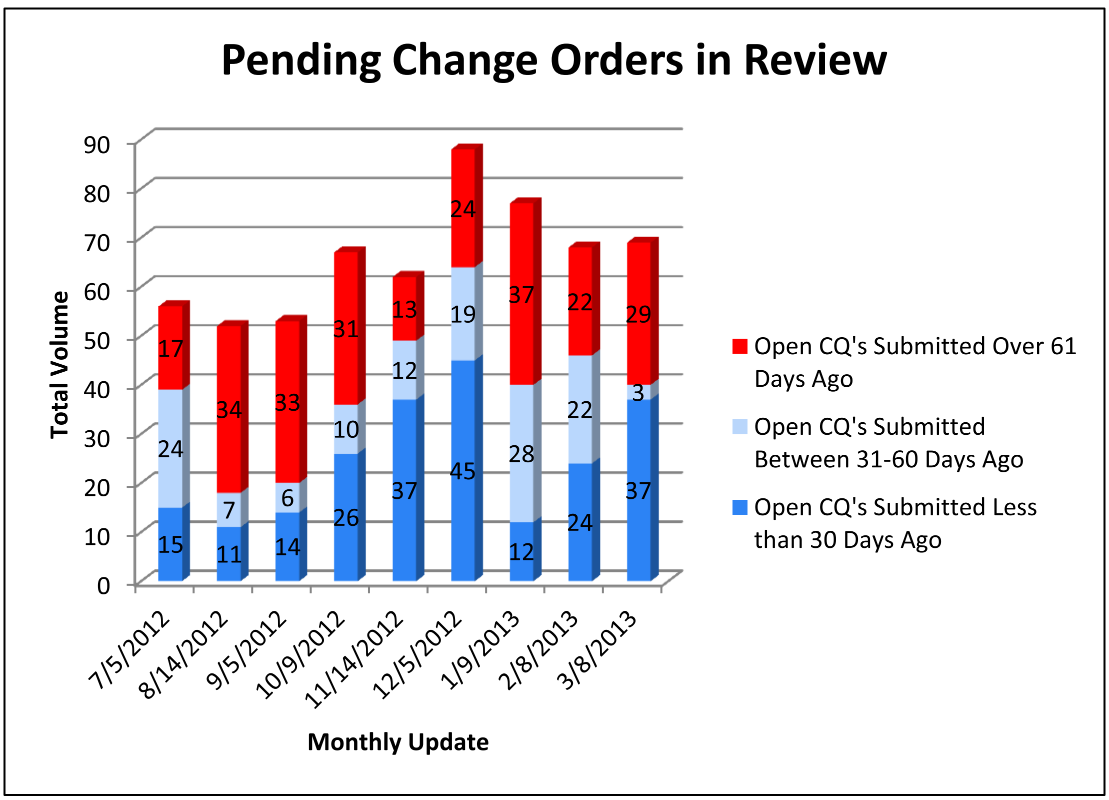


Figure 20 - Documentation of change orders over a nine month duration, from July 2012 through March 2013. Changes that have been documented are those that are pending in review. This graph is intended to break down the total volume of changes by their age. Information provided by DPR, graph created by Chris Pozza.

Each of the factors specified in the case study performed by Moselhi have each been investigated and discussed with the project team as follows. The case studies focus on characteristics of change orders and impacts on labor productivity, but productivity is not the only thing that has been investigated or impacted on this specific project.

Timing

As mentioned in the Background Investigation section, the timing of changes is significant. The impact of timing increases from the project's initiation to completion in a linear manner. Substantial completion has been set at the end of March, only a few weeks after the most recent data that has been gathered. It is evident in Figure 20 that there was a steady increase of change orders that are less than 30 days old from August through December; the total amount quadrupling from 11 to 45 with only three months until substantial completion.

Intensity

Figure 20 describes the age of change orders that are pending in review, but Figure 21 more clearly defines the sheer volume of changes as they amassed throughout construction. The total volume of changes has required DPR to bring on additional staffing to keep construction moving as smooth as possible. The volume and intensity has led to rework, and out of sequence work that continuously interrupted momentum and forced trade stacking. It should be noted that it was discovered after acquiring this information that the total volume decreased from December to January only because the information provided as of January did not include changes impacting the renovation.

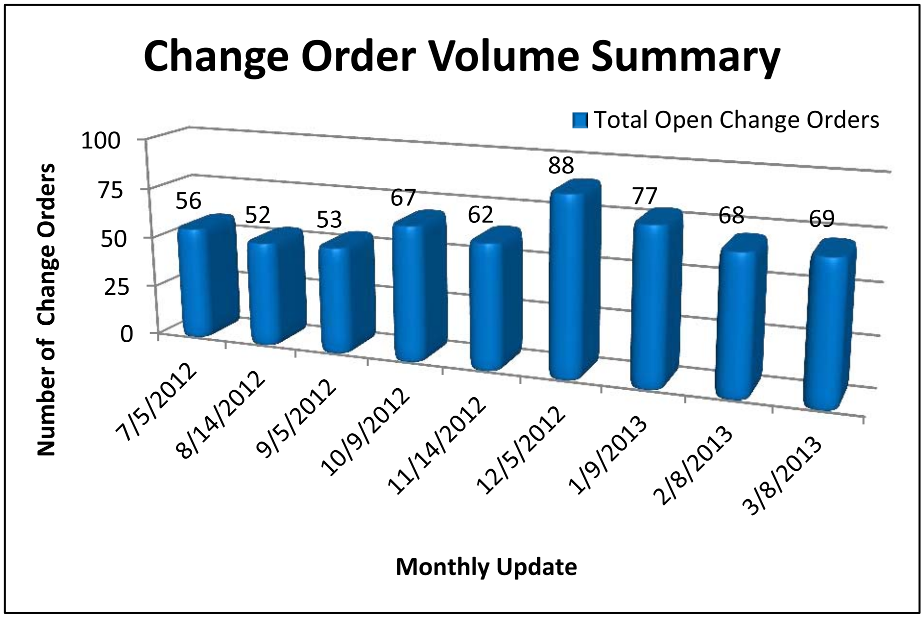


Figure 21 - Total volume of change orders can be seen over a nine-month period. The number of changes open and pending is still very extensive considering substantial completion is set for the end of March.

Type of Work and Impact

Although data regarding the skill and trades affected by changes could not be gathered for investigation in great detail, all trades have been impacted in some way while it has been necessary to re-sequence work. The impact has been severe enough that laborers wore blue vests to specify they were working on work affected by change orders. A larger workforce was often times required for it to be possible to complete all of the necessary scope changes in a timely fashion. Regular crew sizes were on site to perform scheduled work and laborers wearing blue vests increased the total amount of laborers on site and caused congestion at times. The laborers performing change order work often worked premium time, further increasing the total cost of labor. More information regarding labor tracking of change order work can be seen in Figure 22.

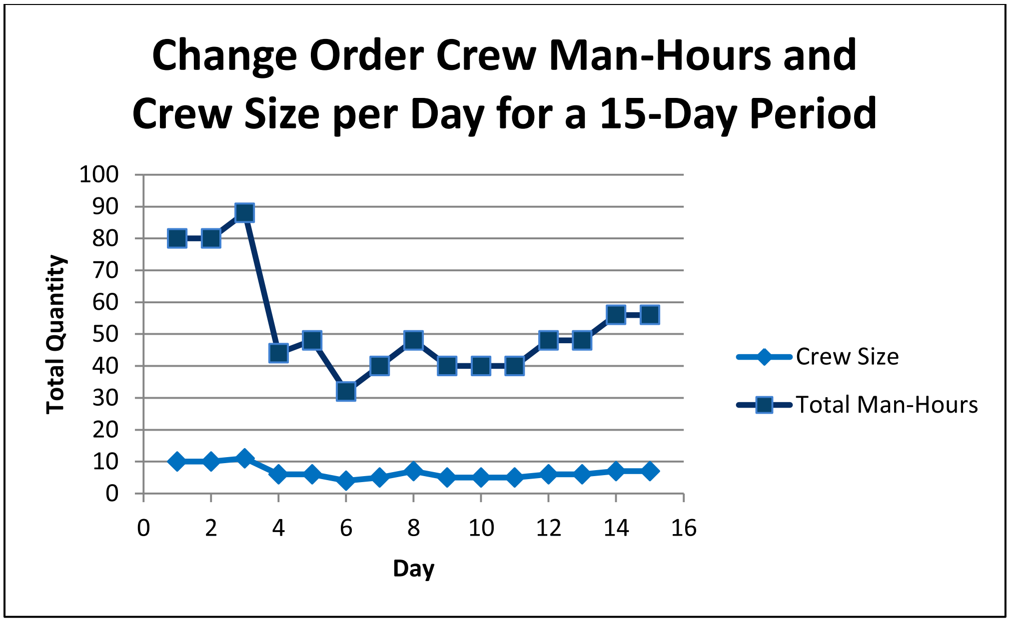


Figure 22 - Data collected for 15 days of change order work performed by laborers in the "Blue Vest" Crew. It can be seen there is a significant amount of man-hours added per day due to changes. Information provided by DPR, graph created by Chris Pozza.

These 15 days alone show there is a significant amount of man-hours added each day, although it does not necessarily prove there is site congestion. Laborers began wearing blue vests during work shifts in November 2012 and continued through January 2013, roughly a three-month period. The information gathered for 15 days is not all inclusive, but clearly show that changes have had a significant impact on the project. At times, these numbers have fluctuated but, on average, change orders were responsible for about seven laborers each day on work and over 50 man-hours per day. There were a total of 788 man-hours tracked over this 15 day sample, accounting for over $58,000 in purely labor costs. This number was arrived at using RSMeans; assuming skilled workers, not taking into account the much work was done on premium time by electricians and plumbers. See **Appendix D** for more details.

Project Phase and Management

Depending on the phase a necessary change is discovered, the associated costs can greatly vary. Based off of the "1-10-100" concept discussed in past courses, conceptual design is relatively easy to change. Once a design is created, it is about 10 times more expensive to edit that design. Finally, it is roughly 100 times more costly to change work that is under construction or has been constructed and requires rework (Faust). It can be noted that the project was well underway before the start of the 9-month period for which data has been collected. Figure 23 shows the costs associated with changes during each month. There is a steady monthly increase in costs associated with changes in eight out of the nine months documented. The decrease in cost is due to the same reason the volume decreased; only changes related to the addition was included as of January. From July, the value of change orders has increased roughly 65% and the total value in March ($12,900,000) accounts for nearly a 40% increase in total contract value for the addition itself. To handle processing changes, tracking changes, project costs, and several other items concerning changes, DPR has assigned two additional experienced employees to manage changes and allow for construction to move as smooth as possible. They, along with the rest of the project team, have proved to be doing a very good job as construction has been able to continue even with the extreme volume of changes and amount of work affected.

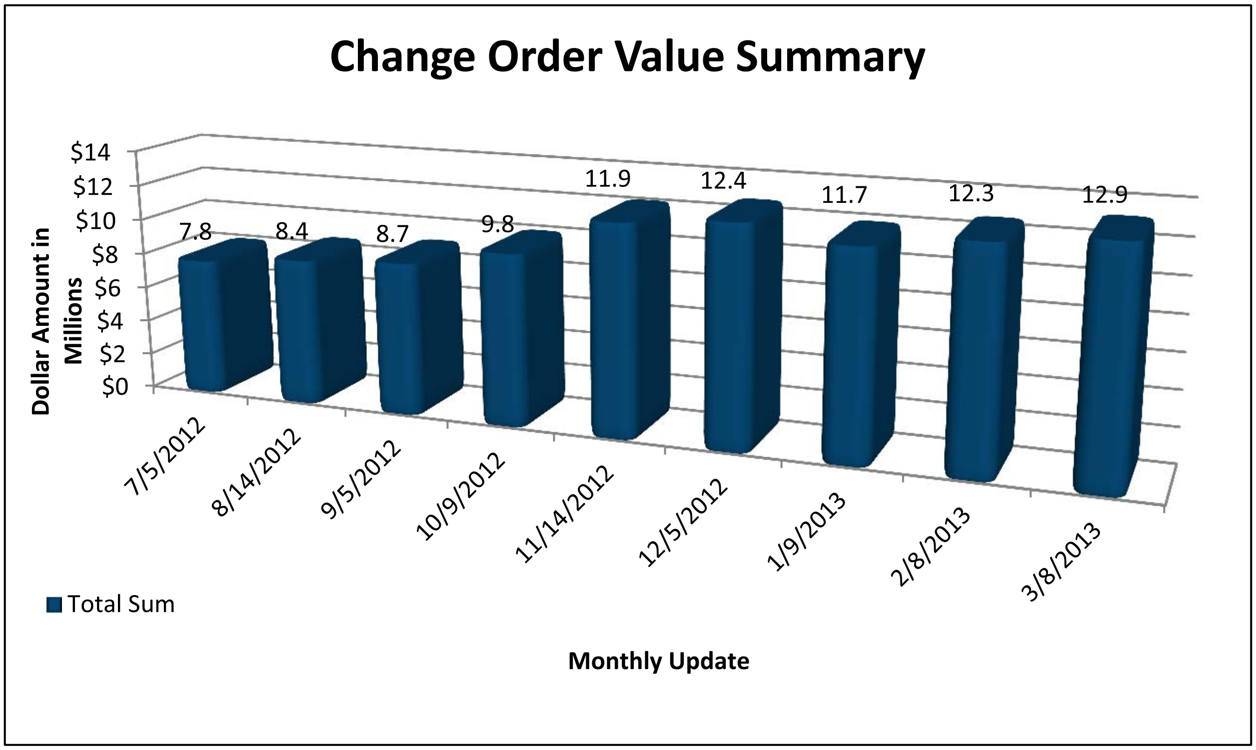


Figure 23 - Summary of the costs associated with changes over the nine-month period investigated. Notice that the total has increased in eight out of the nine months.

Project Impacts

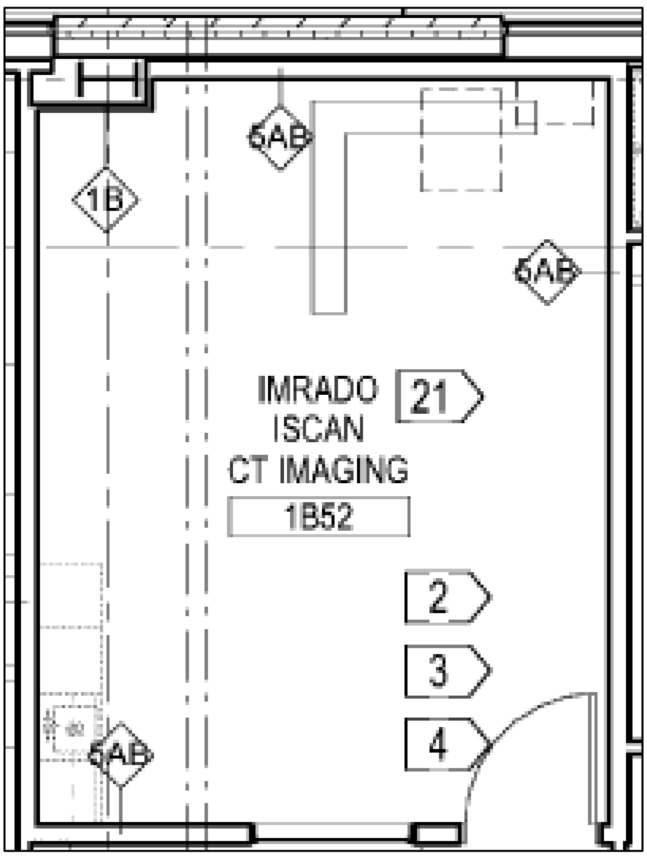
Other project impacts have been investigated further that align with the side effects described in the case studies. Again, both case studies performed by Awad S. Hanna and J. Russell look at change order impacts on productivity of mechanical and electrical contractors. Several of the issues are closely related and key information used has been acquired through interviews as obtaining data was difficult to specifically quantify as evidence. The main findings of these studies suggest that change orders lead to trade stacking, schedule compression, overmanning, multiple-shift work, and morale issues (Hanna and Russel 1999). All of these issues are brought together by a specific example at the end of this section.

Overcrowding of trades in the same area due to rework and the re-sequencing of work has been commonly found on site. Changes can turn sequenced work in disorderly activities that need to be done concurrently. Throughout construction, it has been determined by project superintendents that several situations required trades to be stacked in specific areas.

Accelerated work is closely tied to trade stacking; if schedule compression is required, often trade stacking will also occur. With that, work had to be re-sequenced continuously due to changes. After discussion with project superintendent, Tim Miner, one specific area to note was the sterilization room. Adjustments made to the floor slab and architecture around sterilization equipment had significant project impacts. While this was a location of intense medical and mechanical equipment, work performed by several trades was held up for a large section of the third floor in Area C. Duct, electric, and plumbing contractors were severely delayed as the design was being edited, hindering construction for several weeks in this area.

Another side effect closely related to both trade stacking and schedule compression is overmanning and multiple-shift work. Other than the workforce wearing blue vests to indicate change order work as previously described, working overtime for most trades was been very common in order to keep pace with the project schedule and meet milestones. Multiple-shift and overtime work has been almost a necessity for trades; especially the mason, electrical, plumbing, and HVAC contractors. Although precise amounts of overtime and crew sizes were not determined, overtime and laborers working multiple shifts has been almost a daily occurrence during the last several months of construction, including working Saturdays and sometimes Sundays.

The final topic discussed in the case study and with different project team members was morale. As work is re-sequenced and interrupted, momentum is slowed and hurts productivity. Rework can take its toll on laborers as work that has been completed then needs to be ripped out and done over. Not only laborers deal with morale issues, added stress due to the vast quantity of changes on a project can be taxing on general contractors, construction managers, and owners.



One example that has been described to cover each of the above project impacts due to a change is the Computed Tomography (CT) Imaging room. The layout is relatively simple, but X-ray equipment is used. To keep the rest of the building safe from raditaion, the walls are required to be lined with lead. Lead lining is also required for the underside of the 2nd level floor slab above the finished ceiling and utiliites because radiation is able to pass through metal decking and several inches of concrete.

Figure 24 - Floor plan of the CT Imaging Room. This room requires lead lining in the walls and above the finished ceiling and utilities, on the bottom of the second floor slab. This room is a prime example of how several changes can affect productivity. Image courtesy of Ellerbe Beckett.

Figure 25 - Images of the CT Imaging room ceiling and temporary light fixture used inside the space. This picture was taken after a ceiling close-in inspection was performed and approved. An issue with the lead-lining required all utilities and the ceiling overhead in this room to be removed. Personal photographs taken by Chris Pozza.

Images shown in Figure 25 were taken after a ceiling close-in inspection was performed and approved in the CT Imaging room. All utilities were tested and lights were operational. An issue was discovered that involved the lead lining on the underside of the floor slab above the finished ceiling. Lead sheets were required to overlap so that the lead lining is continuous. As no details were included in the original drawings, it was assumed the work put in place was accurate until it was discovered to be unacceptable. There were several hangar rods supporting all of the different utilities penetrating through the lead lining, so even though the sheets overlap, the several very small penetrations through the lining were found to be unsatisfactory.

This problem required removing the entire ceiling grid, utility, hangar rod, and anything else between the finished ceiling and floor slab above so that all penetrations could be sealed and the lead lining be entirely continuous. All utilities were required to be cut out before revisions could be done; affecting several of the surrounding rooms. On an already rigorous schedule, overtime and trade stacking occurred as trades were required to reinstall and connect utilities. Utility lines also had to be re-tested. The whole process of this rework added stress and hurt morale as almost every contractor working inside the building was affected by this. The total impact was estimated to cost around $80,000 (Miner).

Cash Flow

As discussed in previous construction classes such as AE 472, Building Construction Planning and Management, it was established that “cash is king.” This phrase means that the success of any type of construction project relies heavily on payments being made in a timely fashion throughout the project’s duration. Invoices are created by subcontractors for material costs and work put in place, and then submitted to the general contractor. Once it is confirmed that pricing is fair and accurate, the general contractor submits the invoice to the owner. Pay schedules vary, but owners are usually responsible to make payments for work put in place within 30 days of the invoice submission. When payments are not made for work put in place, cash flow is quickly disrupted. Subcontractors suffer financially by paying for work out of pocket which strains resources and can lead to missed opportunities for further financial gains (Faust).

Potential Solutions

There are several reasons that change orders are required and need to be dealt with throughout both design and construction. No measures can be taken to completely avoid all changes on a typical construction project. A few valid points were made through discussion and discovered through further research. In summary, three key suggestions are summarized and described as follows:

1. Give the construction manager authority to approve necessary changes up to a specific value
2. Purchase preconstruction services
3. Implement a different change review strategy

Provide CM with Authority to Approve Changes to a Reasonable Point

What's believed to be the most effective solution to improve the overall change process is to provide the construction manager with authority to approve changes up to a maximum predetermined value. If Jacobs were allowed to approve small changes that were necessary, a large impact could be made. Turnaround time could potentially be significantly reduced as management at KP could focus on larger changes.

In the time since the project initiated through March 2013, there have been 446 change quotations created. Out of that total, 349 have costs associated with them and were investigated further. The 349 total does not include changes either approved to be paid for out of contingency or that were completely rejected. Looking at the costs, 117 changes were priced at values less than or equal to $5,000. An additional 81 CQ's were priced between $5,000 and $10,000.

If Jacobs were permitted to act as a fiduciary for KP and approve changes up to $5,000, approximately 33.5% of changes with associated costs or 26% of all change quotes created could have made a significant difference. Granting Jacobs permission to give approval could have prevented about a third of all changes from awaiting consent from KP's management while payments were being withheld from subcontractors; thus creating a more stable cash flow. If the dollar value was capped at $10,000 instead, approximately 44% of total project CQ volume could have been approved in a much timelier fashion. This accounts for more than half, approximately 57%, of changes with associated costs Permitting a maximum allowable value that Jacobs can approve or increasing contingency at the start of the project can help allow more work to proceed and reduce the burden on the project managers and project team. Subcontractors could also benefit from a more stable cash flow. When millions of dollars of scope is changing one way or another, the contingency for a project with over a 33% rate of change can quickly run out.

Durations associated with changes costing less than $10,000 has also been investigated. Looking at the time frames it took from the time the change was initiated until the ROM estimate was submitted, and from the time the ROM was submitted until final pricing was submitted, they tended to be consistent with the averages determined in Table 5. One difference determined was the time it took for KP to approve the final pricing after it was submitted. The four change orders used for example estimated a 2-3 month response time. The average response time determined for less costly changes which have been approved to date is less than the examples, actually averaging 50 calendar days or roughly seven weeks. Even though this is shorter than the examples, it is still an average of over 1.5 months. Again, giving Jacobs authority to deal with these changes can eliminate over 1.5 months of pending responses from the KP Mid-Atlantic representative, and potentially be a large benefit to the project overall. Also, this could have a ripple effect as the larger change orders could thus be processed faster as those with significant value can be focused on by KP's management.

Purchase Preconstruction Services

Another effective way to lessen the impact due to changes would be to fully utilize the general contractor's preconstruction and building information modeling (BIM) services. This would also permit getting other trades involved sooner which can allow for earlier coordination of the intense MEP systems included in this medical office building. This could allow for taking complete advantage of the contractors' expertise. As discovered, BIM coordination took over 100 days longer than originally expected because design and coordination were taking place simultaneously. Each area of the building was being modeled and approved only weeks before construction of that area was to begin. Had DPR been able to coordinate and model during preconstruction, it is believed that a large number of changes found during construction could have instead been discovered and amended before construction, when design adjustments were much easier to make.

Meeting the client's needs is always one of the top priorities on a project. However, the later scope or design changes occur in construction, the more of what is already in place gets impacted. Earlier involvement and coordination between trades could thus prevent design changes or issues from becoming problematic during construction. Doing so could greatly reduce the amount of rework required at later stages of construction when they are more timely and costly to complete. Other possible benefits include improving design efficiency for all project stakeholders, reducing the design firm's project management time by reducing RFI's, saving resources by providing accurate information, and improving design efficiency for all project stakeholders.

Implement an Alternative Change Review Process

With supporting evidence that change has been an issue on the project, it is suggested to implement an alternative review process to deal with changes. As future projects that include larger scopes of work are to come, the scale of costs associated with changes is bound to lead to even more substantial impacts than experienced on this $33,000,000 addition with over a 33% rate of change.

If response time is becoming an issue while volume continues to accumulate, steps should be taken in attempt to expedite the overall process. This can be done through adding people to both project teams and those in charge of making decisions for the owner. Once DPR team members responsible for managing changes started to become overburdened, the decision was made to add staff when necessary. Since that has been done, project manager John Stull has reported that turnaround time for ROM estimates and response times have been much more efficient. Although DPR has brought on staff to deal with the problem, Jacobs and KP each have one representative responsible for changes.

As previously described, all changes under $250,000 are the responsibility of one person at Kaiser Permanente, the Mid-Atlantic region representative. Table 5 shows that average response time was around 2-3 months before official owner change orders are approved. Distributing the responsibility of approving changes or assigning a single person to a specific project could significantly reduce the bottlenecking which was occurring. Allocating this responsibility could greatly reduce the burden and volume of work for which one person is accountable, especially with three major construction projects occurring simultaneously in the region.

Other measures that can be implemented include defining time frames which each party is responsible for providing notice, estimates, replies, and approval for changes. This would call for eliminating vague contract language. For example, the contract states the owner is required to respond in a "reasonable" time frame. Had a specific response time been agreed upon for the owner's approval, the 2-3 month example study average would need to be reduced if the contract instead required reply within a month.

Final Summary & Conclusion

It was interesting and a great learning experience to explore the process of how changes are brought about and managed on a project that was experienced directly during an internship. It was also very helpful to get perspectives from different team members and management involved. In-depth investigation revealed intriguing facts about the project, as summarized in Figure 26, including several opportunities from which future projects could potentially benefit. It is recommended to give the construction manager the authority to approve small-scale changes as that potentially has the largest impact. It is also recommended to purchase preconstruction services allowing much of the BIM coordination to take place before construction and to utilize contractors' expertise. Transitioning to an alternative change review process can also prevent similar issues from occurring. Implementing all of these methods could potentially reduce the overall project cost and schedule delays while greatly increasing labor productivity on future projects.

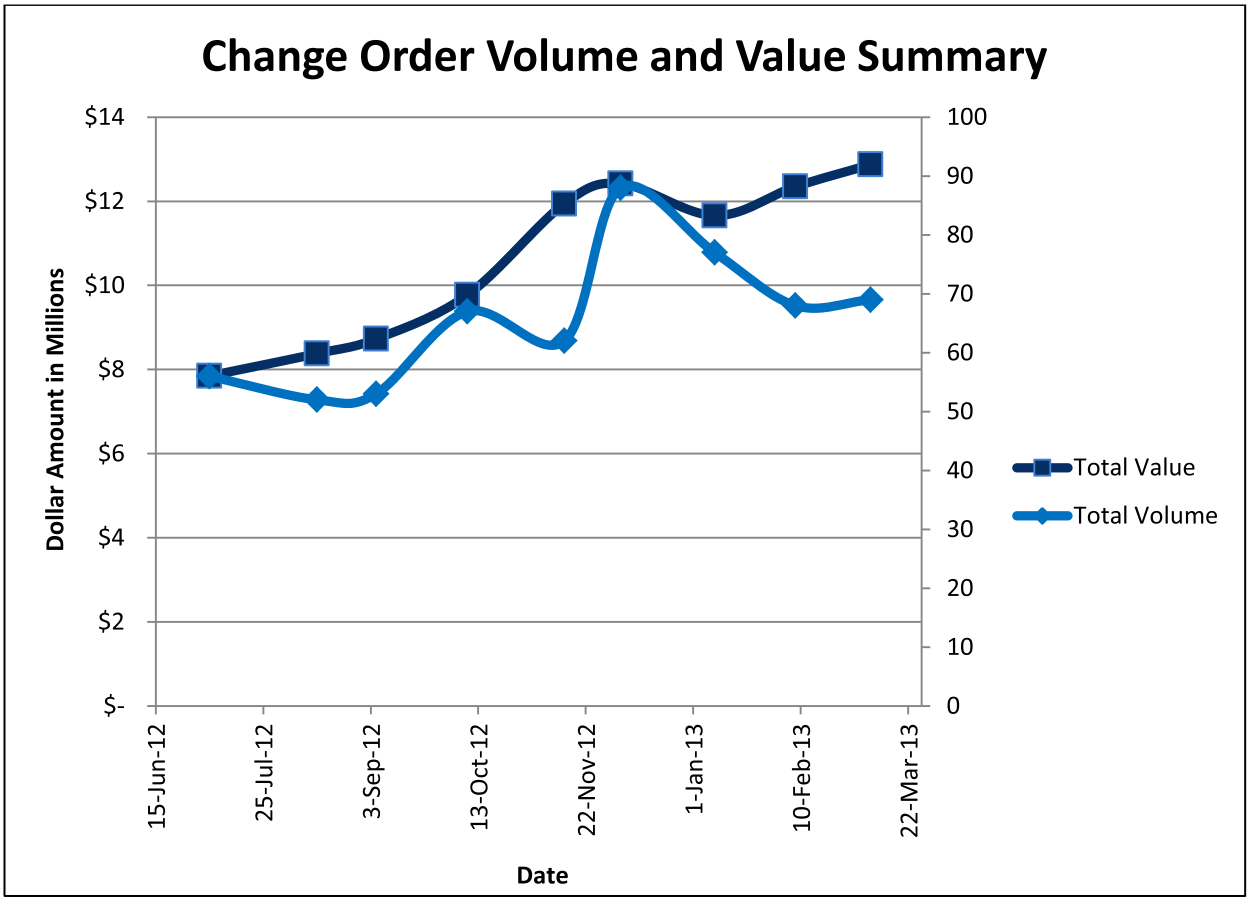


Figure 26 - Summary of change order volume and values throughout the last nine months of construction. The volume of pending changes varied but remained above 50 in every month while the total value increased each month except for January, but this decerase was due to the elimination of renovation-related changes.

Analysis 2 – Implementation of Precast Panels

Problem Identification

With schedule being a key factor, finding alternate ways to accelerate work being put in place has been a key focus of construction depths. A combination of detailing issues and weather delays in early months of construction severely impacted the façade's progression. Delay of the Watertight Milestone can be directly linked to this, which has other construction impacts that will be discussed.

Large quantities of space were taken by brick material; limiting laydown area and congesting the site for an extended period of time. Fraco Lifts were used around the entire south and east facades of the addition, taking up more valuable space and limiting the access into the building for an extended period of time. The implementation of precast panels has been explored because of the potential for significant schedule reductions and quicker site congestion relief.

Research Purpose

The goal of investigating implementation of precast panels is to determine how panels would affect the critical path. All steps through design, procurement, and placement of panels along with all constructability issues have been explored to conclude if panels would have provided an overall benefit for the project.

Analyzing the implementation of precast panels also includes both breadth studies; focusing on the structural and mechanical impacts of using precast panels. Detailed research of both systems provides a much more complete analysis of using precast panels and was performed to further determine whether their use on this project was feasible.

Background Investigation and Panel Fabrication

Superintendents specifically recommended researching the use of precast panels versus brick due to the delays and difficulties faced throughout construction as it was believed that the benefits would far outweigh the costs. For the addition, Ellerbe Becket architects decided hand-laid brick would be appropriate for connecting to the existing building. After discussion with an Endicott Brick representative, it has been noted that several projects he has dealt with have specifically involved additions, comprised entirely of architectural precast panels, which are adjacent to existing buildings constructed with a brick veneer.

Use of prefabrication and modularization was a major discussion topic at the PACE Roundtable. Producing and combining more components off site allows for much quicker field installation, which would be especially beneficial for this project. Once construction of the brick facade fell behind schedule, it was nearly impossible to make up for the time that was lost due to weather and other delays as only so many feet of brick can be placed vertically in a single day. Putting more manpower for longer-than-normal hours to try to make up for time had significant costs associated with it; and included much more extensive labor costs compared to fabricating panels in a shop.

All of these reasons support the choice to analyze whether or not the use of prefabricated panels are feasible to use on this specific project. Precast panels have several advantages and disadvantages compared to brick for many different reasons. The following table summarizes the findings used to guide the analysis.

Precast Panel Comparison to Traditional Brick Facade	
Advantages	**Disadvantages**
• Faster installation for schedule savings • Stronger and more durable than brick façade and tougher to penetrate • More favorable working conditions and no weather issues during fabrication • Higher quality product produced off-site • Panels typically have better insulation properties	• Higher upfront cost to fabricate panels • Often requires heavier structural support members • Can be less aesthetically pleasing due to less imperfections and more joints • Customization of panels can significantly increases cost • Cranes required depending on panel sizes

Table 7 - Summary of advantages and disadvantages of using precast panels compared to brick facades.

Different manufacturers were contacted to gain a better understanding of the types of precast panels available, how they're fabricated, what's practical for this specific project, typical procurement steps, and much more. The main two manufacturers contacted were Nitterhouse and Tindall Corporation. Both manufacturers recommended different types of panels, either completely vertical or horizontal panels, and each for logical reasons. The façade of this building wasn't designed for use of prefabricated panels, which provides some unique challenges. For transportation reasons, a major factor limiting design was practical size for transportation. Panels were recommended to be a maximum of 12' wide. Widths over this size would require special permits and make transportation more expensive.

Solid horizontal panels were recommended due to the variability in façade bays, heights, and spacing. Although the bays and window spaces vary, there is some repetition from elevation to elevation. Repetition of panel design is desired to reduce the amount of customization. The more repetition and simplified the panels are, the easier and cheaper they are to fabricate. A negative effect of using entirely horizontal panels is the significant amount of panels required. Panels are costly to put in place, regardless of their size, and can largely impact the total cost of the system.

Vertical panels were recommended precisely for the reason previously mentioned; to reduce the total amount of panels used on the façade. If all panels could be vertical, the total amount of panels would be greatly reduced. However, because it was recommended to use panels 12' wide where possibly, the level of customization needed for each panel could greatly increase the cost of fabrication. Very few panels would be identical using this strategy compared to horizontal panels.

Before a final design was chosen, a more complete analysis was carried out through the following structural and mechanical breadth studies. These were performed to determine the effects of both vertical and horizontal panels on the building's structure and foundations, and the potential impact on the mechanical system due to changing of the façade's materials.

Breadth 1 – Structural Analysis: Column and Foundation Loading

The Kaiser Permanente Largo Medical Office Building has a unique SidePlate Moment Connection System, which has been discussed in more detail in the Building Systems Summary section. Because a precast system was proposed, the structural system will be required to carry a larger load that must be calculated. Steel upgrades require costly implications; results have been determined whether or not the benefits during construction will outweigh the cost. Producers of panels were consulted to determine expected loads along with other design considerations.

As mentioned, SidePlate connections were chosen over braced frames because they allow lateral framing to be located more conveniently and smaller members provide more usable space inside the building. Smaller members allow for quicker steel erection and have a positive cost impact as members' reduced sizes lower the overall loading on the building's foundation.

Analyzing the feasibility of precast panels involved much more than looking at cost and schedule impacts of using precast concrete versus brick. To conduct a structural analysis, loads due to panels, both 7" and 8" thick, which were recommended by different manufacturers, were compared to the current building design. The actual brick façade is supported by the strip footing until the second level where a relief angle has been placed. It was discovered that the building's façade is not entirely self-supporting as the L7x4x3/8 angle transfers the load due to brick above this point back to the structure. This is logical as the Brick Institute of America defines the maximum veneer height permitted to be supported on foundations is 30 feet to the top of a wall or 38 feet to the top of gable. Shelf angles may support no more than one story of brick unless sufficiently designed to do so (BIA 2005). Other than that, the façade is only tied into the structure through use of brick ties, which do not transfer lateral loads.

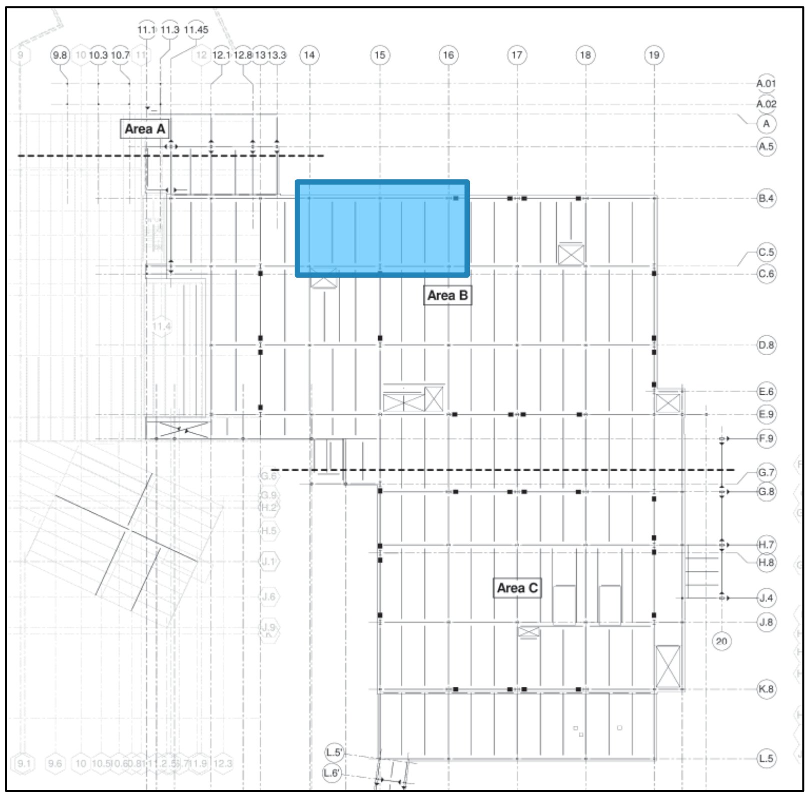


Figure 27 - Plan view of the addition's structure. The area being analyzed can be seen calling out on the east elevation, column lines 14, 15, and 16 along column B.4. Image courtesy of Ellerbe Becket.

Before going into the analysis, the existing structure needs to be explained to identify the reasoning for the specific areas chosen. The area that was selected for the analysis can be seen in Figure 27. Moment connections, represented by dark squares on either one or both sides of a column, can be seen at locations around the perimeter and within the building's footprint.

To perform a structural analysis, a column without moment connections was chosen for a few key reasons. First, it is out of the scope of this breadth study to perform an entire lateral analysis, which would be required at a column with a SidePlate moment connection. Second, there are a limited amount of “typical bays” incorporated into the design. Only four bays, from column line 15 through 19, are equal lengths. Bays running east to west along the numbered column lines vary drastically. Spaces on either side of column 15/B.4 has two of the larger bay sizes found on the project, 28’ 4 ½” and 29’ 3”, providing the largest loading for a conservative estimate. The final reason for choosing this location is the column size. W10x39’s and W21x111’s are used around the perimeter and these columns run the full height of the building. The limiting factor due to loading would be the W10x39, which is the size of the selected column at 15/B.4. A closer look at these bays can be seen in Figure 28.

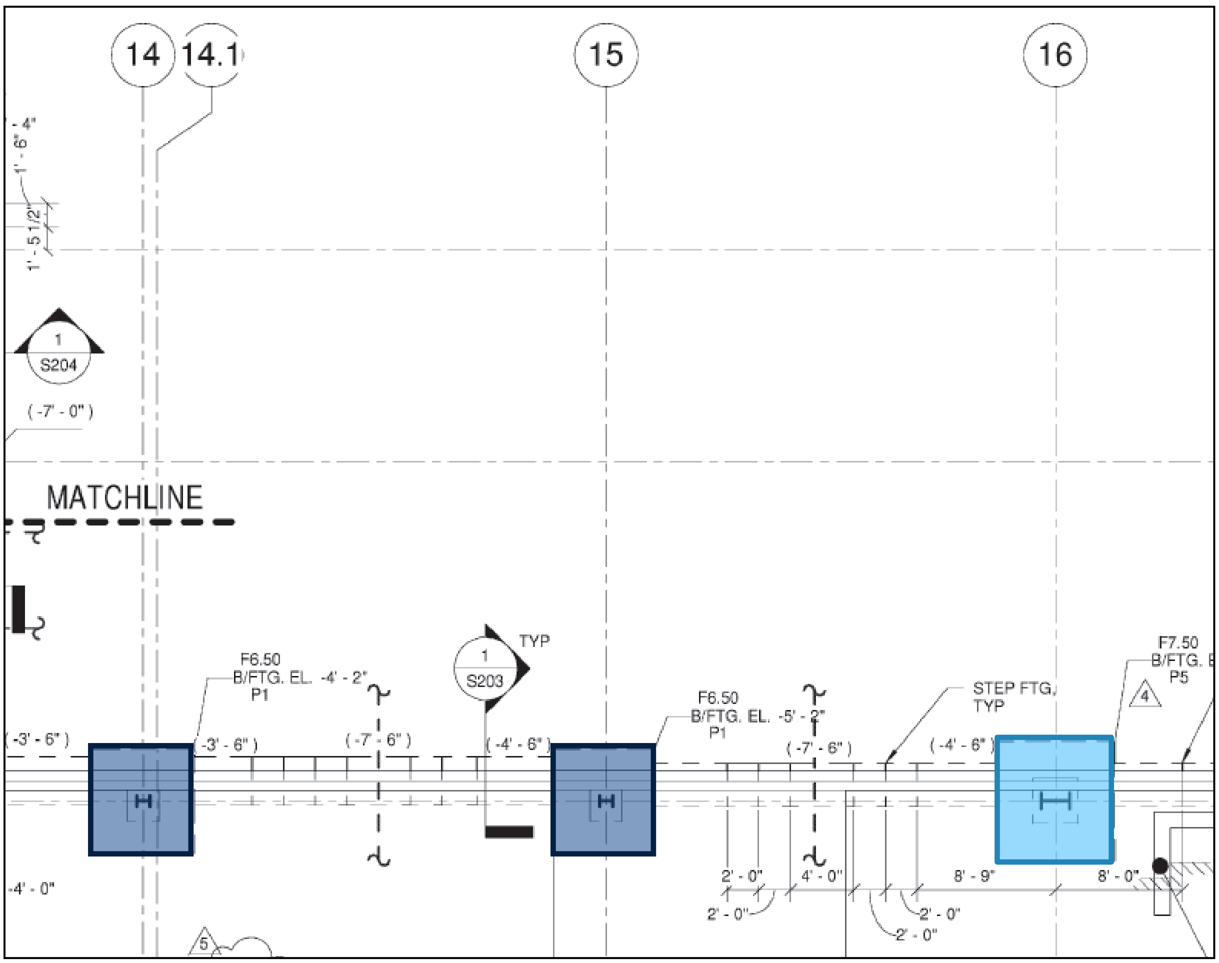


Figure 28 - W10x39 beams can be seen on column lines 14 and 15, while the W21x111 to the right on 16/B.4 is noticeably larger and requires a stronger foundation. Image courtesy of Ellerbe Becket.

Please see the **Appendix E** for the structural calculations performed. Live loads used for calculations were provided in the structural drawings. Dead loads for decking and floor slabs were provided in the Vulcraft catalog. Once it was determined that the influence area was over 400 square feet, live load reductions were calculated using ASCE references which can be found in **Appendix F**.

Exterior wall loads were conservatively assumed to be full floor-to-floor height panels, including no windows or openings, to first see if the structure could adequately support the additional loading. 7" panels weigh 87 PSF and 8" panels weigh 100 PSF. Once total loading for the columns at each floor were determined, tables in the American Institute of Steel Construction (AISC) were used to check whether columns could support the new loading using either type of panels.

The largest floor-to-floor height is 14 feet, so this height was compared to the values calculated in the LRFD table. As effective lengths, or total column-to-column heights, increase, the axial strength decreases. Again, this was another conservative measure taken as columns on the first and second level are both shorter in length than 14 feet. Using Table 4-1: Available Strength in Axial Compression, it was determined that a W10x39 with an effective length can support 306 kips (ASCE 7-05). This is larger than the loading on the lowest level with the heavier 8" panels, which was calculated to be 199.6 kips while the 7" panels were responsible for a load of 187.6 kips. Although there was a maximum 85% loading increase on the column with the proposed design, it has been determined that the structural steel around the perimeter can support the additional loading of either 7" or 8" precast panels and will not need to be upgraded.

It was appropriate to next see if loads were going to affect the foundations. Spread footings are used at the base of columns and strip footings around the perimeter. Before checking the sizes of each, the allowable soil bearing capacity (q_a) needed to be determined. Referencing the project's geo-technical report, q_a was determined to be 5,000 pounds per square foot (PSF), or 5 KSF. The equation used for determining loads permitted is: $q_a > P/A$. While q_a has been described above, P is the total load and A is the area of foundation on which the load is being transferred to the soil.

The spread footing at column lines B.4 and 15 is an F6.50 which has dimensions of 6'6" by 6'6" and is 1'8" thick. When solving for P in the equation, the total load needs to be less than or equal to 211.25 kips. This is acceptable because the largest load on the column determined previously was 199.6 kips. Next the strip footing was checked. Using the unit strip method, a one foot strip of the foundation was analyzed. The same equation above applies, and the width of the footing is 2' 8 5/8". Using the same 5 KSF, the total load this could support is 13,600 PSF, or more appropriate for the unit strip method, 13.6 thousand pounds per linear foot (klf). Because the maximum height is 46' and maximum load on the footing could be due to the 100 PSF 8" panels, this footing can adequately support the wall load.

Conclusion

All structural calculations have proved that no structural upgrade would be required if the building façade were to change from brick (40 PSF) to 8" precast panels (100 PSF). As only axial loading was analyzed, it is clear that the structural steel and foundation designs are not controlled by this loading. Although it was not calculated in more detail, it is assumed that members are sized appropriately to handle lateral loading. One of the main reasons it has been determined that the structure and foundations can support the additional load is due to the building's height. If the building were any more than three stories tall, the structural steel would most likely need to be upgraded if a precast façade system was being used.

Breadth 2 – Mechanical Analysis: System Impact and Thermal Bridging Prevention

Changing materials on a building's envelope can have a major impact on a building's mechanical system. Precast panels' characteristics vary from a conventional brick façade. Investigation of concrete insulation properties was conducted. Heating and cooling loads have been researched along with climate information for the Largo, Maryland area. Preliminary investigation of panels has revealed they often have better insulation properties than traditional hand-placed brick. Investigation determining whether the mechanical system currently in use is the appropriate size has been conducted.

Thermal bridging occurs when a material that is non-insulating disturbs a building's envelope and allows the transfer of energy through the façade. Even though a building can be extremely well-insulated, a thermal bridge has the potential to significantly impact the building's mechanical system if the energy it is producing is free to penetrate through the envelope escaping to the atmosphere. Because of this, façade connections have also been analyzed to fully understand the effects of implementing precast panels on the project and to make the analysis a more thorough. Each measure to be taken to ensure thermal bridging has been prevented and that there are no weak points in the façade allowing for energy to be lost is discussed.

Precast Thermal Properties Comparison

Before calculating any effects the change of façade materials have on the mechanical system, the thermal properties of both a brick and precast façade need to be determined and compared. Calculations learned in AE 310, Fundamentals of Heating, Ventilating and Air-Conditioning; were done to conclude which system provides better insulation.

Heat is measured in British Thermal Units (BTUs) per hour. Conductivity (k) is the amount of heat that flows through one square foot of a material that is one inch thick and subjected to a one degree temperature change. The reciprocal of conductivity is resistance per inch, R. Conductance (C) is the amount of heat flow for a given thickness of material. The reciprocal of conductance is also resistance, R. The only difference between the reciprocal of k and C, which are both forms of resistance, is that one depends on the thickness of a material and whichever resistance is being used needs to be specified. R-values increase as the thickness of material increases. Because of this, 7" panels were used in Table 8 for comparison as opposed to 8" because thicker precast panels will insulate better, thus the 7" panel being used is more conservative.

The entire wall assembly needs to be analyzed, although the only change is the exterior face brick is replaced with 7" concrete. The purpose of looking at the wall assembly is to determine the coefficient of transmission, or U-factor. The unit of U is BTUs per square feet per one hour per degree Fahrenheit [BTU/ (ft^2*hr*°F)]. Four assumptions were made when making calculations; materials are homogenous in nature, temperature changes do not affect thermal performance, air space remains the same, and the vapor barrier has negligible thermal resistance properties. Although the vapor barrier was assumed to be negligent, it is important to note that its location is on the interior (or warm side) of the 2" rigid insulation to prevent moisture from penetrating and getting trapped inside the wall assembly.

Wall R Values (Winter)	3.5" Face Brick	7" Precast Panels
R_o - Outside Air Barrier	0.17	0.17
R_1 - 3 1/2" Face Brick (R=0.11 per inch) Alternate R_1 - 7" Precast Panel with Thin Brick	0.385	0.53
R_2 - 1 7/8" Air Space	1.23	1.23
R_3 - 2" Rigid Insulation (R=5 per inch)	10	10
R_4 - Vapor Barrier	Negligible	Negligible
R_5 - 1/2" Gypsum Sheathing	0.45	0.45
R_6 - 6" Metal Stud / 6" Batt Insulation R-19	7.1	7.1
R_7 - 5/8" Gypsum Sheathing – 51	0.56	0.56
R_i - Inside Air Film (Vertical Position, Horizontal Heat Flow)	0.68	0.68
Total R	**20.575**	**20.72**
U_{avg} or Total U (1/R)	**0.0486**	**0.04826**

Table 8 - R-Values for each material comprising both the existing and proposed facades are listed. Resistance values are summed and reciprocated to determine the coefficient of transmission. The difference is a miniscule 0.00034; with virtually no difference.

See **Appendix G** for more calculations and **Appendix H** for the references used. Table 8 shows the total U factor differs only by 0.00034. This is important to note, as there will be little to no difference between the façades thermal characteristics, but the building will be slightly better insulated using precast panels. It has been established that no major impacts will be made on the mechanical system due to the change in exterior building materials. In order to ensure the mechanical system will not be significantly impacted by thermal bridging, panel connections to the façade have been researched and selected.

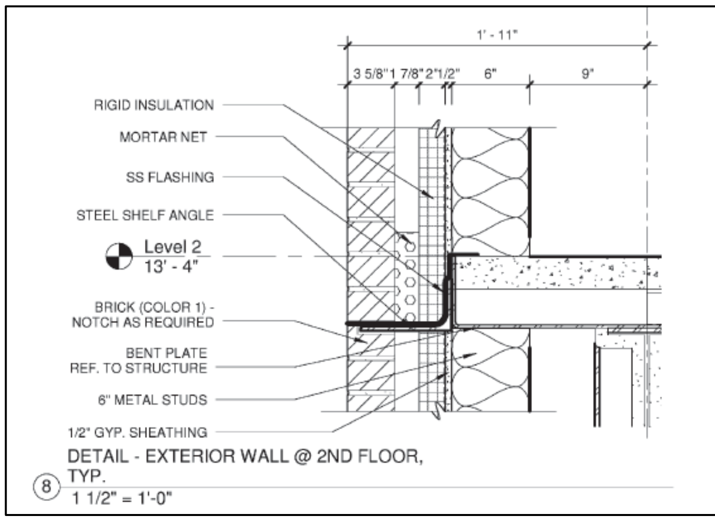


Figure 29 - Detail of the steel relief angle used. Notice the connection of the shelf angle directly connected a shelf angle and second floor level. This detail shows that little is done to prevent thermal bridging as no measures are taken to prevent energy from passing through the building's envelope. Image courtesy of Ellerbe Beckett.

Figure 29 shows an actual detail with a steel lintel connected to a bent plate on the slab's edge. There are various ways to prevent thermal bridging; and solutions don't have to be extremely difficult. Although it might not be extremely intuitive, a very simple solution for something like a brick lintel would be to separate it from the bent plate it's attached to by using a stainless steel shim plate which can be spaced every 24" on center, which can be seen in Figure 30. This has the potential to save at least a few hundred dollars in energy costs every year with larger savings for larger buildings. An alternative way to prevent thermal bridging is to use a fiber reinforced polymer (MSC 2012). Regardless of the analysis, this would have been a good alternative for the way the KP Medical Office Building was actually constructed as the majority of the second level supports a steel relief angle.

By instead using a stainless steel shim plate and decreasing the length of the lintel's horizontal leg, the U-factor decreases from 0.44 to 0.13 for a 70% reduction in the thermal transmission coefficient.

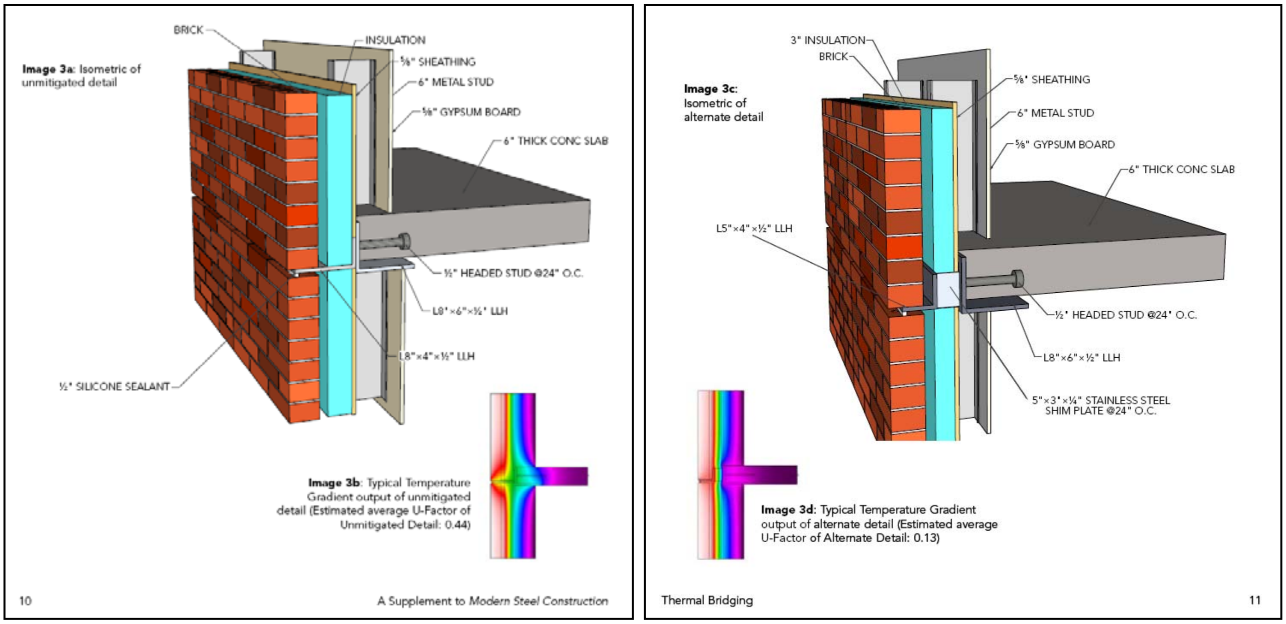


Figure 30 - Detail comparison between masonry facades using a relief angle. The right detail uses a stainless steel shim plate to reduce the U-factor by roughly 70%. Image from Modern Steel Construction.

Connection Details

The first connection determined was a load-bearing column connection. It was recommended to use a detail provided by Nitterhouse, Figure 32. Two pieces of tube steel are used to support horizontal precast panels at each end of the panel. Plastic shims can be seen in the connection section and are used between both pieces of the tube steel. Although the piece of tube steel that is embedded in the precast panel will be penetrating through the exterior insulation, the shims used will effectively separate the two pieces of steel and prevent significant energy from being lost.

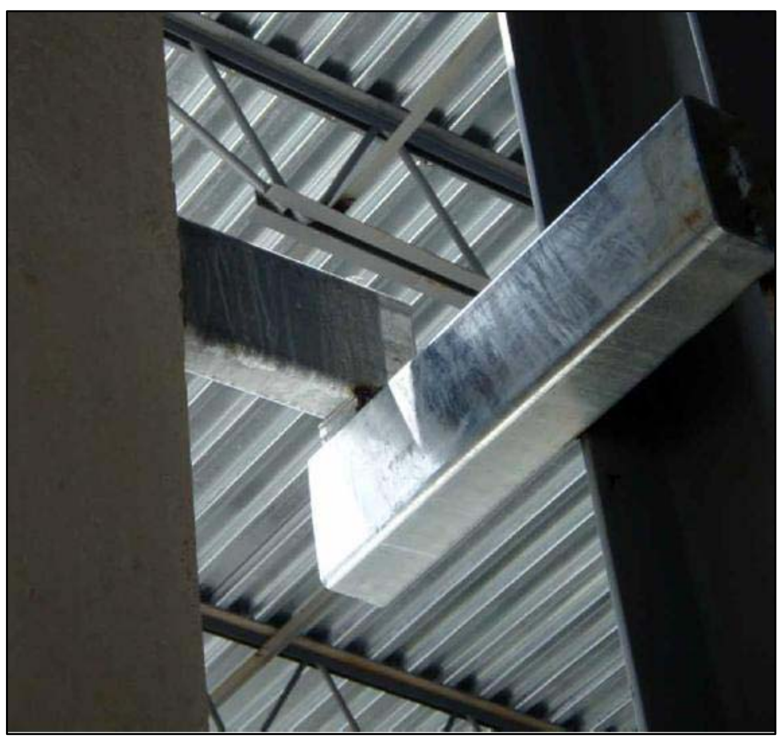


Figure 31 - Photo of a similar connection supporting a precast panel. Shims can be seen between the tub steel used, similarly to the left section, to prevent thermal bridging. Image from the NCPA Architectural Precast Connection Guide.

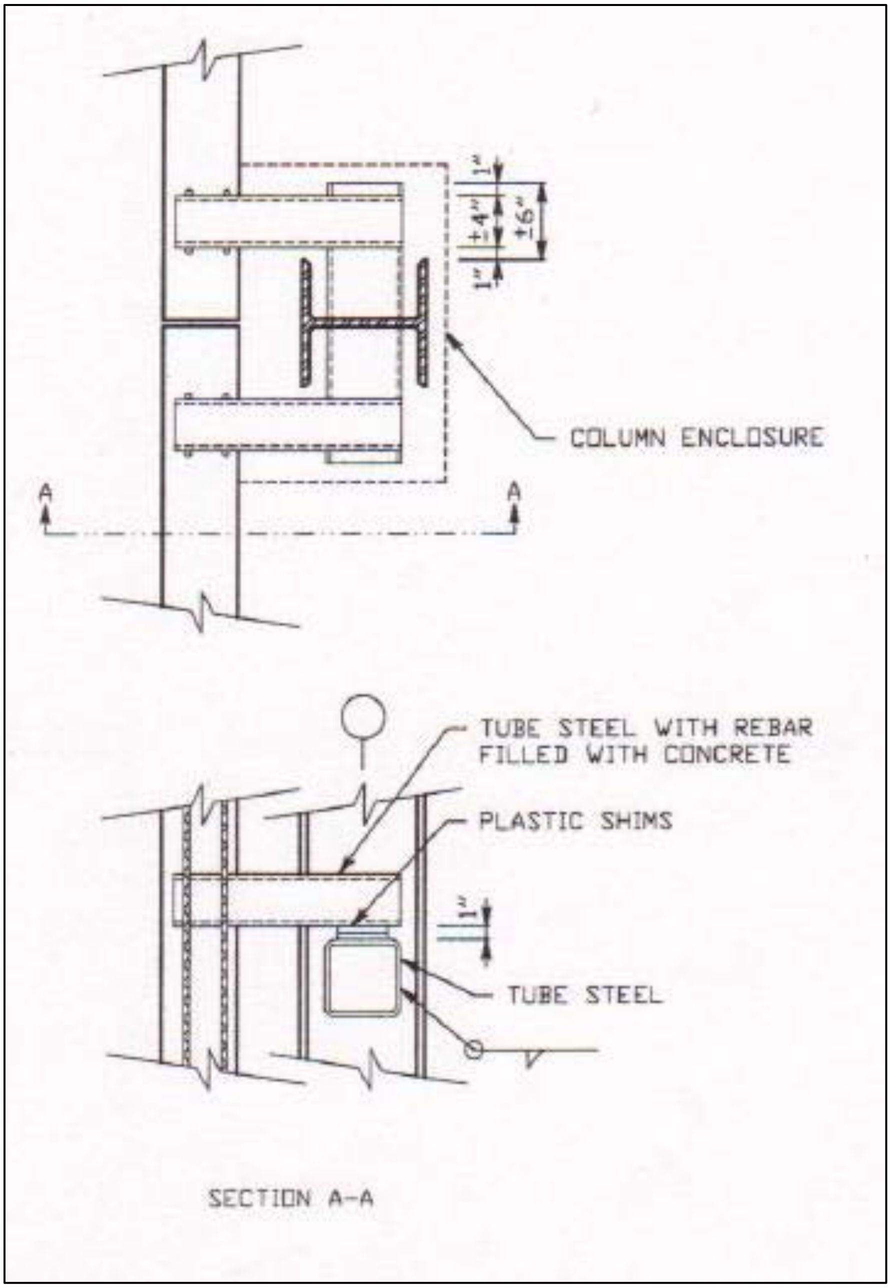


Figure 32 - Plan view and section of the load-bearing panel connections selected. Plastic shims are used between the tube steel supports which protect the system from transferring energy. Image courtesy of Nitterhouse.

Panels have multiple connection types other than bearing connections. Tie-backs are necessary near the corners of each panel to stabilize panels and prevent significant movement that can be damaging to any window or door frames. A panel tie-back can be seen below in Figure 33. An angle welded to the column includes a slot for a threaded rod to pass through and be held in place with nuts and washers.

The rod itself connects to a slotted insert in the panel, with the only penetration through the exterior insulation being the rod itself. Much similar to the details in Figure 30, use of a stainless steel shim between the angle and column would adequately prevent the impact of thermal bridging.

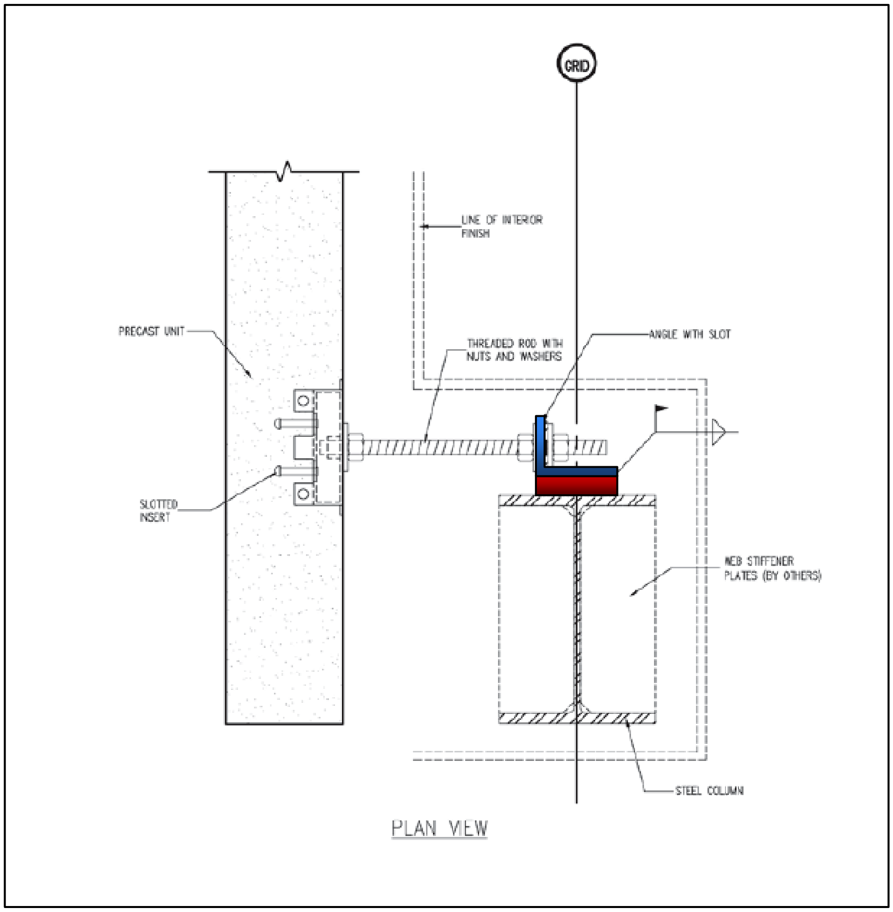


Figure 33 - Plan view of a panel tie-back connection. The red represents a shim angle used to separate the column and the steel angle, shown in blue. Image from the NCPA Architectural Precast Connection Guide.

Between panels, a material is needed that is flexible to deal with movement but won't allow water or air to penetrate. A silicone sealant is needed that performs well between precast concrete panels. For this reason, DOW Corning 790 Silicone Building Sealant has been chosen. This can be used in both expansion and control joints and has effective weatherproofing characteristics (Dow Corning). This product has been listed in the project's specifications as the only acceptable product to use for joints in contact with EIFS. Panels are recommended to apply this sealant on the interior and exterior edges of the panel-to-panel joints. Figure 34 shows material being applied to a horizontal joint between precast panels.

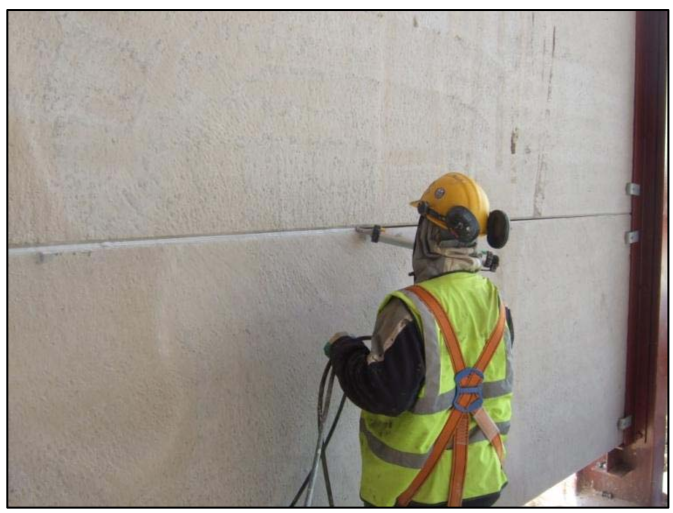


Figure 34 - Silicone sealant is necessary for application between panels for waterproofing. Image from ACP Concrete.

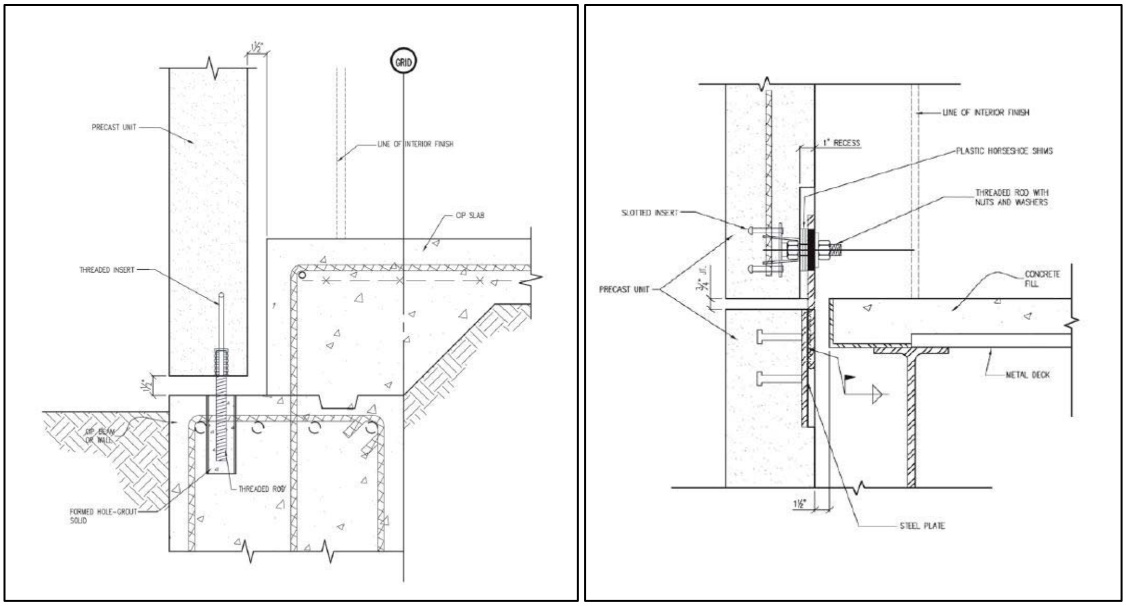


Figure 35 - Far Left: Panel-foundation connection detail and panel-to-panel connection. Image from the NCPA Architectural Precast Connection Guide.

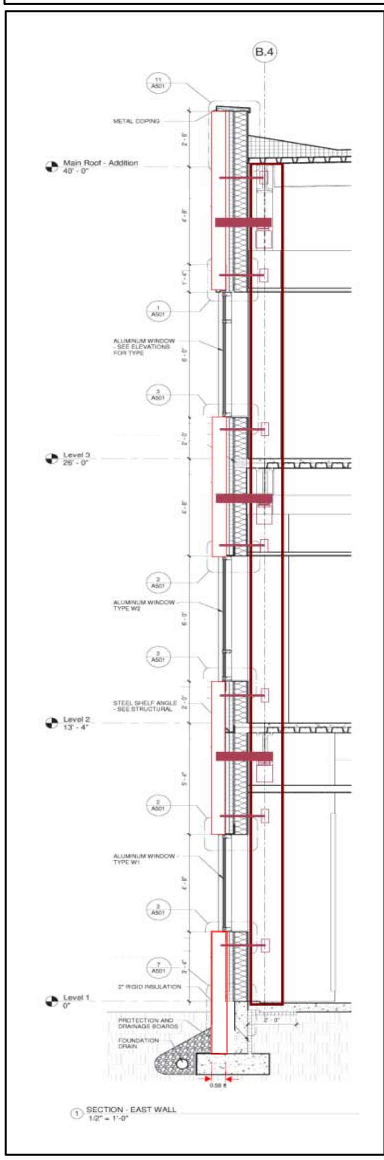


Figure 36 - A section located at column lines 15 and B.4 which has been analyzed in the structural analysis. Connections based off of Figures 32and 33 are represented in their approximate locations. Each penetration is larger than brick tie-backs, but much less numerous. Each connection requires the use of plastic or stainless steel shims, while the connections between panels and openings require silicone sealant. These two systems should adequately prevent the passing of air and moisture, greatly reducing the potential for thermal bridging to occur.

Conclusion

As sustainable measures continue to be incorporated into building designs, full analyses of building envelopes will need to be thoroughly considered. After studying how the proposed precast system will perform, it has been established that the facades will have very similar thermal characteristics. Penetrations through the building's exterior insulation always create a potential for energy produced to escape; creating inefficiencies. The same column analyzed in the structural analysis can be seen to the left, showing both bearing and tie-back connections. Several penetrations are located at each column, these penetrations are much fewer than brick tie backs located across the entire façade, but are much larger in area. As long as connections between panels and the structure are designed with shims and silicone sealant to prevent thermal bridging as previously discussed, there should be virtually no major impacts on the mechanical system requiring it to be resized.

Precast Design Process

One of the biggest benefits listed in Table 7 is the working conditions which panels are fabricated. Being fabricated in a controlled environment allows for much safer and comfortable working conditions. The flexibility of design is another strong advantage which can be seen in Figure 37. As discussed in the Structural Breadth, a wide variety of panels is necessary to accommodate the varying bay widths and heights. A wide range of façade materials can be used with precast panels and windows can be framed out relatively easy; therefore, most shapes can be created to accommodate numerous design needs. Once formwork is constructed, architectural thin brick is placed within the forms. The biggest challenge is determining the most cost efficient design as it is not a perfect practice and does not always provide an obvious layout, this project being a prime example.

Figure 37 - Workers are able to fabricate panels comfortably in a controlled environment; increasing quality and productivity. Image taken from Gate Precast.

Structural Breadth calculations prove that the current foundations and steel can support both column-supported and foundation-supported panels. Regardless of the design chosen, the total cost of the system will be significantly more expensive than a building with a relatively uniform design that provides for much more repetitive panels to be produced. It was established that, on average, about 15 panels can be placed a day which should allow for significant schedule savings (Taylor). The next step was to create an appropriate design before looking at associated costs and schedule impacts.

Discussion with several industry professionals commenced. The original design included all horizontal panels with small panels filling spaces between windows. A redesign was suggested by Mark Taylor, President of Nitterhouse, to span panels from column to column for appropriate connection points. An image of the east elevation re-design can be seen in Figure 38. Design of the entire building's façade using horizontal panels would require 244 panels, which is extremely high for a building of this size. Although it is possible fabricate the façade in such a way, alternative design choices were still explored.

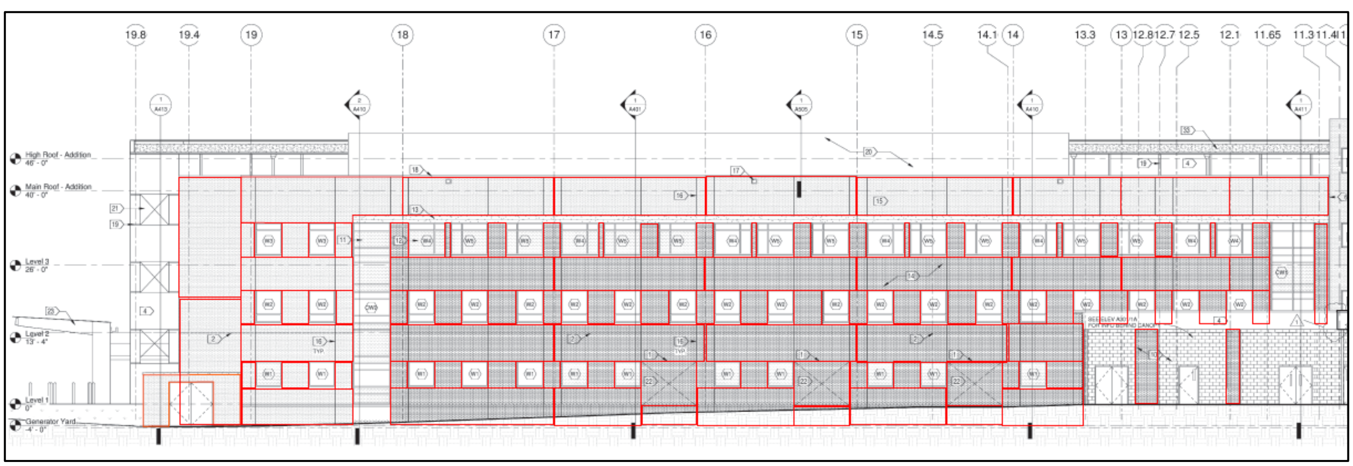


Figure 38 - Original design of precast panels using all horizontal panels. This image is the east elevation broken into different panels. Image courtesy of Ellerbe Beckett and edited by Chris Pozza.

Once use of vertical panels was encouraged by a different manufacturer, an early design was drafted as an alternative. Even though the number of total panels could be significantly reduced, a substantial problem was discovered in a few key areas; one specific example being the pharmacy in Area C. The pharmacy protrudes from the west elevation on the lower level; therefore, vertical panels cannot rest on foundations. Also, the column spacing that would be responsible for supporting the panels would be too wide for columns to be able to be supported, not allowing for use of vertical panels. Another design lesson was that panels could not include the narrow widths between windows on the third floor, which can be seen in Figure 39. Very small portions extending from large panels are not ideal as they tend to be damaged easily and, being at the very top, cannot support panels during erection, so these became individual panels. Also, openings for medical equipment installation could not be easily designed.

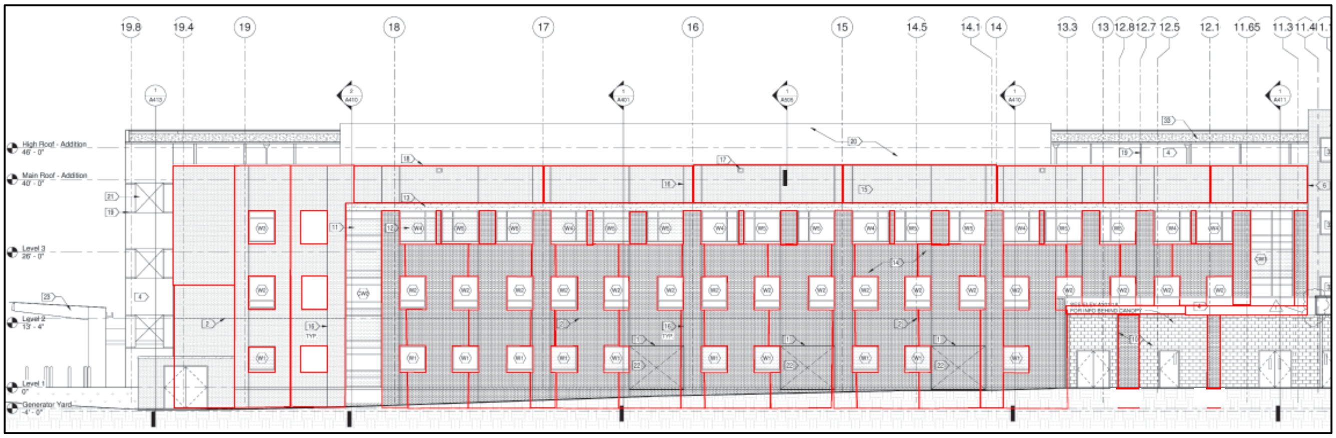


Figure 39, *East Elevation* - It can be seen that a combination of horizontal and vertical panels are used.

As the design progressed, it was attempted to try using both vertical and horizontal panels. Exactly where each type used would be determined on what layout worked best with the facade's bay and window spacing. The previous design required significant editing while evolving into a combination of the previous attempts. In order to replace the majority of the small panels between windows, large "E" shaped panels were used.

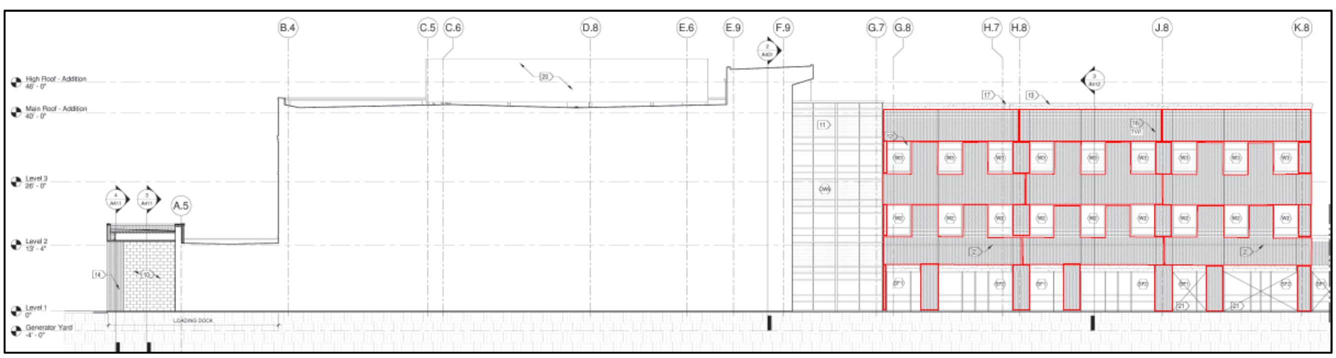


Figure 40, *North Elevation* – Storefront windows on the first floor do not permit use of vertical panels.

Overall widths of these E-shaped panels are not ideal due to the floor-to-floor heights and window spacing. Although there would be a reduction of total panels, the complexity of the design would require extreme customization and very untraditional panel shapes and sizes. These modifications would require facades to have joints at locations that would not be too aesthetically pleasing while being difficult to align perfectly. For these reasons, the final design chosen was to be that of horizontal panels. The difference in schedule savings by a reduced number of panels would not have a substantial enough impact to justify additional challenges due to logistics and complexity of the design (Varga).

The breakdown of the final façade design can be seen on the following page in Figures 43-46. This design has been determined to be the most viable solution and provide the project with a great opportunity for schedule savings. The design includes 244 individual panels which is a large amount for a building this size. Even though the alternate hybrid design shown in Figure 40 would require only 126 panels, it has been established that using the alternate design with E-shaped and vertical panels would lead to panels being too cumbersome to handle due to much larger weights and irregular shapes. This would entail use of a second crane or additional precautions. This is still a relatively high number due to the total size of the façade, but it is required due to the varying bay sizes and floor-to-floor heights. The alternative façade design and quantity takeoff for both can be found in **Appendix I** through **Appendix K.**

Delivery & Erection

The supplier chosen for panel fabrication was Nitterhosue. Estimated distance from its fabrication plant to the site in Largo, MD, is 108 miles and expected travel time is 1 hour and 49 minutes. Panel sizes and loads were determined to see if special permitting was necessary. This route involves highways in both Pennsylvania and Maryland. Permitting information was found at Wideloadshipping.com. Width was determined to be the controlling factor. Both states require permits for hauling loads over 8’6” wide. However, the main concern is that escorts are required for certain sizes. Pennsylvania and Maryland both require escort vehicles in the front and back loads 13’ wide.

Because of these common design considerations, it was recommended to design panels to be no more than 12’ wide. Although horizontal panels require more individual panels than using vertical panels, the façade could be designed so that no single panel would require any additional permitting, escorts, or other transportation issues with associated cost.

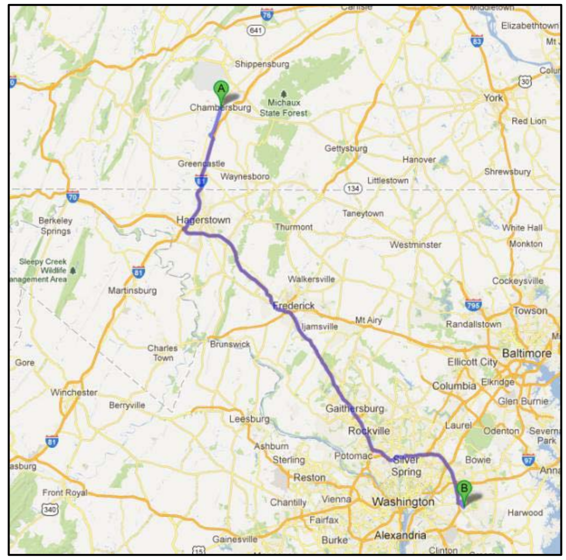


Figure 41 - Route to be taken from Nitterhouse's manufacturing plant to Largo, Maryland. The 108-mile distance is expected to take roughly 1 hours and 49 minutes. Image from GoogleMaps.

Use of vertical panels would require several oversized loads which would impose additional escorts and costs. Although it could be argued that the oversize panels would reduce cost as fewer panels would need to be transported and handled, the additional panels are small enough that several could be transported at once. More in-depth pricing was not investigated as the cost of transportation and erecting panels was included in an estimate quote from Mark Taylor.

For panel erection, a 110-ton crane was selected as it has a single line pull maximum of 40,640 pounds, well over the highest load of about 27,000 pounds. Crane information was provided by Carde Pacific. Additional general conditions costs were estimated to be $44,078.

Figure 42 - 110-ton crawler crane selected for precast panel erection. Image from Carde Specific.

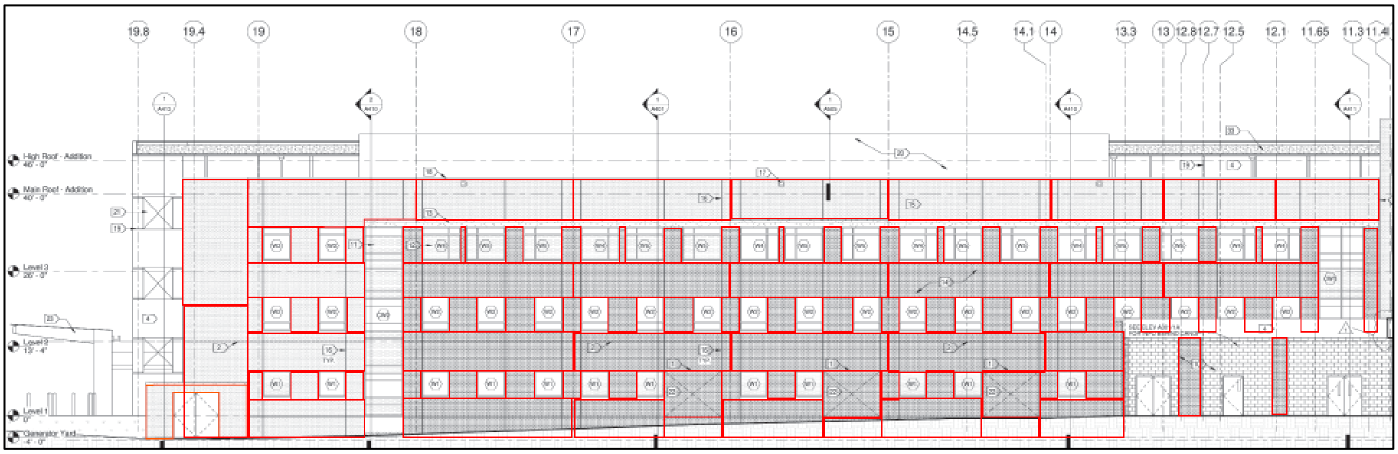


Figure 43, *East elevation* - Design using all horizontal panels.

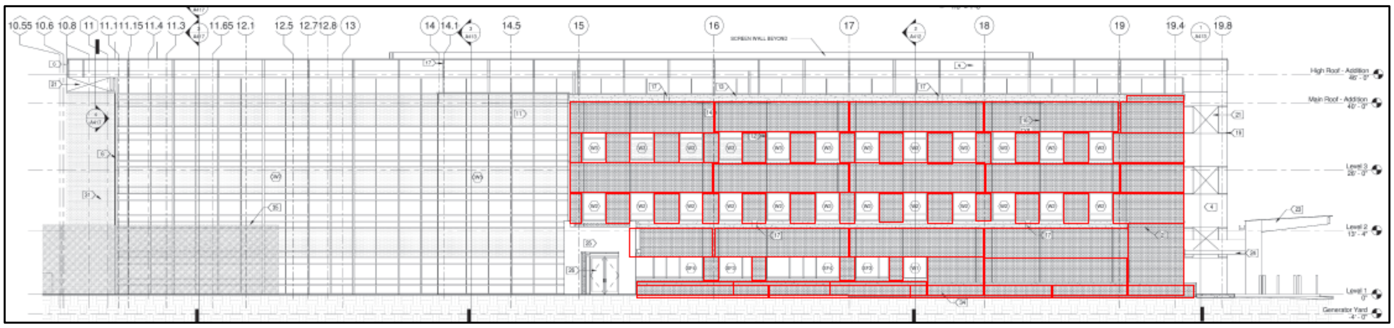


Figure 44, *West elevation* - The first floor pharmacy did not permit use of vertical panels on this facade.

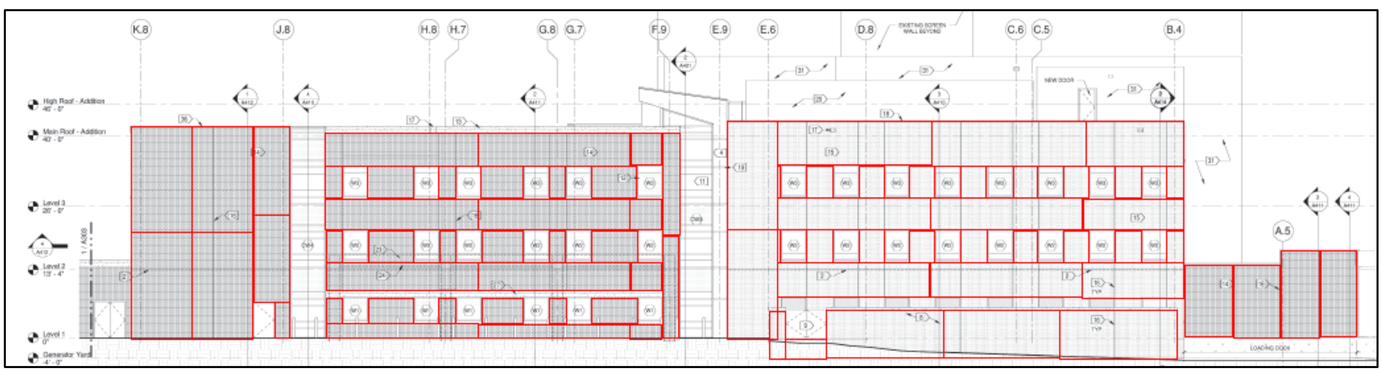


Figure 45, *South elevation* - The generator yard and loading dock can be seen in the lower right of the image.

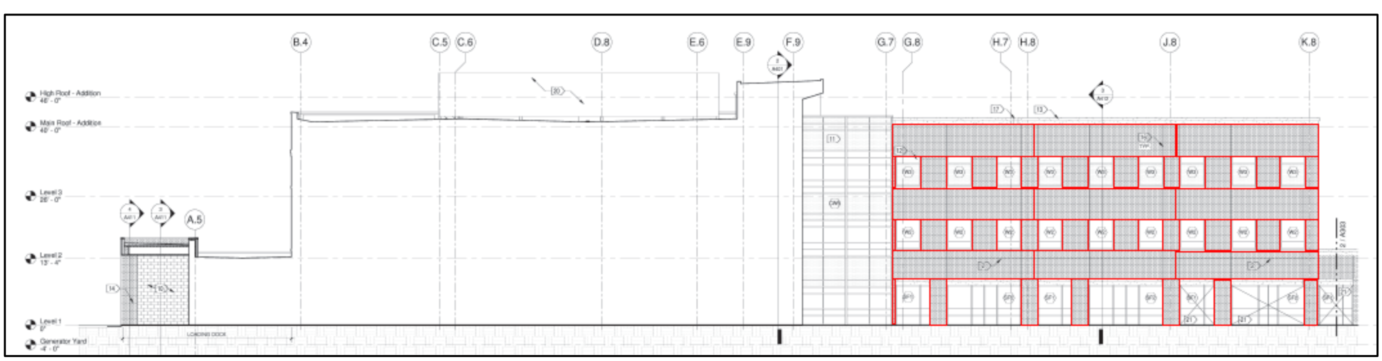


Figure 46, *North elevation* - Storefront windows on the first floor did not permit use of vertical panels on this facade.

Schedule Analysis

With schedule being the driver on this project, a significant opportunity for schedule savings have been revealed through more than just looking at the time to install brick as opposed to precast panels. Ties have been specified to be 32 inches on center horizontally and 18 inches on center vertically, or one tie for each 2.6 square feet of wall area. Due to the large surface area of the building, installing ties takes substantial time. By using precast panels, this step has been eliminated, along with their estimated $21,700 cost. Not only is ample time saved by eliminating the ties, but also due to the elimination of flashing otherwise required to be installed around each tie individually.

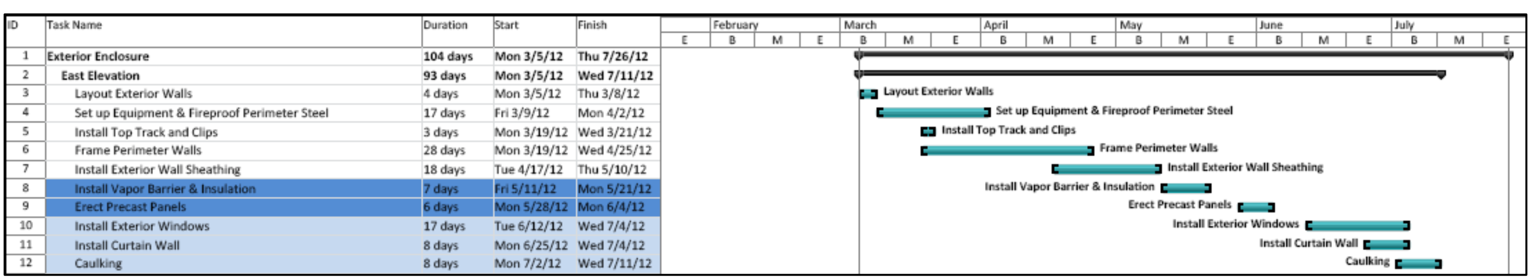
Figure 47 is a picture taken during construction looking at the south façade. Exterior sheathing, DensGlass, can be seen covering the exterior of the building. Brick ties can be seen also running across the entire façade. Blueskin was used on each brick tie because it is waterproof and prevents air or moisture from passing through the penetrations created by the brick ties. Once the Blueskin is placed and all spaces between the DensGlass were sealed, the air and vapor barrier was next applied. Air and vapor barrier can be seen applied on the east façade to the right of Figure 47. It has been estimated that 75% of the time it originally took to install the vapor barrier and wall ties could be saved.

Figure 47 - View looking at the corner of the south and east facade. DensGlass can be seen in yellow, with each individual brick tie having Blueskin applied. This is a necessary step before the air and vapor barrier can be applied. Personal photograph taken by Chris Pozza.

As it has been advised by Mark Taylor, an average of 15 panels could be erected per day. Taking this into account with the 244 total panels used, it is expected to take about 17 days to complete placement of the precast panels.

A detailed project schedule can be found in **Appendix B**. The actual schedule of the exterior façade can be found in **Appendix M**. This schedule is important because it shows planned original durations for individual activities and also their actual durations, which was updated on September 13, 2012.

A schedule for the proposed system can be found in **Appendix N.** All activities prior to the installation of vapor barrier remained the same as the proposed system would not affect these activities. A partial image of the schedule can be seen below in Figure 48. Total panels have been broken down by façade. Using an average of 15 panels per day, total durations needed to be determined for each façade to align with the project schedule's breakdown.



ID	Task Name	Duration	Start	Finish
1	Exterior Enclosure	104 days	Mon 3/5/12	Thu 7/26/12
2	East Elevation	93 days	Mon 3/5/12	Wed 7/11/12
3	Layout Exterior Walls	4 days	Mon 3/5/12	Thu 3/8/12
4	Set up Equipment & Fireproof Perimeter Steel	17 days	Fri 3/9/12	Mon 4/2/12
5	Install Top Track and Clips	3 days	Mon 3/19/12	Wed 3/21/12
6	Frame Perimeter Walls	28 days	Mon 3/19/12	Wed 4/25/12
7	Install Exterior Wall Sheathing	18 days	Tue 4/17/12	Thu 5/10/12
8	Install Vapor Barrier & Insulation	7 days	Fri 5/11/12	Mon 5/21/12
9	Erect Precast Panels	6 days	Mon 5/28/12	Mon 6/4/12
10	Install Exterior Windows	17 days	Tue 6/12/12	Wed 7/4/12
11	Install Curtain Wall	8 days	Mon 6/25/12	Wed 7/4/12
12	Caulking	8 days	Mon 7/2/12	Wed 7/11/12

Figure 48 - Partial image taken from the proposed exterior schedule which can be found in Appendix N. Activities 8 and 9 are highlighted dark blue as the have had their durations significantly shortened. The activities following activities are highlighted light blue to represent their earlier start and finish dates.

Using precast panels could not speed up work or prevent the issues that were associated with previous activities such as framing the perimeter walls, or installing vapor barrier or exterior insulation. However, there are some key advantages that should be pointed out. As discussed, brick ties are completely eliminated using this system. The time built into the actual schedule to apply Blueskin around each individual tie has allowed this activity's durations to be reduced by up to 75%, taking only seven days as opposed to 26 for the east elevation alone. The time it is expected to erect the panels for the same elevation is six days, compared to the 22 days it took to place brick and the accent band on this elevation. These activities are called out in darker blue as they have had their durations shortened. Although the activities that follow, highlighted light blue, don't have durations affected, they are able to be completed much earlier than what was actually done as work is streamlined much smoother.

Significant schedule savings have been made, only looking at one elevation, but these savings could not simply be quadrupled to look at the combined savings. There is a short amount of time allotted in Figure 48 between when the vapor barrier is installed and the start of the precast panel erection. This is because, in all cases, it is estimated that placing the vapor barrier and insulation will take longer than placing the panels themselves. This is built in intentionally as a buffer and to provide the appropriate time needed to mobilize the crane and work ahead of this façade before bringing a crane on site so it can remain actively in use. In an attempt to reduce overall general conditions cost and reduce site congestion, it was desired to have the crane be on site for the shortest duration possible. By sequencing the activities the way it was done, the crane will be required on site for about 17 days.

It has been determined that using precast panels has the potential to save the project a total of 61 calendar days, or two months. Also, the Building Watertight milestone would be pushed up by this same duration. That has other important benefits as interior work can start much earlier than it did. It was also discovered that the watertight milestone was delayed until October 18, 2012. With the proposed exterior work proposed to finish on July 26, 2012, this would be a time period of nearly three months.

Cost & General Conditions Analysis

The price quote provided by Mark Taylor used for the precast system was $35 per square foot. This estimate includes the cost of fabrication, delivery, connections, and panel erection. With masonry being the only material to change while the rest of the system remains the same, only two additional items were necessary to be added to cost of the precast system; joint sealant and rigid insulation. Using precast panels instead of brick requires a significant amount of sealant for panel-to-panel connections. Rigid insulation has been added because that scope of work was included in the estimate provided by DPR for masonry work, $1,131,376. Table 9 below compares the two systems prices. The precast system is more expensive as it requires a significant amount of panels that are various shapes and sizes. This system is estimated to cost an additional $125,814.37.

Proposed Precast System Cost			
Description	Quantity	Unit	Total Cost ($)
Precast Wall Panels	33,780	SF	$1,182,300.00
2" Rigid Insulation	33,780	SF	$58,777.20
Joint Sealant	7,459.8	LF	$16,113.17
	Total Cost		**$1,257,190.37**
System Cost Comparison			
Precast Panel System			**$1,257,190.37**
Masonry Façade			**($1,131,376.00)**
Proposed Precast Additional Cost			**$125,814.37**

Table 9 - Precast panel cost breakdown and comparison to the actual façade used.

Proposed Schedule Savings			
	Days	Weeks	Months
Activity Savings	**61**	**8.7**	**2.0**
Schedule Savings	**45**	**6.5**	**1.5**
General Conditions Costs			
Total Savings (1.5 Months)	**$295,264.35**		
Additional Crane Cost	**$44,078.22**		
Total GC Cost Savings	**$251,186.13**		

Table 10 - Schedule savings and general conditions costs including the crane required for panel placement.

Table 10 summarizes the schedule savings and general conditions costs. The exterior enclosure is expected to have a total of 61 calendar days saved, which moves the watertight milestone up by two months. Although there are significant savings for this activity, the entire project duration is not shortened by this amount. Further investigation of the schedule and discussion with the project team has led to the conclusion that roughly 45 days could be saved, or 1.5 months.

A 110-ton crane has been determined fit for the scope of work, which will be an additional $44,087.22. Average monthly general conditions costs are $196,842.90. Taking into account the month and a half time savings, the total savings is estimated to be $251,186.13. Table 11 is the final summary depicting that precast panels will be cost effective to implement as there will be a total of $125,371.76.

Final Cost Comparison Summary	
Proposed System Cost	$1,257,190.37
Additional Crane Cost	$44,078.22
Actual System Cost	$1,131,376
General Conditions Savings	$295,264.35
Total Cost Savings	**$125,371.76**

Table 11 - Final cost summary of the facade analysis. The total savings are over $100,000 as the duration to complete the facade has been significantly shortened.

Final Recommendation & Conclusion

A complete analysis of the building façade has shown that the mechanical system will not be severely affected as long as proper measures are taken to prevent thermal bridging while the structural steel will not need to be upgraded for the additional loading. The high unit cost of the system is due to the irregularity of the façade and limited amount of repetition the current design permits. It has been learned that it is difficult to design a precast façade for a building with a system already designed; especially one not intended to incorporate any more than a single precast accent band. Even with the extensive design, major schedule savings offset the upfront cost of the system.

It is recommended to use precast panels because schedule savings would be the largest benefit for the project. Use of panels will reduce the overall amount of time and limit the issues due to both weather and details that hindered progress of the façade. Additional labor costs due to larger crew sizes and overtime that were required of the masonry was not taken into account in the cost, which further supports the benefit to be gained through use of precast panels. With the watertight milestone advancing two months, major interior finishes work and construction of the elevator could begin much sooner. The estimated $125,371.56 savings make incorporation of precast panels a worthwhile alternative.

Analysis 3 – Use of Virtual Mock-ups and Implementation to SIPS

Problem Identification

Use of virtual mock-ups is often beneficial to all parties involved as cost of labor and materials are greatly reduced, if not entirely eliminated, compared to fabricating physical mock-ups. It is also beneficial to show project team members; including designers, engineers, and laborers, that details on drawings can physically be constructed with the highest level of quality. Virtual mock-ups have a much higher potential of being implemented on a project when BIM is used. Discussion as to why virtual mock-ups were not utilized on this project as originally intended is included in the Background Investigation & Case Study section.

Details tying the new structure to the old along with wall penetrations for egress proved to be problematic throughout construction. The original details provided proved to be challenging and, after investigating it further, it was deemed that they were indeed unworkable. It is believed that creating virtual mock-ups could have helped expedite the process of determining a viable solution. Also, because details did not capture all the issues needed to be dealt with, the time it took to physically construct the wall penetrations was not as efficient as it could have been. Therefore, a short interval production schedule (SIPS) was created using the mock-up generated to have as little disturbance as possible for the existing building's occupants.

Had the detail been created in a virtual mock-up, issues could have been discovered much earlier and most likely led to a quicker solution. With several connections and passages between the addition and existing building, time and effort could have been saved before construction of these areas was approaching.

Research Purpose

Virtual mock-ups were originally intended to be created for an operating room, patient room, an office, building interface details, connection details, and other locations judged necessary. The reasons why these were never created have been determined and it was a goal to establish where mock-ups could have been beneficial and their associated potential value for the project.

Once researching how to implement mock-ups for this specific process, a goal was to determine the constructability issues associated with each mock-up and time it required to complete the work. Research was done in an effort to determine how this scope of work could be done more efficiently. Once it was decided to incorporate a SIPS, the purpose of the investigation conducted was to see if creating this detailed schedule in relation to the mock-ups created could add value to the project.

Background Investigation & Case Studies

Virtual mock-ups have been discussed more frequently in the construction curriculum as BIM continues to gain momentum in the industry. The benefits of mock-ups seem to make them very logical embellishments. Potential benefits include:

- Solve design/constructability issues
- Provide visuals for end users and laborers
- Compare alternative designs
- Eliminate rework and schedule time
- Make projects safer and reduce risk

These are a few examples how virtual mock-ups can add value to a project, although precise cost assessments cannot be quantified for each. More time is typically required upfront, but time is to be saved during construction by eliminating coordination issues and design modification. Before looking at potential areas practical for creating mock-ups, investigation was conducted as to why mock-ups were not created as originally planned.

BIM services were contractually required to be performed by DPR; however, preconstruction services were not purchased by KP. This led to several missed value engineering opportunities and did not permit any early design input from healthcare-experienced team leaders. Creating the BIM took approximately 100 days longer than expected. This was due to coordination and finalizing the design occurring simultaneously during construction, extending the time necessary compared to if a large portion of the design had been modeled and complete prior to construction. Some of the major design issues included coordination of the imaging area, limited ceiling space for both 2nd floor ducts and operating room MEP and boom supports, and arched ceilings.

Because coordination of the BIM took nearly twice as long as expected, time was never allotted for mock-ups to be created virtually. Another opportunity soon discovered after researching mock-ups were the potential to create short interval production schedules based off the actual mock-up, which will be discussed in more detail later in this analysis.

Case Study – Tyson's Corner

DPR has worked with KP previously. One location is Tyson's Corner, Virginia, where renovation of an existing office building was converted to a medical office building and outpatient service facility. Virtual mock-ups were created to be reviewed by the end users. It was estimated to cost about $7,500 for the BIM Champion to model 32 rooms. Stemming from the mock-ups were 110 individual changes costing roughly $38,000. Subcontractors were not released to price and proceed until three months after the reviews took place. Another interesting fact was that the changes took a long time to be approved. In correlation, finished rooms had to be changed and mock-ups weren't practical for contractors putting the work in place (Goodman).

Figure 49 - Mock-up of a patient room for Tyson's Corner. A mistake found here was that electrical drawings specified outlets were to be placed 8" above the counter, but no counter exists in this room. Image courtesy of Shane Goodman.

After learning more about Tyson's Corner and knowing where some major challenges were experienced on this thesis project, it was decided to focus on implementing mock-ups of building connections. Interfaces and penetrations between the addition and existing building have been identified as locations where virtual mock-ups could have been a key benefit. Creating the details could have showed the difficulty involved with the original design, and a solution could have been discovered much earlier. During construction, RFI's were created as new details were needed and additional labor was required by the unexpected issues. More in-depth coordination could have strongly aided laborers during construction as well as the owner to see how the existing building was going to be impacted. There are several locations that the addition affects the existing building. Main locations include:

Northwest Connection and Egress Penetration

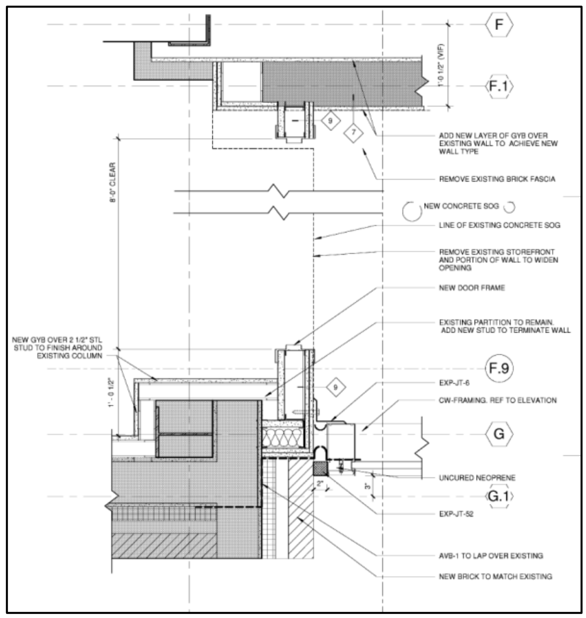


Figure 50 - *Far Left* - Corner of the existing building before aluminum curtain wall tied into it. Also, a board can be seen covering the opening of where the new doorframe will be placed. Personal photograph taken by Chris Pozza. *Right image* - Detail of the original tie-in connection. Detail courtesy of Ellerbe Becket.

A similar penetration on exists on all three floors in this location. The original detail created can be seen above in Figure 50. This area has been analyzed in more detail and will be discussed in the Implementation & Schedule section.

Third Floor Office Window

Plans specified that the window seen in Figure 51 was to remain in place, although this is not possible as the addition ties into the building at this location. Coordination was necessary to try completing this work on premium time to avoid impacting this room's occupants at any time throughout construction.

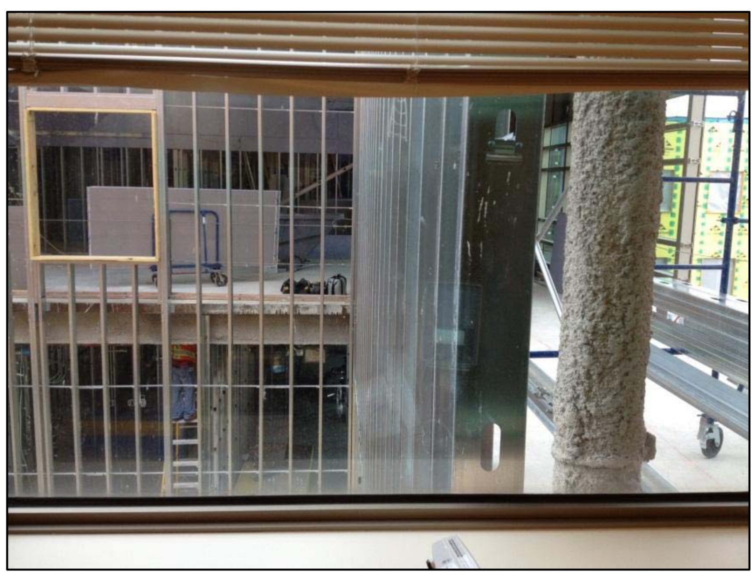


Figure 51 - 3rd floor window that was required to be removed and replaced with a smaller window and filled with brick for the addition to be able to tie. Work was performed off hours to limit the impact of building occupants. Photo taken from inside the existing building looking south at the addition. Taken by Chris Pozza.

Existing Building Stair Tie-Ins

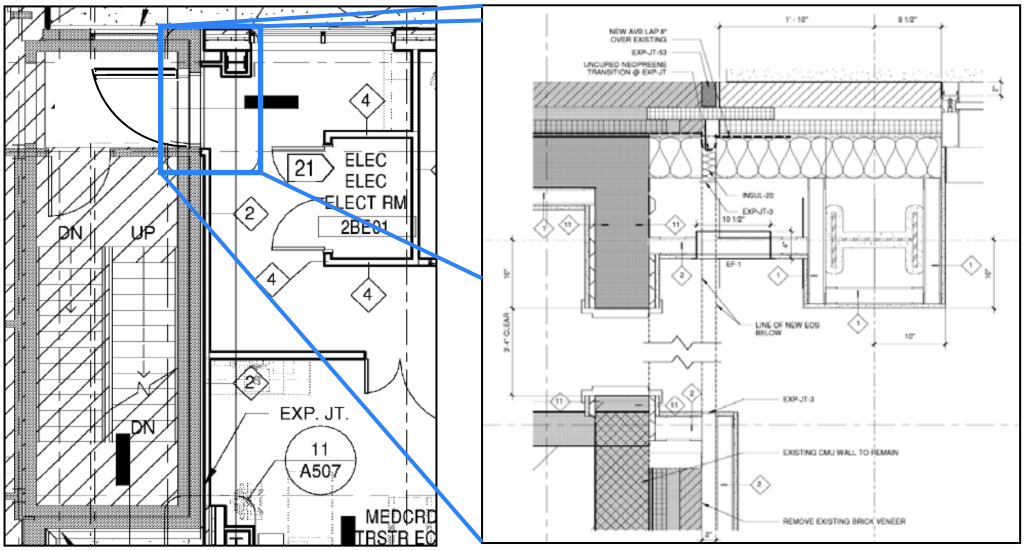


Figure 52, *Far Left* - Partial image of the second floor connection tying the addition to the existing stairwell. The diagonal hatching represents areas of the existing building not to be affected during construction. *Right* - Detail of the wall penetration which occurs on the second and third floor, as well as a final penetration providing access to the addition's roof. Images courtesy of Ellerbe Becket.

Very similar to the northwest building connections, the northeast connections in Figure52 show egress between the buildings. The doorway to be added ties the addition into an existing stairwell. There are a total of three tie-ins to this stairwell. One issue with this scope of work required additional work estimated to cost over $43,000.

Characteristics of Short Interval Production Scheduling (SIPS)

Short Interval Production Scheduling has been a topic in several Penn State construction courses. AE Professor, Dr. Craig Dubler, has incorporated SIPS into class projects in both AE 372 and AE 473 along with a variety of discussions and case studies. A case study included in this report includes creating a schedule for the mechanical scope of work in the Pentagon renovation project. There are three key traits of a SIPS that differentiate it from traditional scheduling:

1. One specific operation is analyzed
2. A much higher level of detail is developed
3. Personnel input and commitment from all involved parties is required

The largest benefit of SIPS is to maximize field productivity. Doing so can quickly offset any of the upfront cost of coordination and project team involvement. As construction tasks are divided into repetitive activities, this becomes extremely useful for large projects having these activities extensively impacting the project schedule. With buildings such as high rise offices, hotels, apartments, and prisons being facilities that typically utilize SIPS, there is also a learning curve associated with the work providing even larger schedule savings as the project progresses. The level of detail involved usually requires activity durations to be listed in hours unlike most traditional schedules that measure durations in days (Dubler).

Even though there have been only a few specific examples listed above, it is believed that both construction time and schedule savings could be provided by performing the level of detail provided through a SIPS. This level of detail could only be provided through use of virtual mock-ups as neither drawings details existed nor was there ever an official schedule created with specified durations for the required activities.

Case Study – The Pentagon

A presentation provided by Craig Dubler and Southland Industries discussed how a SIPS was used on wedges 2-5 of the Pentagon renovation project. A SIPS was developed for highly repetitive mechanical work to be done in five stories of each wedge. The process required to develop this schedule include:

- Define zones
- Identify activities
- Calculate durations
- Develop activity sequence
- Plan work / material space
- Review plan with foremen and superintendents
- Modify and communicate plan

There were some major challenges the project team faced trying to develop this schedule for the mechanical scope of work. During planning, absence of a 3D model made coordination more difficult. Another challenge was getting buy-in from all parties involved. Foremen, especially, were skeptical at first and it was difficult to get their buy-in for the more in-depth coordination.

Activities by Zone

Job Name: Pentagon - Wedge 2-5 Renovation — Zone: Main Bar

ID	Trade	Activity	Quanity	Unit	Budget Production (Units / MHR)	Total Budget Time (MHR)	Crew Size (People)	Activity Duration (HR)	Activity Duration (Days)	Resources Needed	Notes
10	SM	Layout/Install Duct Hangers	1	total	0.03	32	2	16.0	2.0		
20	PF	Layout/Install Pipe Hangers	1	total	0.02	48	2	24.0	3.0		
50	SM	Hang Induction Units	20	ea	0.25	80	2	40.0	5.0		
60	PF	Chilled Water Mains (S&R)	290	lf	7.50	39	2	19.3	2.4		
70	SM	Install Duct Mains (OA)	490	lf	7.00	70	2	35.0	4.4		
80	PF	Install Branch CHW Lines	20	ea	1.00	20	2	10.0	1.3		
90	PF	CHW Coil Connections	20	ea	0.50	40	2	20.0	2.5		

Figure 53 - Example of SIPS used for the mechanical scope of work. Image provided by Southland Industries.

Once all parties were on board, the methodology proved to be very effective in producing an efficient plan for the scope of work. An important thing to note is a lesson learned which was discussed; virtual and physical mock-ups were extremely helpful. The simulation model was also advantageous for getting constructability feedback from foremen and incorporating any necessary changes into the plan. The model became a very useful communication tool (Dubler).

Virtual Mock-Ups and Opportunity for Short Interval Production Scheduling (SIPS)

Although projects that use SIPS are usually highly repetitive, large-scale projects; that does not mean that there is not a significant benefit to be gained by incorporating them into smaller projects. Virtual mock-ups have proved to be beneficial on projects of all sizes. It was decided to perform this analysis as schedule has been the driving factor on this project and the reoccurring theme of this report. Regardless of the time allotted in the schedule for it, coordination of each of the potential areas described required additional coordination to be completed. However, this coordination could have potentially been done more efficiently if scrupulous modeling took place to reach the level of detail required to successfully implement a SIPS. Unlike Tyson's Corner, the individuals performing work could have the same, if not greater, opportunity as the owner to benefit from use of virtual mock-ups.

Process

The area that has been analyzed is the building connection at the northwest corner of the addition. First, a detail of the building connection was created. A mock-up was initially created using the original details. At a quick glance, it might seem that this detail is acceptable, but there are two major issues with it that are much more transparent when modeled. The first and most obvious issue shows a break in the building envelope. This can be easily fixed in the drawings; the bigger problem is the air/vapor barrier and expansion joints listed. The air/vapor barrier was originally supposed to be connected both the aluminum framing of the curtain wall, span the gap between structures and expansion joints, and finally overlap the existing structure's exterior sheathing (beneath the rigid insulation).

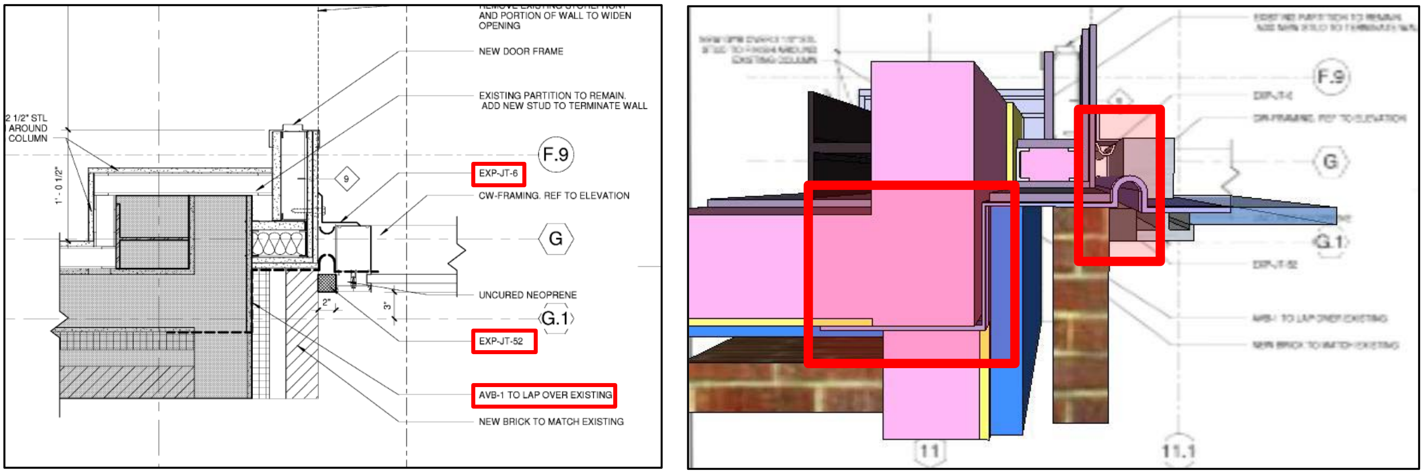


Figure 54, *Left* - Original detail for the addition tie-in to the existing structure. The three main concerns with this detail are highlighted in red; the two expansion joints and air/vapor barrier. *Right* - Plan view of the same detail created in Google SketchUp. It is much easier to see the challenges with this detail, especially with overlapping the air/vapor barrier on the existing exterior sheathing and beneath the rigid insulation.

After speaking with superintendent, Jeff Bush, it was established that trying to determine how this detail could be constructed was a lengthy process that involved several information exchanges over roughly a two-month period before a design was accepted. He added that having a mock-up to use for proposing a solution could have rapidly sped up this process. Although reaching the solution was time consuming, the actual solution itself was relatively simple. An EMSEAL expansion joint was used, replacing the need for all three items previously discussed. This is an extremely durable, waterproof sealant that was acceptable to use between the aluminum framing and brick façade. Once the solution for the building interface was accepted, modeling of the rest of the tie-in could ensue.

Figure 55 - SketchUp view of the proposed doorframe in place providing a means of egress to and from the existing building. Model created by Chris Pozza.

Because no details or drawings specified how to construct the connections, outside help was pursued to get a better understanding of the means and methods of building this detail. Having a model was extremely helpful for me to see what physically needed to be done, but sequencing activities and durations associated with each were yet to be determined. A construction foreman, Mark Pozza, with over 30 years of experience was interviewed before developing a SIPS for the content seen modeled in Figure 55. It took about one hour to compare the draft schedule initially created with the model and make appropriate adjustments to both the model and schedule based off of his input. The original SIPS can be seen below in Figure56, and the final schedule is attached in **Appendix Q**.

Project: Kaiser Permanente Largo Medical Office Building   *Zone:* Northwest Building Connection

Activity	Quanity	Unit	Budget Production (Units / MHR)	Total Budget Time (MHR)	Crew Size (People)	Activity Duration (HR)	Activity Duration (Days)	Notes
Construct Temporary Partition	1	EA	0.25	4	2	2.0	0.3	Wood Studs/Drywall Enclosure - Off-hours (OH)
Remove Drywall/Insulation	75	SF	18.75	4	2	2.0	0.3	Tear Down / Clean Up - (OH)
Relocate Electric Conduit	15	LF	5.00	3	1	3.0	0.4	Determine source location if needed
Saw Cut Brick/Remove Studs	75	SF	4.70	16	4	8.0	1.0	Including 3 courses below finished floor - (OH)
Insert 5/16" Bent Plate	8	LF	2.00	4	4	2.0	0.3	1/2" Diameter 6" Imbeds, 24" O.C. - (OH)
Place Concrete/Expansion Joint	1	CY	0.50	2	2	2.0	0.3	Joint depressed 3/4" for cover
Set Door Frame	1	EA	0.33	3	1	3.0	0.4	
Frame Opening/Header & Studs	1	EA	0.13	8	2	4.0	0.5	
Drywall & Spackle	75	SF	25.00	3	1	3.0	0.4	Both sides, assume half the total area each side
Hang Doors/Install Hardware	1	EA	0.20	5	1	5.0	0.6	Double Set with Panic Hardware
Prime/Paint	75	SF	25.00	3	1	3.0	0.4	Both sides, assume half the total area each side
Remove Parition/Cleanup	1	EA	0.25	4	2	2.0	0.3	Off-hours (OH)
TOTALS				55	21.0	37.0	4.6	

Figure 56 - SIPS created for the northwest building connection on the first floor. The total duration to complete the work will be roughly 37 hours.

Quantifying the total work, it is expected to take 37 hours to complete one tie-in. During a site visit in early March, this schedule was discussed with the superintendent responsible for this scope of work, Tony Gill. It took Tony roughly five minutes to point out the activities that required to be done during off-hours and make some slight adjustments for crew sizes required for various project-specific reasons, but not affecting the overall durations assumed.

Because the model components were grouped in layers by material and a Google SketchUp file, it can easily be exported to Navisworks where next one can be check for clashes as well as schedule the activities. Again, this is something that takes very little additional time as long as the model is portrayed accurately in SketchUp. This, along with other ways models can add value to the project will be discussed in the Potential Benefits section. Without use of the model for the mock-up created, no clashes detections were performed, but this is a key step that led to missed opportunities on the project as field-discovered issues could have possibly been prevented through this 3D coordination.

Subcontractor Buy-In

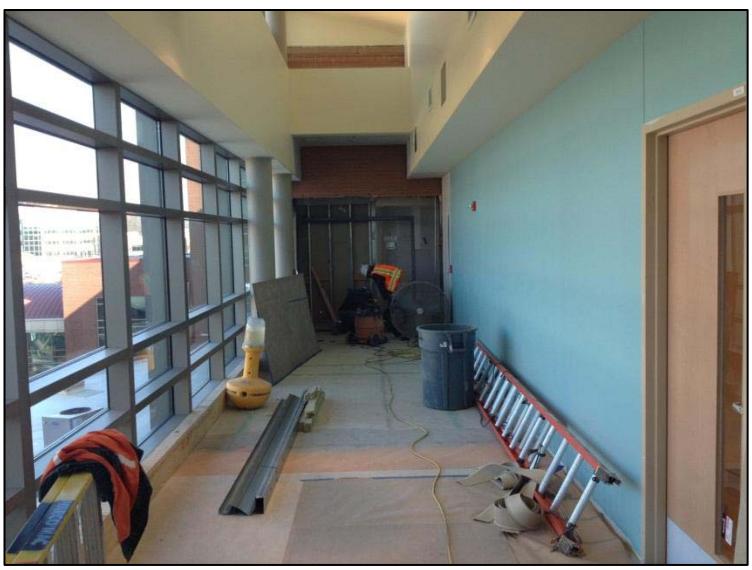
Getting people to set aside the time necessary to coordinate such a plan is not always easy. Many people are skeptics of technology and would prefer to instead start the work and do their best to get the job done as quickly as possible. Although BIM coordination did not go as smooth as it was originally expected, the subcontractors involved were responsive and believed that modeling was an added benefit as the coordination had to take place with or without a model. It should also be noted that a large portion of the work involved was to be completed by DPR's self-performing group.

Potential Benefits

Several opportunities for adding value to the project are presented through developing a SIPS using virtual mock-ups, many of which have been discussed in the case studies. One of the first benefits is to show end users what these areas are going to look like. Seeing how the existing building is going to be affected by the penetration and tie-in work is important to owners as the building occupants are always a main concern during construction. Owners can decide if the architectural features are acceptable before work goes in place as well as possibly eliminate any need for rework. If any major clashes are detected or challenges presented by dimensions or variations from the contract drawings that require a scope change, the model can help justify any additional work necessary. Any design issues requiring further information can help provide more timely responses as well.

Another great benefit for the owner would be to reduce the opportunity for any possible inconvenience for the existing building occupants during their regular work day. Work can be planned as efficiently as possible with accurate information from subcontractors. With nearly half of the work required to be completed done on premium time, each activity being scheduled in the most effective manner will cut down on additional overtime costs.

The main reason that building connections are being analyzed is for the potential benefit to be shared by those in the field responsible for putting work in place. Getting subcontractor input ensures that activities are scheduled appropriately and holds them accountable for their work. Having a well-coordinated model can help prevent unforeseeable issues that would otherwise be easily detected virtually. A model would also be able to provide specific dimensions for laborers reference as no details existed other than in Figure 52. The left image in Figure 57 shows two laborers working on the expansion joint on the third floor tie-in. A problem arose here as the expansion joint did not line up as expected, setting back progress in the area as additional concrete was required to be chipped away. Code defined this passageway as a means of egress in case of emergency. This issue was discovered with less than a week until an inspection of this area was planned, making completion of this work urgent (Gill).



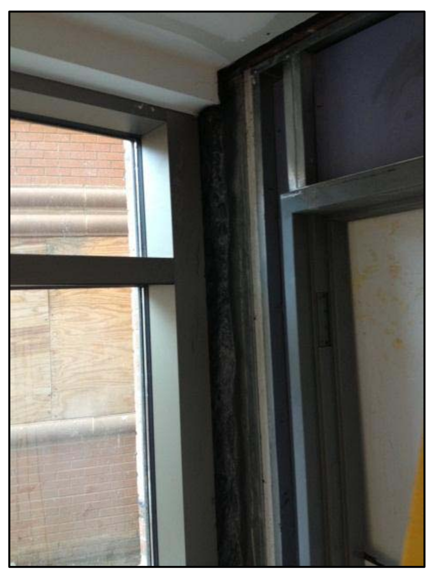


Figure 57, *Left* - Laborers working on the expansion joint between the floor slabs of the existing floor slab and addition. Issues required this scope of work to take much longer than anticipated due to the slabs not lining up as intended. *Right* - Building connection between the addition's aluminum curtain wall and existing building. Framing and a door frame can be seen already in place.

Final Schedule

It has been determined that the entire scope of work associated with making a connection tie-in can be started on a Friday and completed on a Tuesday. Taking into account the activities that needed to be done on premium time and can't be performed during the existing building's regular hours, construction of each penetration should commence on a Friday evening. Because the critical activities of saw cutting brick, removing studs, and placing the steel bent plate will require the most man-hours and need to be done during off hours; Saturday has been designated for this time so this work can be continuous. Other activities can take place during regular scheduled hours as there will be minimal disturbance created. The final task to be done on premium time will be to remove the temporary partition wall and cleanup. Overall, the duration to complete work can be done over a period of five days if a by using a virtual mock-up to conduct proper coordination.

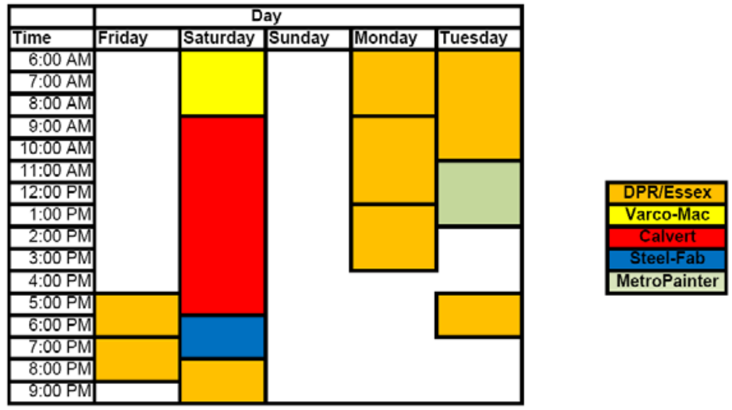


Figure 52 - SIPS breakdown by day and appropriate trade during each designated activity. The majority of work can be seen being done on Saturday to create as little disturbance as possible for the existing building occupants.

Although a schedule for the actual construction was never created, discussion with the superintendent responsible for this scope of work has confirmed that work took a significant amount of time. The total duration it actually took was much longer than what was originally anticipated. Also, coordination between activities and trades was not as integrated as it could have been so work was not continuous. With that, two activities took longer than anticipated, including demolishing the parts of the wall for the frame and inserting the steel bent plate; both of which were performed on premium time. There were very similar issues for tie-ins to the existing stairwell.

Associated Costs

Before looking at the durations required to plan and coordinate this work, the time it took me to complete each task were analyzed. It is important to note that this was my first time creating a virtual mock-up and no corrected details were actually produced for use. To create the entire mock-up of the building interface and penetration with no details, it took roughly five hours to do so. This included revision time and exporting the file to Navisworks to create a 4D schedule. One hour was required from a construction foreman, Mark Pozza, to review the model and revise the schedule created.

It was discovered in the Tyson's Corner case study that creating each virtual mock-up averaged roughly six hours, but this duration was for mock-ups of entire rooms. It also needs to be taken into account that BIM Champions have a significant amount of experience with mock-ups, so it is expected to take an experienced professional much less than it would take me at this point of my career. After discussion with Matt Hedrick, the project's BIM Champion, it was assumed that creating the same mock-up would take roughly two hours as he was much more familiar with the project and solutions for these types of issues. The time it would take to plan the work by a superintendent is estimated to be roughly one hour. This time includes investigating the area, looking at specific times activities could be performed, and considering any site logistical issues that could pose a challenge. An additional half hour has been added for the BIM Champion and superintendent for review of the mock-up created and discuss any unexpected issues, which also comprises revising and editing the model and schedule as necessary.

Even though additional coordination was required, time was saved in other ways. The superintendent was required to plan this work and discuss issues with each involved trade individually. This was a repetitive process that included visiting the areas being discussed and trying to determine durations. Because the electrician, mason, and DPR's self-performing crew each had foreman on site, one meeting could take place after the model and schedule are complete to bring all trades together and ensure the scope of work can be completed as planned. Assuming coordination with trades could be combined, this would save the superintendent at least half an hour. Coordination time for foremen is assumed to be the same, so there is no additional cost included; but the value of the information exchanges are anticipated to be much more beneficial. Instead of documenting project team member's salaries, the combined total for 2.5 hours of the BIM engineers time and 1 hour for the superintendent involved has been combined to approximately $307.50.

As previously discussed, the major issues were with placement of the steel bent plate and expansion joint. The additional duration for each activity was estimated to be 3 and 4 hours due to issues discovered in the field, compared to the proposed time determined in the SIPS. Table 11 summarizes the total man-hours. Using RSMeans to determine the hourly rate of an average skilled worker and making appropriate adjustments, 20 additional man-hours at a premium rate translates to a cost of $2,034.60.

Additional Man-Hours for Building Tie-In			
Activity	Time (hr.)	Crew Size	Man-hours
Insert 5/16" Bent Plate	3	4	12
Place Concrete/Expansion Joint	4	2	8
		Total Man-Hours	**20**

Table 11 - Additional man-hours that could have potentially been eliminated by using virtual mock-ups for a SIPS. This is an estimated to cost over $2,000 due to work being done at premium rate.

For the mock-up analyzed, the estimated savings determined was $1,727.10 due to the amount of premium-rate labor that could be eliminated. Although more specific examples could not be determined, it is expected that creating virtual mock-ups to tie into a SIPS for building connections would add value to the project for both the owner and construction team.

Final Summary & Conclusion

It is recommended to use virtual mock-ups for building interface and tie-ins, and implement the use of SIPS. The following reasons summarize the potential value to be added:

1. Models serve as a strong visualization and communication tool for all parties
2. Subcontractors are able to accurately prepare for work and provide planning feedback
3. Eliminate coordination issues otherwise unforeseeable without a virtual mock-up
4. Show end users how existing building will be impacted
5. Perform premium-rate work the most efficient way possible
6. Cause as little disturbance for building occupants

Although these activities did not affect the critical path, time savings can help offset the cost of additional upfront coordination. A precise duration how long each tie-in took could not be determined, although it required a few to several weeks. With mock-ups proving to be helpful at Tyson's Corner for the owner, they provided little use for the tradesmen in the field. It is believed that creating mock-ups for these connections will be equally as beneficial for the people responsible for putting the work in place. Many of the benefits cannot be assigned values, but the estimates determined are summarized in Figure 59.

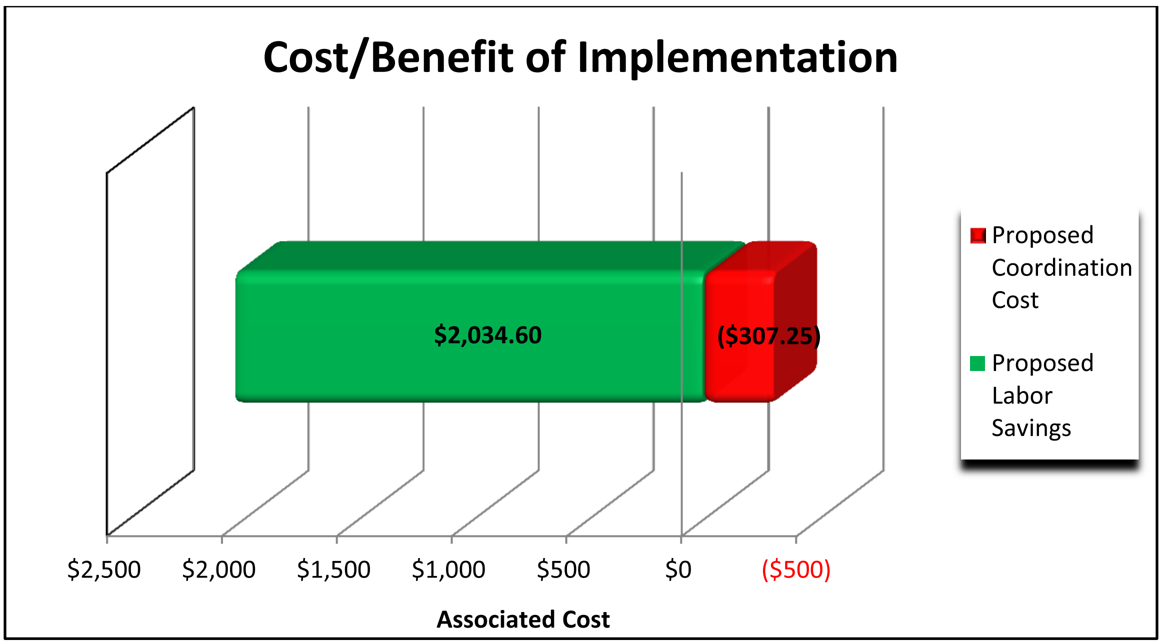


Figure 59 - Proposed savings shown against expected costs associated with producing a virtual mock-up for the building tie-in at the northwest corner of the addition. Estimated total savings are $1,727.10.

Reducing any form of disturbance that could hinder productivity for the building occupants is another added benefit making all of these worthwhile. The use of the single mock-up analyzed can produce over $1,700 worth of possible savings. Savings are expected to greater if the same measures were taken for other areas of the building.

Analysis 4 – Complete Headwall Modularization vs. Partial Modularization

Problem Identification

With an extremely challenging project schedule, it became a goal to find the most effective ways to increase productivity on site. Having too little time to perform too much work was common on this project. More in-depth use of modularization has been a common topic in the construction industry, and was a major discussion point at the PACE Roundtable in the fall semester.

Determining the best area to the implement modularization wasn't clear until after discussion with industry professionals. In hospitals and medical office buildings, headwalls are commonly modularized. On this project, headwall units were prefabricated offsite by Modular Services, however, just because a modularized headwall is being used, that doesn't mean that time and labor are going to be used as efficiently as they can be.

Research Purpose

The goal of all research conducted has been to learn more about headwall units, prefabrication process, constructability issues, and means and methods of installation. Fabrication and installation of an entire wall assembly will be compared to the process that was actually performed with only having the headwall itself being prefabricated. After discussion with industry professionals at the PACE roundtable, it was noted that headwalls are commonly prefabricated and would be a good area to analyze, especially for the increase in labor productivity.

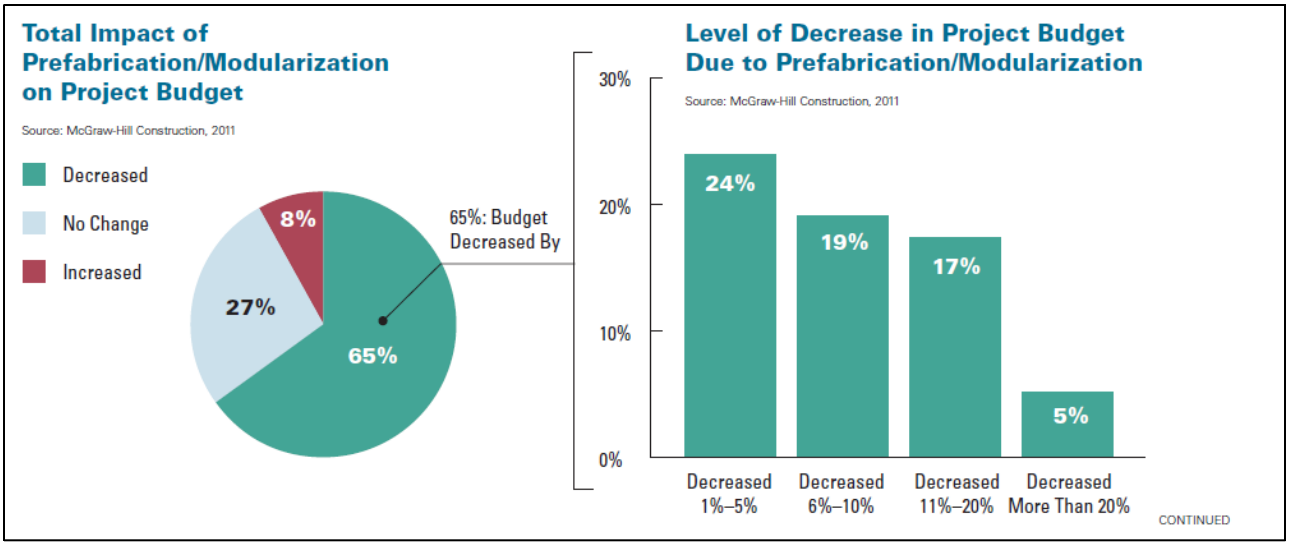
It is easy for people to be misconstrued in thinking that because the headwall units are delivered in modules, they are the best thing available for construction; but this isn't always the case. Project team members recommended prefabricating headwall units because of the significant time that each trade spends on each unit. Further investigation has been done on the potential opportunities available for improving installation efficiency.

Background Investigation & Research

Modularization was a major discussion topic at the PACE Roundtable as prefabrication is becoming more prevalent in the construction industry. More systems are able to be modularized as technology improves and schedules can be destined to fail before construction starts without the use of modules. Headwall units involve work to be done by several trades as they are tied to power, medical gas, nurse stations, and other systems. This medical office building has two different types of headwalls; 42 of Type 1 and 7 of Type 2 for a total of 49. With so much repetition, work could be much better streamlined as trades wouldn't be required to spend as much time dealing with the headwall rough-ins.

There is significant lead time associated with any sort of modules. Unlike some medical equipment, such as MRI equipment, that is installed as late as possible to have the latest technology, headwalls are relatively simple in design. Lead time for prefabrication of these units was not an issue for a few reasons. Outlets on each unit are going to be designed to match those on headwall units in the existing building to keep equipment similar throughout the facility. This was decided so that all equipment currently being used will be compatible and consistent to prevent staff confusion.

Even though there is more time and cost associated with producing modules, there is usually a significant payback later. It is evident why use of prefabrication and modularization is catching on quickly in the industry. A study done by McGraw-Hill Construction included in a SmartMarket report shows 65% of projects decreased budget as well as schedule savings. There is a widespread advantage to be gained throughout the construction industry, and it is evident in Figure 60.



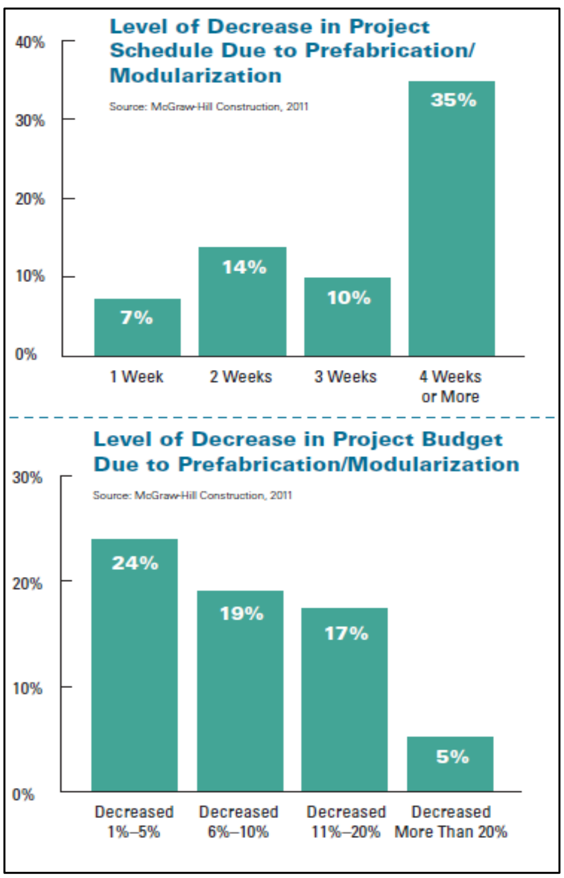


Figure 60 - Data established in McGraw-Hill's SmartMarket report. *Above* - 65% of projects have seen a reduced project budget due to prefabrication/modularization. Only 8% of project budgets increased. *Left* - Significant schedule savings and budget savings can be seen. These projects include a wide variety costs and degree of implementation. Information from the 2011 McGraw Hill *SmartMarket Report; Prefabrication and Modularization: Increasing Productivtiy in the Construction Industry.*

Traditional Installation

Each headwall used on the project is shipped with its own specific template to be used during construction before drywall is installed, as seen in Figure 61. Prior to installing the template, stud walls need to be built and framed to house and support the headwall unit. The template shown here spans three spaces between studs, but the actual headwall extends well past this width to be either 96" or 102" wide.

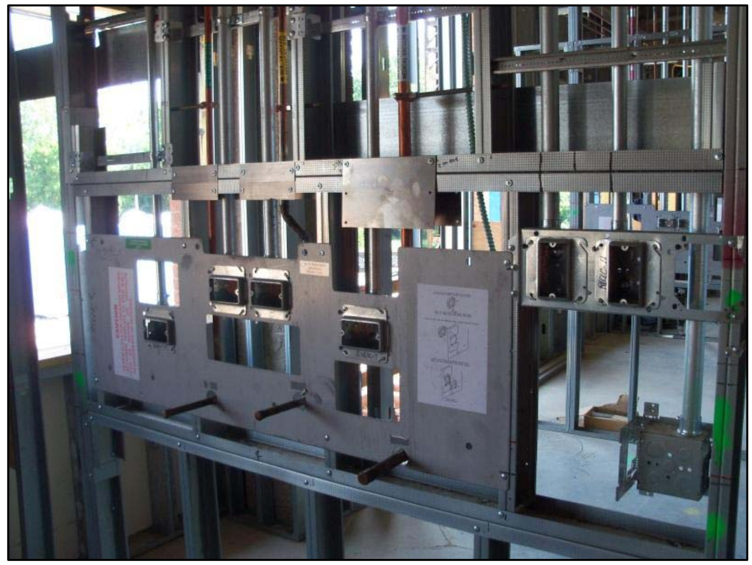


Figure 61 - Headwall template can be seen in place with medical gas and conduit rough-ins. Personal photograph taken by Chris Pozza.

Medical air, vacuum, and oxygen pipes can be seen in Figure 61. Each pipe needs to protrude several inches beyond the template and be capped for pressure testing. Once the pressure tests take place, each pipe needs to be measured and cut to specific lengths that are indicated on the template. After all rough-ins are complete and all dimensions are adjusted and correct, the modular unit can be installed when drywall is hung and painting is complete.

Typical construction involves one subcontractor installing vertical drops from the ceiling tie-in points to the headwall system. Once either the pipe or conduit is installed and connected to the wall studs for support, the subcontractor is finished and able to move on; the next subcontractor to follow will proceed with his respective scope of work for that particular headwall. Although this seems like a normal sequence of work, the problem is that there is no actual coordination between subcontractors. As long as laborers are not physically in each other's way, there doesn't appear to be an obvious problem hindering productivity (Rhodes).

Figure 62 - Modular headwall units used on the project. This image was taken on the third floor of the KP Medical Office Building. Personal photograph taken by Chris Pozza.

Trades are required to work around pipe and conduit already installed, that also includes obstacles located on the other side of the headwall template. After discussion with Dan Crutchfield of DPR's drywall and framing group, it was clear that quality issues can arise because of this. Headers that have been framed to house the equipment are sometimes cut and modified for penetrations to the point that they are more damaged and need replacement.

A picture of the finished headwalls can be seen in Figure 62. These units are what are prefabricated as pre-wired modules, which still requires connections to be made for final installation.

Proposed Modules

Headwalls can be prefabricated to include almost any possible combination of medical gases, electrical systems, communications, and many more. Cory Trent of Modular Services was consulted to learn more about headwalls and their fabrication. Modularized headwall units are framed using 16 gage steel studs. Connections to junction boxes and other equipment can be made at the ceiling, thus eliminating the need for any vertical drops such as the ones used on this project. Similarly to the ones installed, the general contractor coordinates installation and the warranty starts once the facility is open for patients, although they are the contractor's liability upon arrival to the site.

An image of the proposed modules can be seen in Figure 63. Notice junction boxes and medical gases are already installed to the top of the unit, even though no conduit or piping can be seen anywhere else in the photograph. This provides for significant labor savings opportunities and quality is guaranteed due to prefabricating the panels off site in a controlled environment.

Figure 63 - Proposed headwall module. The entire unit consists of piping, conduit, wiring, framing, and other necessary components. Connections are made above the finished ceiling for a convenient means of installation as no vertical drops are necessary to be roughed in. Image from Modular Services.

Transportation & Placement

The proposed units are to be transported generally the same way the actual systems were. Although these systems are much larger, the width is only a maximum of a few inches thicker than the entire headwall's width. Units are shipped in cardboard and all of them should be able to fit in one shipment as well. It is a two-person job to install these units and usually an electrician and plumber are present to make connections once the modules are placed. Modules are estimated to take one-half to one-third the time install as units that are not modularized; labor time depends on the amount of connections in each headwall. Standard lead time associated with the modules is 60-90 days, the same as the actual units.

Schedule Analysis

Discussion with project team members and tradesmen has led to the average durations determined per headwall unit. Activities that have time savings include framing headwalls, and in-wall electric, med gas, and tele/data rough-ins. The actual schedule has been used, which can be seen in **Appendix R.** Actual durations took much longer than originally anticipated. Discussion with the DPR project scheduler, Bob Nimorwicz confirmed that the durations were indeed excessive due to change order work. Proposed durations are included with the actual schedule. Because of the extended durations, it was deemed that the critical path would not be shortened, although there are significant labor savings. The following tables summarize the total savings for each activity, area of the building, and total. Table 12 shows total man-hour savings while Table 13 determines total daily savings.

Labor Savings (Man-Hours)					
Activity	Average Unit Durations (hr.)	L1 - Area B	L1 - Area C	L3 - Area B	Total
Frame Walls	2	32	16	50	**98**
In-Wall Electric Rough-Ins	3	48	24	75	**147**
In-Wall Med Gas Rough-Ins	5	80	40	125	**245**
In-Wall Tele/Data Rough-Ins	1.5	24	12	37.5	**73.5**
				Total	**563.5**

Table 12 - Breakdown of man-hours saved per building area. For the four activities combined, a total of 563.5 man-hours could be saved using modules spanning floor to ceiling allowing for tie-ins to me made to overhead rough-ins.

Schedule Savings (Days)					
Activity	Average Unit Durations (hr.)	L1 - Area B	L1 - Area C	L3 - Area B	Total
Frame Walls	2	4	2	6.3	**12.3**
In-Wall Electric Rough-Ins	3	6	3	9.4	**18.4**
In-Wall Med Gas Rough-Ins	5	10	5	15.6	**30.6**
In-Wall Tele/Data Rough-Ins	1.5	3	1.5	4.7	**9.2**
				Total	**70.4**

Table 13 - Activity savings provided in days. 70 full days will be eliminated by using larger modules that include vertical drops, but changes during construction added a significant amount of time to each activity, thus not allowing for any savings for the overall project schedule.

Disclaimer

Headwall units were purchased directly by Kaiser Permanente so precise cost information could not be provided. Vendors provided estimates, but requested that all quotes remain confidential. Estimates have been taken into account for the total cost analysis, but exact amounts were left out of this report.

Cost Analysis

Using RSMeans, labor and material values have been estimated which can be found in **Appendix T**, but exact prices have been left out of this report. Values quantified include additional materials and labor that would be eliminated by using the proposed modules. Things like connections to overhead utilities were not included as this would take place with both systems.

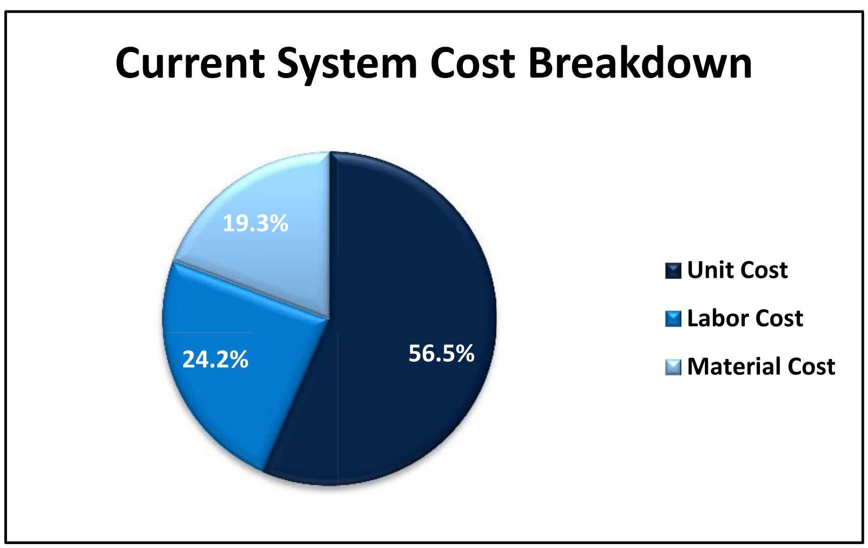


Figure 64 - Pie chart representing the cost associated with the modules used. It is important to note that these labor and material costs are the additional costs that would be eliminated by using the proposed module.

Figure 65 shows the cost comparison of the systems. Red represents the total cost of the proposed system while green represents the potential value to be saved from elimination of the labor, and unit and material cost that was estimated. It has been determined that for each module, only 47% of the proposed cost would be offset; therefore, the new systems are expected to be about 53% more expensive. It was expected that the cost would be substantially more, but that the labor and schedule savings would offset the cost. Because it could not be determined that there were any schedule savings for the overall project, this cost could not be offset by any general conditions savings.

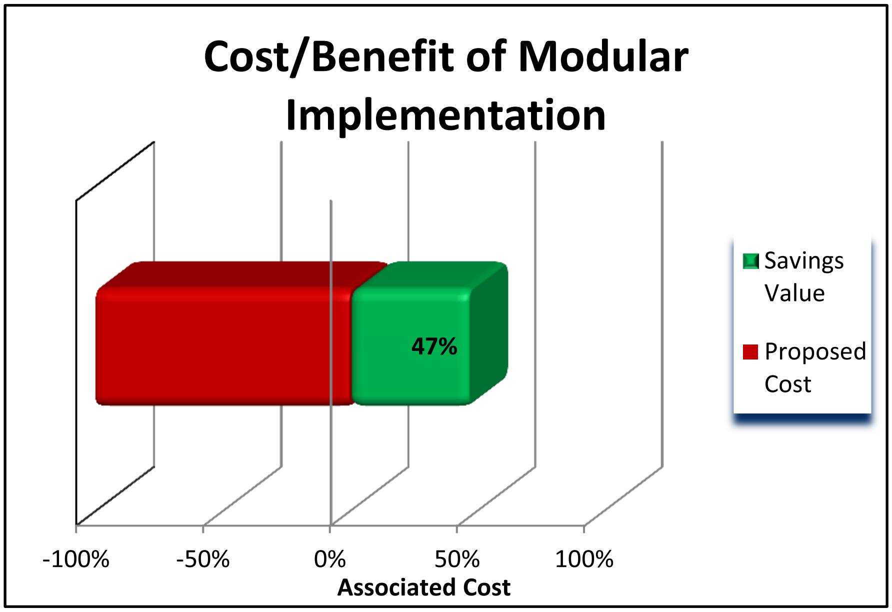


Figure 65 - Table showing the percentage difference between the value the can be saved compared to the total cost of the proposed system.

Final Summary & Conclusion

This project could have definitely benefitted from the use of modularized headwall units because the design of the headwalls was predetermined before the start of construction. Utilizing the proposed system could have better streamlined the flow of construction by eliminating congestion and disorderly in-wall connections and sequencing. With MEP rough-ins being a critical path activity, significant savings could have existed as was proved, a total of 563 man-hours, which could have led to overall schedule reductions. Had changes not delayed the overall scope of rough-in work, potential schedule savings could further offset the higher unit cost. Looking at the actual schedule, each activity that would be impacted, as shown in Table 13, actually took anywhere from 2-7 times longer than originally expected. Medical gas and electrical rough-ins, at a minimum, took 30 days or more compared to the original 10-day estimate.

Although it appears that costs could not be justified in this case due to a 0.49% increase of the original contract value, it should be noted that benefits could be experienced on future projects. Larger projects with more units have a better opportunity to provide schedule savings, especially when systems used are repetitive from facility to facility and could be prefabricated well in advance. If changes not had such a large impact setting back MEP rough-in productivity, full-size wall assembly modules would have been an ideal opportunity for increasing labor productivity and better streamlining the rough-in sequence.

BAE/MAE Requirements

AE 570 – Production Management

Labor tracking has been performed in each analysis. Man-hours for the change order crew ("Blue Vest Crew"), project team time to produce virtual mock-ups and a SIPS, and labor time for MEP rough-ins have all been investigated. As alternative systems or solutions were proposed for each analysis, determining labor was an integral part for an accurate comparison. Labor is often more expensive than the building materials and crew sizes were important for determining man-hours to perform schedule and general conditions comparisons. Working with the project team helped determine accurate durations for those activities that could not be easily determined.

Modularization was a key topic that was the focus of Analysis 4 which was discussed throughout the semester. Collaborative efforts are required of team members for modularization and it was necessary to understand this whole process before planning how to manage the work. The information covered in this course helped determine what areas to focus on for research and discussions provided to be valuable as a goal of each analysis was to understand relationships between involved parties and tasks to enhance labor and process performances.

AE 572 – Project Development and Delivery Planning

The process of change order management that was investigated thoroughly for Analysis 1 relates to this course as methods of the owner was studied. How change is dealt with has been a challenge on this project; to learn more a process map was created, the project delivery method, contractual language, and decision making process of the owner have all been analyzed. Financing was also a course topic investigated as changes have led to a significant increase in the project cost.

Delivery planning was also investigated. Because BIM coordination took much longer than anticipated, preconstruction services were investigated to reveal that KP did not purchase these services and the impacts the project experienced were a negative cause of this. Building industry professionals that presented in this class were later consulted with for further research as topics investigated were directly related to their lectures. Case studies discussed in this class proved to be helpful during thesis research and serve as background information as well.

Final Recommendations

Analysis 1 – Research revealed that change orders have become a major nuisance on this project, with changes accounting for nearly a 40% increase in the original contract value. Because of this, three key recommendations have been made. It is suggested to give the construction manager the authority to approve small-scale changes as that potentially has the largest impact. It is also recommended for the owner to purchase preconstruction services; thus allowing significant BIM coordination to take place before construction and to utilize contractors' healthcare expertise. Transitioning to an alternative change review process is also encouraged in an effort to reduce significant buildup of pending changes. Implementing all of these methods could potentially reduce the overall project cost, greatly increase labor productivity on future projects, and reduce management time spent on changes.

Analysis 2 - A complete analysis of the building façade has shown that the mechanical system will not be affected as long as proper measures are taken to prevent thermal bridging while the structural steel will not need to be upgraded for the additional loading. The high unit cost of the system is due to the irregularity of the façade and limited amount of repetition the current design permits. A lesson learned is that it is very difficult to design a precast façade for a building with a system already designed that is not intended to incorporate any more than a single precast accent band. Even with this high unit price, it is recommended to use precast panels because schedule savings would be the largest benefit for the project. Use of panels will reduce the overall amount of time and limit the issues due to both weather and details that hindered progress of the façade. Additional masonry labor costs due to larger crew sizes and overtime required was not taken into account in the cost analysis, which further supports the benefit to be gained through use of precast panels. With the watertight milestone advancing two months, major interior finishes work and construction of the elevator could begin much sooner. The estimated $125,371.56 savings make incorporation of precast panels a worthwhile alternative.

Analysis 3 – The use of the single mock-up analyzed can produce over $1,700 worth of possible savings. Savings are expected to greater if the same measures were taken for other areas of the building. It is recommended to use virtual mock-ups for building interface and tie-ins, and implement the use of SIPS. Although these activities did not affect the critical path, time savings can help offset the cost of additional upfront coordination. With mock-ups proving to be helpful at Tyson's Corner for the owner, they provided little use for the tradesmen in the field. It is believed that creating mock-ups for these connections will be equally as beneficial for the people responsible for putting the work in place. Many of the benefits cannot be assigned values, but more detailed coordination typically pays for itself as estimates provided in this analysis prove.

Analysis 4 - This project could have definitely benefitted from the use of modularized headwall units because the design was predetermined before the start of construction. Utilizing the proposed system could have better streamlined the flow of construction by eliminating congestion and disorderly in-wall connections. With MEP rough-ins being a critical path activity, significant savings could have existed as was proved, a total of 563 man-hours, which could have led to overall schedule reductions. Even though critical path savings could not be found for this specific project due to changes, potential schedule savings could further offset the higher unit cost on future projects. Although it appears that costs could not be justified in this case; instead there is an estimated 0.49% increase to the original contract value, it should be noted that other issues could be benefitted on future projects. Larger projects with more units have a better opportunity to provide schedule savings, especially when systems used are repetitive from facility to facility and could be prefabricated well in advance. Had changes not had such a large impact setting back MEP rough-in productivity, full-size wall assembly modules would have been an ideal opportunity for increasing labor productivity and better streamlining the rough-in sequence.