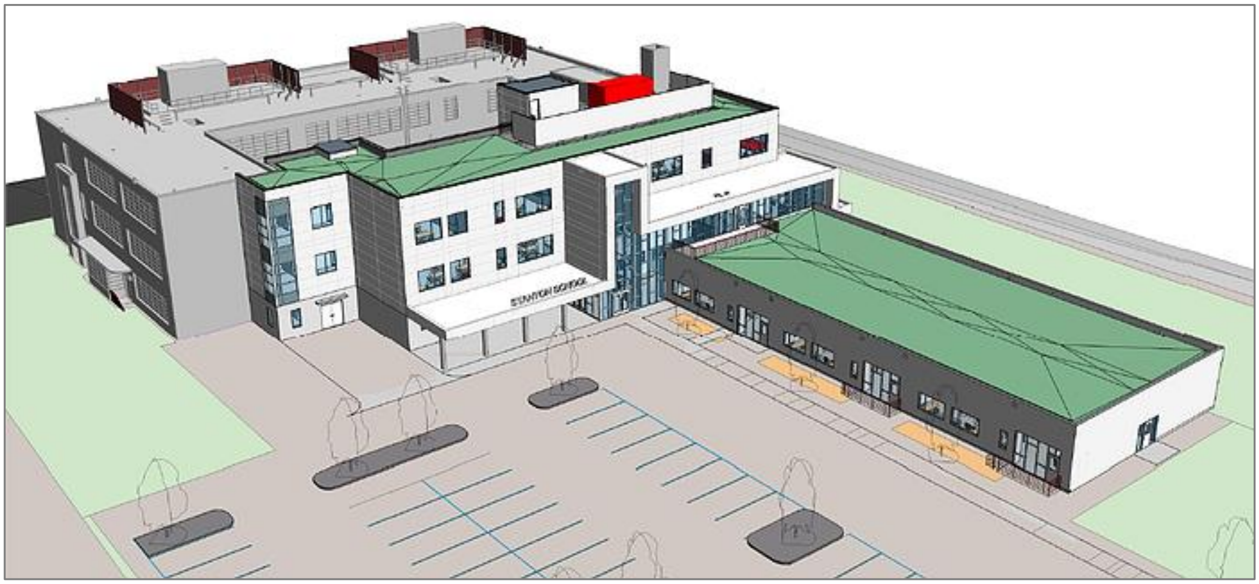


Stanton Elementary School, *Washington, D.C.*

Final Thesis Report

Ryan DeJesso

April 10, 2016

Thesis Abstract

Stanton Elementary West Entrance Rendering (Image Source: Tompkins Builders)

Stanton Elementary School

Washington, D.C.

Ryan DeJesso

Construction Management

Advisor: Dr. Somayeh Asadi

Project Team

Owner: Department of General Services
Architect: Little Diversified Architectural Consulting
Structural Engineer: ReStl Designers, Inc.
MEP Engineer: Engenium Group
Civil Engineer: Wiles Mensch Group
Geotechnical Engineer: ECS
AV/IT/Security Consultant: Polysonics
Construction Manager/Estimator: Tompkins Builders

Project Information

Occupancy: Educational (Elementary)
Project Type: Building Addition
Size: 21,449 SF
Number of Stories: 3
Building Height: 50 feet
Construction Cost: $14,000,000
Overall Project Cost: $16,000,000
Project Delivery Method: Design-Build with GMP
Building Completion: December 28, 2015
Project Completion: April 15, 2016

Project Goals

Design Goals: LEED Silver Certification
Client Goals: Increase building size to meet the enrollment needs of the school district. Enhance the quality of learning for Stanton Elementary School students.
Client Key Concerns: Quality project is delivered as ensured by a third party inspector. Substantial completion by December 28, 2015 to allow for students to move in to building on first day back from winter break.
Client Expectations: Project is delivered on-time and within the expected budget.

Architecture

- Building addition increases square footage of the building from 62,300 to 83,700 square feet. Building will hold 46 classrooms following the addition.
- Brick façade envelopes existing building. Addition will feature both a horizontal and vertical insulated metal panel façade.
- Large glass curtain wall present at the west entrance.

Green Roof

- Located on building first and third story floors and covers a total of 10,450 square feet.
- Made up of 4 inches of media with sedum plantings for roof vegetation. Green roof overlays a system of vapor barriers and drainage on top of roof slab.

Structure

- Steel structure with bolted connections on top of spread footings. Spread footings supported by piles.
- Composite metal deck using a two-inch 20 gage deck with four inches of lightweight concrete
- Helical pile and pile cap system in conjunction with continuous footings makes up foundation system

MEP Systems

- Mechanical system uses a refrigerant flow system with variable air volume (VAV) terminals.
- Electrical system utilizes three main switchboards. The main switchboard operates as a 265V/460V system, while the two main distribution panels operate as a 120V/208V system and a 277V/408V system.

Student CPEP Web Address: http://ryd5110.wix.com/dejesso-cpep

Table of Contents

Executive Summary

This thesis serves to identify and analyze potential issues throughout the construction of the Stanton Elementary School project located in the Washington, D.C. Specifically, three construction depth topics are analyzed, including an analysis on the existing project scheduling and how it could benefit from adjusting the phasing of the project; an analysis on the schedule and how short-interval production scheduling could benefit the project; and an analysis comparing cost data of the existing copper domestic water piping to PVC piping system. A construction research topic is included in addition to the construction depth analyses. Research was performed on BIM usage on smaller projects and explained in the content of this report. Two additional analyses were performed as breadth topics. These topics include a structural breadth which analyzes the existing foundation system and an acoustical breadth which analyzes classrooms acoustical performance.

The first construction depth focuses on beginning the project with the existing phase two of construction and ending with the existing phase one of construction. Through this analysis, opportunities for cost savings, scheduling savings, and scheduling flexibility were identified.

A short-interval production scheduling (SIPS) approach is used to help identify a faster method of construction. The entire project is not suitable for SIPS usage, however, opportunities do arise to implement SIPS during the second phase of construction. By utilizing a SIPS approach, the project team can save fifteen days from the original schedule without cost consequences.

In another method of pursuing cost savings, the domestic water piping costs analysis identifies a path to value engineering. Initially, using a PVC piping system instead of a copper piping system is a much cheaper system, as cost savings would be approximately $50,000. Maintenance and replacement costs are variable, but are most likely cheaper for PVC piping because it is a less expensive material. PVC piping can also be installed quicker than copper piping which can benefit the project schedule.

The structural foundations were analyzed to determine if they would be capable of supporting loading conditions for a two-story addition over the pre-kindergarten wing. The existing foundations were found to have very large loading capacities compared to the existing loading conditions. Minimal improvements are required to enhance the foundations to the point that additional loading created by a two-story addition could be supported.

The acoustical analysis of the building focused on five rooms that experienced potential unwanted sound infiltration from nearby sources. In most cases, deficiencies in acoustical design were found. Acoustical design recommendations were found to be fairly costly.

Acknowledgements

I would like to take this opportunity to thank and acknowledge a number of individuals whose contributions helped me perform the analyses outlined in this thesis.

Kevin Parfitt and Paul Bowers for their guidance and for helping not only myself, but all individuals enrolled in fifth year architectural thesis.

My thesis advisor, Dr. Somayeh Asadi for guiding me through this year long endeavor and for providing help whenever it was requested.

Dr. Michele Vigeant for helping with the acoustical analysis and for making me aware of a variety of resources that allowed me to perform my intended analysis.

Tompkins Builders for allowing me to use the Stanton Elementary School project for my thesis analysis. I would especially like to thank Jessica Marine for being extremely helpful throughout this entire process and for being an unbelieve resource. I would also like to thank Pete Kapsidelis, Patrick Bynum, and Denzel Golden for providing me with project documents that were beneficial to my analyses.

To all my friends and family, thank for your continual support. A special thanks to my parents, Michael and Carrie DeJesso for the support they have given me over the past five years as an architectural engineering student at Penn State University and for making all of this possible.

1 Project Information

Project History

The Stanton Elementary School is a three-story educational building located in the suburbs of Washington D.C. The building has an area of approximately 84,000 square feet and reaches a height of about 45 feet in the main section of the building. The project is a two phase project that includes a renovation of the existing building in phase one, and an addition to the existing building in phase two. The project owner was the Department of General Services (DGS) and the construction manager was Tompkins Builders. The project delivery method used was a design-build with a guaranteed maximum price (GMP) agreement.

The Stanton Elementary School project began on June, 20, 2014. Key elements of building construction include demolition of the existing building, the helical pile and pile cap foundations, erection of the structural steel, placement of the glass curtain wall at the building's back entrance, and the installation of the green roof atop both sections of the building addition. Throughout the course of construction, Tompkins Builders faced many challenges with meeting the tight project schedule. The project owner enforced strict deadlines based on the school's academic schedule. Fortunately, project team was successful in meeting all construction deadlines.

In addition to following a strict schedule the project owner had issues with financing throughout the course of the project. The project team was constantly looking for value engineering opportunities to cut down on project costs. The issues with financing eventually led to a delay in the phase two start date. Phase two was originally intended to occur directly in succession of phase one. However, the phase two building addition was postponed until the spring of 2015. The original schedule would have allowed phase two to begin in the fall of 2014. As the project stands currently, phase two has reached building completion and is on track to achieve substantial completion on April 18, 2016.

Background Information

Architecture

Stanton Elementary School is a small 3-story building located in Washington, D.C. Following the addition that is currently under construction, the elementary school will increase in size from approximately 62,300 square feet to about 83,700 square feet. Once the renovation and addition have occurred, 46 classrooms will fill out the building's floor plan.

A brick façade envelopes the front of the existing building. As a transition is made from the existing building to the building addition, the façade changes from brick veneer to a horizontal insulated metal panel facade. The building first floor addition that holds six classroom spaces utilizes a vertically aligned insulated metal panel façade. Additionally, a concrete masonry unit veneer is also used for the building façade in some instances.

Sustainability

The project is aiming to obtain a LEED Silver certification in compliance with the LEED 2009 for Schools, New Construction, and Major Renovations guidelines. Based on LEED goals identified by the LEED project checklist, at the beginning of construction the building was on pace to receive 62 out of 110 possible points which would make Stanton Elementary School a LEED Gold certified building. Sustainable construction methods for innovation and design process are a large focus in gaining LEED points throughout the project. Additionally, recycling project materials and using more energy efficient systems will occur throughout the course of the project to earn LEED points and make for a more sustainable project. The building green roof plays a role in the focus on sustainability that is seen throughout this project. The green roof is present on the roof of the building addition and is depicted in the figure below.

Structural System

The building utilizes a steel superstructure with mostly bolted connections. The floor system is a composite deck that is composed of four inches of lightweight concrete on top of a two inch 20 gage deck. In the pre-kindergarten wing, beam sizes range from W8x15 to 21x50. Typical girders are W24x68. In the remainder of the building, beam sizes range from W8x15 to W16x26. Typical girders throughout the remainder of the building are between W24x62 and W27x94. Column sizes range from W10x33 toW10x77 throughout the structure.

The building superstructure is supported by a building foundation that features a pile and pile cap system and a continuous footing system. The pile and pile cap system uses a total of 262 helical piles that are capped by a variety of eleven differently sized pile caps. Helical piles range from depths of 5 to 30 feet from the base of its respective pile cap. Variability in soil bearing capacity throughout the site calls for the large difference in drilling depth. The continuous footings run along the perimeter of the building. The foundation wall is concrete masonry unit wall.

Electrical System

The electrical system power is provided to the main switchboard MDPH. Switchboard MDPH supplies power to distribution panels MPDL and GEN. Switchboard MDPH also supports mechanical roof top units, condensing units, kitchen loads, standby loads, and lighting in the building addition. This switchboard operates as a 265 V/460 V system. Distribution Panel MDPL supports the power risers, building addition power, basement power, the HVAC riser, mechanical room loads, and stage lighting. This switchboard operates as a 120 V/ 208 V system. Distribution Panel GEN supports the fire pump, life safety lighting, the building addition elevator, and standby power. This switchboard operates as a 277 V / 408 V system.

Lighting System

The building lighting is defined by seven major unique zones: classrooms; corridors, lobbies, and vestibules; cafeteria; multipurpose room; private offices and open offices; conference rooms; and stairwells. Classroom lighting uses dimmable ballasts and is broken into three different zones that separate the front of the room, the middle of the room and the back of the room. Lighting for the building's corridors, lobbies, and vestibules are controlled by a time clock in a centralized lighting control system. A low voltage override switch is used to turn on the lights in these areas during after-operation hours. The cafeteria uses a simple low voltage two-button switch at each entrance.

The multipurpose room has the most involved lighting system, for it includes lighting for the stage within this space. At the room's entrances, the lighting system is operated by a low voltage two-button switch. A five-button switch is located behind the stage and used for stage lighting specific to scene control. All light fixtures are equipped with dimmable drivers/ballasts between 10% and 100% light output. Each row of fixtures moving back on the stage is under a separate zone.

Office spaces utilize a low voltage two button system. Both the office spaces and conference room spaces use dimmable ballasts. The building stairwells use dimmable ballasts as well. The building stairwell lighting is unique based on the fact that it is tied into the life safety power panel. The classrooms, cafeteria space, offices, conference rooms, and stairwells all utilize occupancy sensors that trigger the lighting within those spaces to emit light up to 100 percent output as an individual enters that space.

Mechanical System

The mechanical system was designed based on a 91-degree Fahrenheit summer dry bulb temperature in the summer and an 11-degree Fahrenheit winter dry bulb temperature. The mechanical system used in the school is a variable refrigerant flow system using variable air volume terminals for distribution. The air temperature and output is controlled by a building automation system computer. This automation system is interconnected between the rooftop mechanical equipment, variable refrigerant flow condenser units, and variable air volume output terminals to regulate desirable building temperatures. This system is supported mostly by switchboard MPDH. Mechanical rooftop and condensing units receive power from the main switchboard MDPH. The mechanical riser and smaller mechanical equipment spread throughout the building receive power from distribution panel MDPL.

Fire Protection System

Fire protection within the building occurs with a quick response sprinkler system with a 155-degree Fahrenheit rating. Sprinkler heads are semi-recessed in the ceiling except for in the main lobby where sprinkler heads are recessed with a cover plate. All sprinklers within the building cover an area of 1500 square feet. Most sprinklers within the building release at a water pressure of 0.15 gallons per minute per square foot area. Fire protection main piping is 2.5" and larger. Branch piping is 2 inches and smaller. The building standpipe in stair A is a 6" pipe. Stair T uses a 4-inch standpipe.

The fire alarm system includes fire alarm strobe lights in each room, whether the room is a classroom, office, or corridor. Classrooms feature extra protection, as they each have fire alarms in addition to the strobe lights, and a fire alarm manual station. Bathrooms also have a fire alarm and strobe light combination. Smoke detectors are located on each floor in the elevator lobby. The fire alarm system is tied in with various building systems to limit the spread of smoke during a fire. The system is able to shut down mechanical units, activate the alarm indicator system, recall the elevator to the primary floor, and close dampers in the mechanical units.

Site Information

Stanton Elementary School stands on a fairly small site which is illustrated in *Figure 1.1* on the following page. The building finds itself between two small roads; Naylor Road to its east and 25th Street to its west. The front of the building is only 40 feet away from Naylor Road. There are two fast food restaurants and an apartment complex directly off the northern portion of the site. The school's athletic fields are at located on the southern-most portion of the site. The football field specifically is within 50 feet of the new building addition that is a part of phase 2 of construction.

In *Figure 1.1* the building footprint separated into distinct area. The maroon-colored area is the footprint of the previously existing building and the section of the building that was renovated during phase 1 of construction. The green-colored area is the portion of the building that was added during phase 2 of construction. The purple-colored section marks where the annex building used to reside. This building remained on campus in the early stages of phase two. Once substantial completion of the building addition occurred, the annex was demolished. The structure is no longer on the school's campus and that space is now used as a parking lot. The blue area to the west of the building will be the parking lot area once construction has finished.

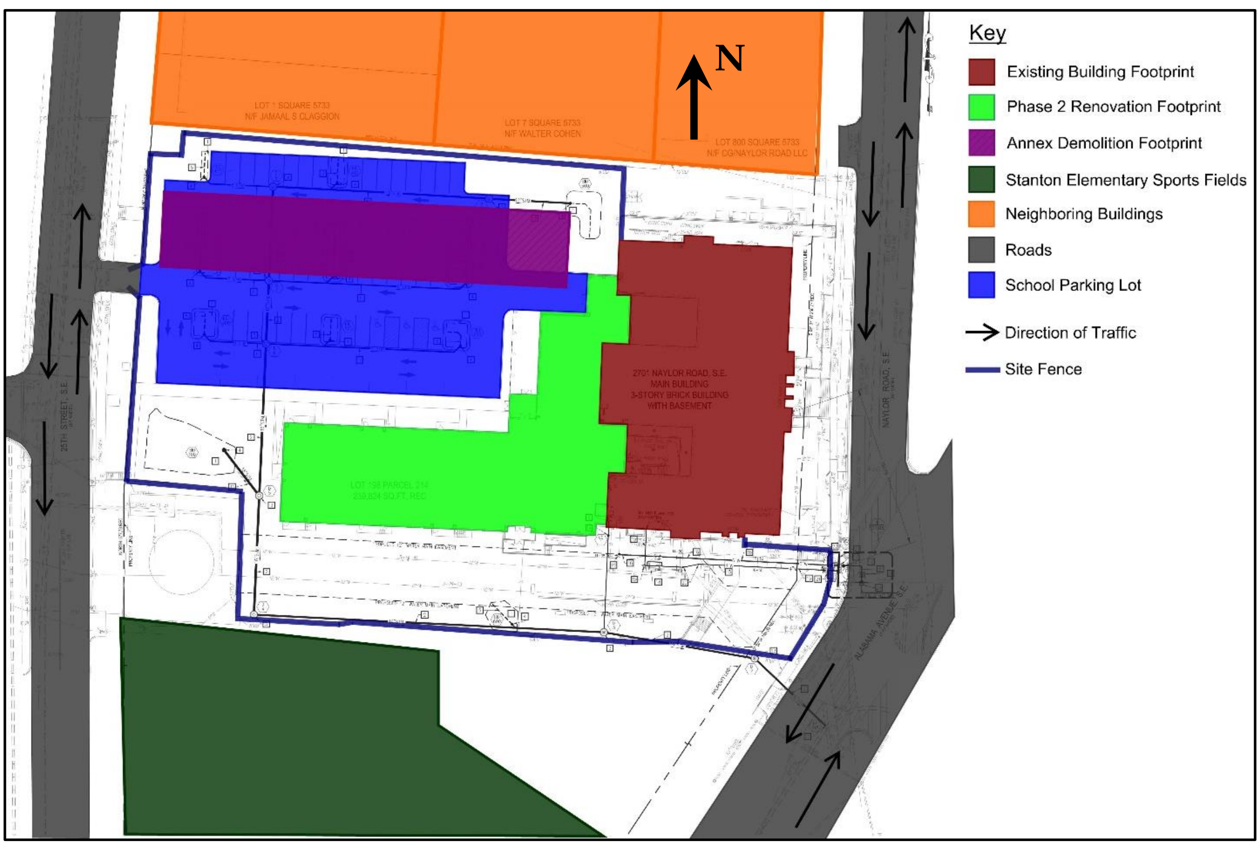


Figure 1.1: Stanton Elementary School Site

2 CONSTRUCTION DEPTH I
Project Phasing Analysis

Introduction

The scope of work for phase one included demolition and renovation of the existing main building. This work was to be completed prior to the first day of classes for the 2014-2015 school year. This work did not include renovation of the existing Annex building located on the northwest portion of the site. The scope of work for phase two of construction includes a one to three story building addition on the west side of the building. Once the addition has been completed, the Annex Building will be demolished and final site work will ensue. Phase two of the project was scheduled to take place immediately after phase one; however, issues with project funding prevented phase two from starting on time. Phase two eventually began in the summer of 2015. The building addition portion of phase two is scheduled to be completed on December 28, 2015, while the entire project is scheduled to be completed by April 15, 2016. The analysis of the schedule will operate under the original scheduling assumption that the second phase of construction will occur immediately after the conclusion of the first phase. For re-phasing, that means the building renovation will occur directly after the conclusion of the phase two building completion.

A major concern for the project team throughout the course of construction dealt with meeting the project deadline for completion. In phase one of construction, the project team was given an extremely strict deadline for when the renovation was expected to be completed. The project team was required to finish the project prior to the 2014-2015 academic year. If this deadline was not met, financial penalties would be enforced by the owner on the construction manager. Not meeting the deadline would mean the school year could not be begin on its intended date. This creates a lack of flexibility in the schedule and forced the project team to work very long hours over the summer of 2014. The project schedule did not stop for weekends or holidays and supported double shifts for the entirety of the summer. The project team was fortunate enough to meet the targeted deadline, however if they were unable, it could have cost them a large amount of profit.

The real issue at hand is that if phase one would not have been completed by the expected date, there would not be enough occupiable space for the elementary school students. If phase two of construction were to be completed prior to phase one, there would be more available space for relocating students if something were to delay the schedule during construction. While the owner had set deadlines for completion of both phases and the project team was striving to meet those deadlines, it could have proved beneficial to have a potential back up plan if something were to go wrong. It is possible that re-phasing the project by switching phases one and two could have provided such a backup plan. The following analysis will look at different ways to determine the feasibility of project re-phasing and how this approach to the schedule would affect the project.

Existing Schedule Analysis and Considerations

The existing schedule called for phase one of construction to begin at the conclusion of the 2013-2014 Stanton Elementary School academic year. The start date was June 20, 2014. The phase one end date was to be only 60 calendar days later on August 18, 2014. As stated in the introduction, the project team worked every day of the summer, including weekends and holidays. Double shifts occurred nearly every day during this phase of construction. The project team was expected to perform $16 million worth of renovations in 60 days. Fortunately they were successful in meeting this deadline.

Phase two of construction was originally supposed to begin immediately after phase one; however, issues with project financing affected the start date. Phase two did not actually begin until March 31, 2015. Tompkins Builders were required to attain completion of the building addition by December 28, 2015. This milestone was met. Substantial completion was scheduled to be met by April 18, 2016. This includes mostly grading, landscaping, parking lot paving, and final site inspections.

The original project schedule lasted a total of 375 construction days. Phase one took 112 days to complete with 60 of those days being over the academic summer. Double shifts occurred during the summer work days to increase daily output. Phase two lasted 263 days and operated under a more typical schedule, as weekends and holidays were observed as days off (unlike the summer schedule for phase one). In addition, normal 8-hour workdays were used. Additional key considerations for the re-phasing schedule analysis are identified below:

- Limitations during academic year prevented the project team from exceeding 8-hour workdays. Construction could not occur during certain parts of the school day.
- Temporary Offices and classrooms that were installed in phase one of construction would not need to be constructed since phase two will contain those spaces as permanent rooms that will already be existing by the time phase one is built. Temporary room locations can are referenced by *Figures 2.1a-2.1c* in Appendix A
- Will the renovation phase of the schedule lineup at a point in the schedule where it is feasible? Will demolition of the classrooms affect the occupiable space in the school to the point where there are not enough classrooms?
- The sequence of activities that is dedicated to “Phase 2 Foundations to Grade” in the original phase one schedule will have to be moved from phase one to phase two. This sequence of activities includes items such as erosion and sediment control, building pad work, excavation, sheeting and shoring, under-slab MEP, vapor barriers, backfilling, and other items that are required to occur prior to the beginning of the phase two schedule.
- The sequence of activities labeled “Phase B Site Work” will have to be moved from phase two to phase one of construction. This construction sequence is concerned with items such as the annex demolition, site grading, landscaping, punchlist items, and final site inspections. This phase of construction was meant to conclude the project.

The process of adjusting the schedule was based not on individual tasks, but on the sequencing umbrella under which each individual task fell. The schedule provided by the project manager did not include information regarding how items were linked to one another, making it extremely difficult to determine a critical path. As a result durations for each activity remained unchanged in this sequencing analysis. The durations between an activity and its predecessor were determined from the existing project schedule and related to one another based on those durations in the new proposed schedule. To summarize, while the actual start and end dates of the activities changes, the duration of the activities and the durations between activities remained unchanged in the proposed schedule that utilizes project re-phasing.

Two approaches were taken in identifying an appropriate solution for re-phasing the project. The first approach used a front-end loaded schedule, and the second approach used a back end loaded schedule. The front-end loaded scheduling approach used double shifts and included working on weekends and holidays during the summer of 2014 section of the schedule. The back-end loaded scheduling approach used double shifts and includes working on weekends and holidays during the summer of 2015 section of the schedule. Including double shifts and seven day work weeks during for one of the two academic summers was done to maintain consistency with the original schedule based on the utilization of double shifts and seven-day work weeks used in the summer of 2014 for phase one.

Front-Loaded Schedule

The front-end loaded approach to the schedule is displayed in *Figure 2.2* in Appendix A. This approach to the schedule did not appear to be effective. Front-end loading sped up the phase two schedule to the point were building completion would occur by April 4, 2015. With the building renovation phase (phase one on the original schedule) starting directly after the building addition completion, issues with available classroom space would arise.

The renovation phase immediately begins with demolition and abatement. Demolishing every floor in the old building (as the schedule calls for) would not be a feasible solution. If this were to happen, Stanton Elementary School would lose a lot of building space, specifically classroom spaces. *Table 2.1* identifies a breakdown of how many classrooms are located in each section of the building. During the original schedule when the new building was under construction, the inhabited buildings were the existing building (old building) and the annex building.

Table 2.1: Classroom Breakdown by building

Section of Building	Number of Classrooms
Old Building (Under Renovation)	20
Old Building – Floor 1	4
Old Building – Floor 2	7
Old Building – Floor 3	9
New Building (Addition)	14
Annex Building	8
Old Building + Annex Building	28
New Building + Annex Building	22

As *Table 2.1* depicts, a combination of 28 total classrooms occurs in the situation where the old building and the annex building were occupiable. The assumption can be made that 28 total classrooms is the minimum amount of classrooms that need to be available during the course of the school year. In the frontloaded scheduling scenario, once the demolition phase occurs, the school would be downgraded to 22 total occupiable classrooms. In addition to the lack of occupiable classrooms, students would have to switch classrooms in the middle of the school year, which could be very inconvenient. There are two possible solutions could have occurred to make the back-loaded schedule work more effectively.

1. The renovation phase of construction could be pushed to the start of the academic summer. This would add 51 construction days between activities and push the start date of the renovation phase of the schedule to June 17, 2015.
2. The renovation schedule could be broken into different phases by floor. In this solution, the demolition, interior construction, and finishing sequences would be completed one floor at a time. This would allow for classrooms to remain available on the two floors in the old building that are not under construction.

The first option is not ideal mostly because it delays the project by a pretty large amount of time. Additionally, this approach only postpones the coordination issues that arise from performing the renovation during the course of the school year. The second option is not ideal either, for this approach will also add to the project schedule. Performing a sequence of demolition, interior construction, and finishing one floor at a time is not the most effective scheduling method. Time will be added to the schedule by implementing this approach. Additionally, if the renovation portion of the schedule occurs during the school year, precautions will need to be taken to consider the safety of the building inhabitants, specifically the students. Temporary partitions will need to be constructed to block the students from entering the construction site. This will add both time, and cost to the project. Having the renovation occur during the course of the school year could also create issues with noise. All of these downfalls should be avoided if possible. For this reason, the front-loaded scheduling approach was not further considered.

Back-Loaded Schedule

The back-loaded approach to the schedule proved to be much more effective. *Figure 2.3* displays the back-loaded schedule and how it is successful in using re-phasing to create and effective schedule. This figure can be found in the Appendix A. As previously stated, the back-loaded schedule uses an 8-hour work day and five day work week (excluding holidays) during the course of the 2014 academic summer and the school year. Double shifts and a seven-day work week (including holidays) is used during the summer of 2015. The project start date of June 20, 2014 conveniently leads to a June 29, 2015 building completion for the addition phase of the project.

Having the building renovation phase begin directly after the building addition phase was the initial idea behind the re-phasing schedule structure. However, after realizing that this would lead to a small portion of the building renovation phase intruding into the 2015 academic school year, the renovation construction phase was moved up to an earlier date. Moving the renovation phase start date to an earlier time does not have much of an effect on the building addition portion of the schedule. Phases one and two will overlap by 11 days as a result. This overlap between the two phases will not create coordination issues, as workers for each phase will be in different sections of the building.

The reason for an 11-day overlap is because this allows the renovation phase of the schedule to begin immediately after the last day of school for the 2014-2015 year, which is June 17, 2015. The 2015 academic summer happens to be 66 days long, which is six says longer than the 2014 academic summer. The renovations schedule still maintained its projection for completion within 60 days, which would mean that the renovation phase would achieve building completion by August 15, 2015. This would allow for six days of float, a luxury that was not provided in the original scheduling plan that put the building renovation before the building addition. Substantial completion of the project would occur on November 23, 2015. The total duration of the schedule would be 375 construction days. The back-loaded schedule is preferred over the front-loaded schedule in this analysis.

In an attempt to provide a comparison between the existing schedule and the proposed schedule, *Figures 2.3 and 2.4* provide summary schedules of each scheduling scenarios. Both schedules have the same project durations with regard to construction days. The existing schedule may appear to last much longer than the proposed schedule. This is not the case, as the calculated schedule duration of 375 days does not include the time in between phases one and two.

Task Name	Start	Finish	Duration
Existing Building Renovation (Phase 1)	**6/20/2014**	**11/6/2014**	**195 days?**
Mobilization	6/20/2014	6/25/2014	6 days
Demolition and Abatement	**6/21/2014**	**7/14/2014**	**48 days**
3rd Floor	6/21/2014	7/3/2014	24 days
2nd Floor	6/25/2014	7/8/2014	26 days
1st Floor	6/28/2014	7/10/2014	24 days
Basement	7/2/2014	7/14/2014	24 days
Interior Construction	**7/4/2015**	**8/14/2014**	**74 days**
3rd Floor	7/4/2013	7/31/2014	52 days
2nd Floor	7/9/2014	8/14/2014	48 days
1st Floor	7/11/2014	8/14/2014	52 days
Basement	7/15/2014	8/11/2014	50 days
Interior Finishes	**7/28/2014**	**8/14/2014**	**37 days**
3rd Floor	7/28/2014	8/5/2014	15 days
2nd Floor	8/1/2014	8/8/2014	15 days
1st Floor	8/4/2014	8/12/2014	15 days
Basement	8/7/2014	8/14/2016	15 days
Exterior Skin	6/28/2014	8/15/2014	96 days
Comminsioning and Closeout	7/28/2014	8/18/2014	42 days
Phase 2 Foundations to Grade	6/23/2014	11/6/2014	96 days
New Building Addition (Phase 2)	**3/31/2015**	**12/16/2015**	**283 days**
Mobilization, Site work, Ext Demo	3/31/2015	12/16/2015	184 days
Foundations	6/3/2015	9/21/2015	63 days
Structure	8/18/2015	10/3/2015	32 days
Pre-Kindergarten Wing	**9/3/2015**	**11/25/2015**	**56 days**
Pre-K Wing Envelope	9/8/2015	9/18/2015	24 days
Pre-K Wing	9/3/2015	11/25/2015	56 days
Main Building	**9/22/2015**	**12/29/2015**	**67 days**
Main Building Envelope	10/12/2015	10/16/2015	47 days
1st Floor	9/22/2015	12/16/2015	60 days
2nd Floor	9/28/2015	12/17/2015	58 days
3rd Floor	10/5/2015	12/29/2015	60 days
Phase B Site Work	12/29/2015	4/18/2016	78 days
Total Construction Days			375

Figure 2.3: Summary schedule of existing project schedule

Task Name	Start	Finish	Duration
New Building Addition (Phase 2)	**6/20/2014**	**6/29/2015**	**283 days**
Phase 2 Foundations to Grade (from phase 1)	6/20/2014	10/31/2014	96 days
Mobilization, Site work, Ext Demo	11/3/2014	6/27/2015	184 days
Foundations	1/5/2015	4/1/2015	63 days
Structure	3/19/2015	5/1/2015	32 days
Pre-Kindergarten Wing	**4/6/2015**	**6/18/2015**	**56 days**
Pre-K Wing Envelope	4/8/2015	5/11/2015	24 days
Pre-K Wing	4/6/2015	6/18/2015	56 days
Main Building	**4/20/2015**	**6/29/2015**	**67 days**
Main Building Envelope	4/30/2015	6/23/2015	47 days
1st Floor	4/20/2015	6/25/2015	60 days
2nd Floor	4/24/2015	6/26/2015	58 days
3rd Floor	4/29/2015	6/29/2015	60 days
Existing Building Renovation (Phase 1)	**6/18/2015**	**11/23/2015**	**195 days**
Mobilization	6/18/2015	6/21/2015	6 days
Demolition and Abatement	**6/19/2015**	**7/13/2015**	**48 days**
3rd Floor	6/19/2015	7/1/2015	24 days
2nd Floor	6/23/2015	7/6/2015	26 days
1st Floor	6/27/2015	7/9/2015	24 days
Basement	7/1/2015	7/13/2015	24 days
Interior Construction	**7/1/2015**	**8/7/2015**	**74 days**
3rd Floor	7/1/2015	7/27/2015	52 days
2nd Floor	7/6/2015	7/30/2015	48 days
1st Floor	7/9/2015	8/4/2015	52 days
Basement	7/13/2015	8/7/2015	50 days
Interior Finishes	**7/26/2015**	**8/13/2015**	**37 days**
3rd Floor	7/26/2015	8/2/2015	15 days
2nd Floor	7/29/2015	8/5/2015	15 days
1st Floor	8/3/2015	8/10/2015	15 days
Basement	8/6/2015	8/13/2015	15 days
Exterior Skin	6/28/2015	8/15/2015	96 days
Comminsioning and Closeout	7/26/2015	8/15/2015	42 days
Phase B Site Work	8/16/2015	11/23/2015	78 days
Total Construction Days			**375 days**

Figure 2.4: Summary schedule of proposed project schedule using re-phasing approach

Potential for Cost Savings

Cost savings can occur as a result of re-phasing because it eliminates the need for building and demolishing temporary structures in phase on and two respectively. With phase two constructed prior to phase one, the office spaces that are constructed temporarily in phase one will no longer be needed. The room's temporary spaces that are affected by swapping the construction phases are listed below and on the following page:

- Principal's office (Room 128)
- Assistant principal's office (Room 126)
- Admin workroom & mailroom (Room 123)
- Records room (Room 125)
- Conference room (Room 130)
- Storage room (Room 117)

- Stairwell Y 0005
- Elevator 0003
- Various partitions and doors
- Furnishing in music room (Room 319)

The elimination of the need for demolition of items that were constructed in phase one presents the opportunity for value engineering. Given the problems the project owner has experienced with financing, using this opportunity to cut costs would be especially beneficial. Calculations for cost savings opportunities were not determined.

Conclusion

Switching phase one and phase two of construction and incorporating a back-end loaded schedule provides many benefits to the project team. Based on the scheduling model that is presented in *Figure 2.3*, the overall duration that the project is under construction would remain the same if phases one and two were switched. This does not include the opportunity for scheduling savings that would be accounted for by eliminating the need for construction and demolition of temporary spaces in phases one and two respectively. The cost savings that come from this source of value engineering also serves as a benefit to re-phasing that otherwise is not possible in the original schedule.

In addition to the potential cost and time savings, re-phasing grants an added flexibility to the project that the current project schedule does not provide. By the time the second phase of construction would occur (the renovation phase), the building addition will be constructed and readily available to use if the renovation phase takes longer than expected. By using a back-loaded schedule, the schedule sets itself up in a way that would allow the building renovation phase to occur at the start of the summer. This was the major concern during the analysis because of the obstacles that could arise if the renovation phase occurred during the academic year. The renovation phase would occur during the 2015 summer instead of the 2014, which is six days longer and provides the project team with more flexibility in executing the renovation phase.

Re-phasing should be implemented following the example set in place by the back-loaded construction schedule referenced by *Figure 2.3* in Appendix A. Phase two of construction and phase one should be swapped to place the building addition before the building renovation on the schedule.

3 CONSTRUCTION DEPTH II
Short Interval Production Scheduling

Introduction

Short Interval Production Scheduling (SIPS) creates opportunities to shorten construction schedules by means of identifying repetitive processes in construction and providing a detailed method for these processes. Creating this type of detailed schedule allows workers to become increasingly familiar with the space that they are constructing. This familiarity paired with the repetitive nature of the spaces allows workers to be more efficient and minimize mistakes and construction errors that could prove costly in the grand scheme of a project. In addition, workers will develop a learning curve and will be able to perform work quicker towards the end of the schedule. The detailed planning that goes into SIPS is beneficial to project managers as well, as it forces the project team to really study building layouts and systems. This mastery of the building design helps project managers identify potential issues before they occur in the field, thus limiting the amount of construction delays and change orders in the field.

Educational buildings are suitable candidates for SIPS given the repetitive nature of classroom designs and the repetitive nature of floor plan designs if the elementary school happens to be multiple stories. This is certainly the case with the Stanton Elementary School.

Specifically, in phase two of the Stanton Elementary School project, the building design features a repetitive floor plan with very similar room layouts. The following analysis will target the pre-kindergarten wing on the first floor of the addition and floors two and three of the addition. Only the pre-kindergarten wing of the first floor will be included for the remainder of the first floor is full of office type spaces. The floor plan is inconsistent and does not bode well for SIPS utilization. Tompkins builders must have also noticed the differences between the pre-kindergarten wing and the remainder of the first floor, as the schedule created by Tompkins separates each of these areas into two separate phases. In this analysis, the first floor of the main building will not be included as a part of the SIPS process. The SIPS will begin with the pre-kindergarten wing classrooms, then link to the second floor classrooms, and finally will link the third floor classrooms. The main building first floor will begin at the same time as the as the pre-kindergarten wing, but follow its original schedule.

Pre-Kindergarten Wing SIPS Utilization

The pre-kindergarten wing extends outward from the remainder of the building and houses only pre-kindergarten classrooms. Each classroom has its own set of individual bathrooms. This wing is on the first floor only, and does not extend upward to additional floors. *Figure 3.1* depicts the floor plan for this wing. The floor plan for each of the six classrooms within this wing are essentially exactly the same, minus a few minor dimensional differences. This wing of the building is pretty independent from the remainder of phase two, and receives its own designation on the phase two schedule.

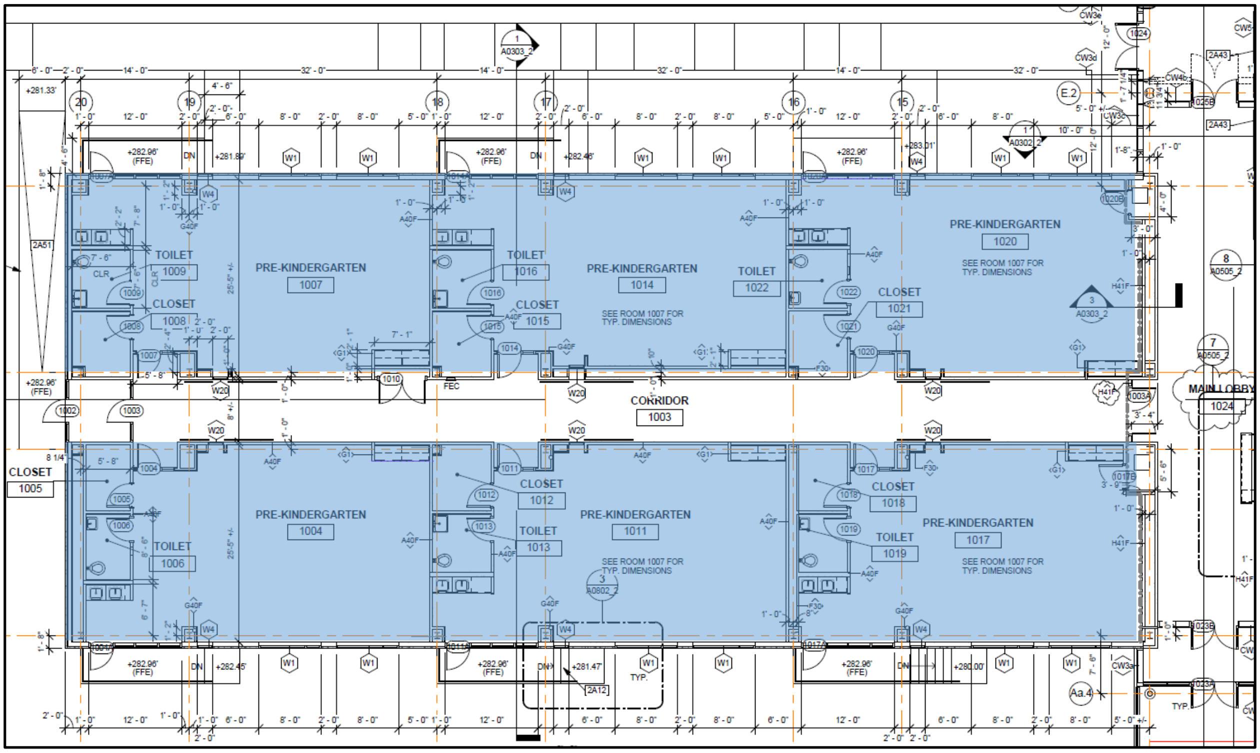


Figure 3.1: Pre-Kindergarten wing floor plan

Each of the six rooms in the pre-kindergarten wing uses the same floor plan design with regard to the layout of its classroom space, bathroom spaces, sinks and counters, and board locations. Each room uses the same finishing materials in reference to the room's carpeting, acoustical tile ceilings, bulkheads, and hard lids. In addition, placement of doors and windows are similar, leading to similar framing plans.

The SIPS for this space was broken down into seven sequences. The sequences were determined by grouping activities that already had start to start relationships on the original project schedule provided my Tompkins Builders. Additionally, some phases group tasks together that are similar in nature and would require similar crews. These particular phases do not necessarily have start to start relationships on the schedule, but mostly do. *Table 3.1* on the following page identifies the tasks that were assigned to each particular SIPS sequence. The 'Days to Complete' column identifies how long the activity was expected to take for the entire pre-kindergarten wing based on the original project schedule provided by Tompkins Builders. The 'Duration per Room' column identifies the expected duration of the activity if the total duration were to be equally divided between six rooms. The 'Actual Duration per Room' column indicates the duration that will be scheduled and expected to be executed. Items were sequenced together based on their relationship with each other. For example, items such as door and wall framing were linked together due to the similarity between the two items and the coordination issues that could arise. Items such as plumbing, electrical, duct, and mechanical rough-in were included in the same sequence because of the start-start-to-start relationship that they maintain.

Table 3.1: Pre-Kindergarten Wing SIPS Durations

ID	Activity	Days to Complete (All 6 rms)	Days to Complete 1 room	Duration per Room (days)	Actual Duration Per room (days)
1	Layout	2	0.33	2.00	2.0
	Door Frames	2	0.33		
	Wall Framing	10	1.67		
2	Plumbing R/I	10	1.67	1.67	1.5
	Electrical R/I	10	1.67		
	Duct R/I	10	1.67		
	Mech Pipe R/I & Units	10	1.67		
	Sprinkler Main R/I	5	0.83		
3	One-Side	8	1.33	2.00	2.0
	Insulation	4	0.67		
	Frame Bulkheads	4	0.67		
	Sprinkler Laterals	4	0.67		
4	Wall Close-In	3	0.50	2.17	2.0
	Grid	10	1.67		
	Prime & First Coat	4	0.67		
	Frame Hard Lids	5	0.83		
5	Casework/Cabniets	5	0.83	2.00	2.0
	Tack/Marker Boards	4	0.67		
	Close-in Hard Lids	3	0.50		
	Tile Bathrooms	6	1.00		
6	Devices and Fixtures Trim-out	10	1.67	2.00	2.0
	Drop Tile	2	0.33		
7	Bathroom Tiles	4	0.67	1.83	2.0
	Room Floors	5	0.83		
	Finish Coat Paint	3	0.50		
	FFE	3	0.50		
***	Corridor Floors	5	5.00	5.0	5.0
Total Duration				13.7	13.5

Each sequence (with the exception of sequence 2) is projected to take approximately two days to complete. Sequence 7 could potentially be completed slightly quicker than in two days. This allows for some float within the schedule. Sequence 4 is projected to take about two days and one and a half hours to complete. The expectation is that crews may have to work later on the second day to complete their required tasks within the expected two-day timeframe. Laborers for this project are not unionized and have come to expect that they will be working overtime hours. The contractual agreement between Tompkins and its subcontractors do not restrict subcontractors from exceeding an 8-hour work day. Laborers are accustomed to long work days for this project, and having to work more than an 8-hour day would be most likely be a nonissue to workers. In addition, it is likely that workers would complete tasks quicker than expected towards the end of the schedule given the repetitive nature of SIPS.

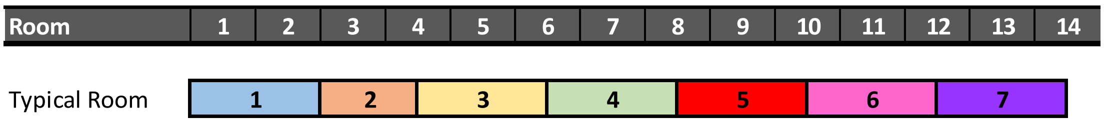


Figure 3.2: First floor pre-kindergarten wing typical schedule for a typical classroom

The figure above shows the schedule for a typical room in the pre-kindergarten wing on the first floor. The numbered tasks are compatible with the items that are identified on *Table 2.1* on the previous page. *Figure 3.3* identifies how the SIPS would be comprised with all six pre-kindergarten rooms. A larger version of the schedule is accessible in the Appendix B.

The graphic below identifies the first sequence of each room has a finish-to-start relationship with the first sequence of the proceeding room. On the full schedule (*Figure 3.6)* that demonstrates how SIPS could be utilized on this project, the construction tasks are listed by room only. The task reads Room 1017 and has a duration of 13.5 days similar to how it is shown below. However, the order of the sequences is neglected.

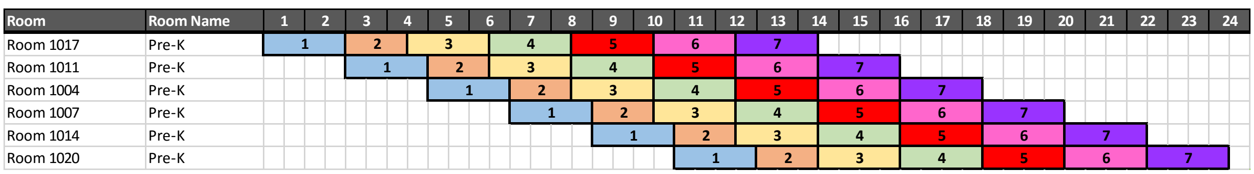


Figure 3.3 First floor pre-kindergarten wing SIPS

The pre-kindergarten wing short-interval production schedule identifies that construction of the classrooms can be completed in as little as 24 days. In addition to the classrooms, this schedule includes the bathrooms within each of the classrooms, the hallway walls and the hallway ceilings as well. The SIPS does not include the duration for installing hallway flooring. The duration of the Hallway flooring from the original schedule provided by Tompkins Builders is five days. Tompkins Builders scheduled the hallway flooring installation directly following the installation of the bathroom tiling with a finish-to-start relationship between the two tasks. Maintaining the same relationship would place hallway flooring installation directly succeeding item seven (tile bathrooms, room floors, finish coat paint, and FFE) for room 1020, the final room. The addition of the corridor flooring installation to the schedule would complete the pre-kindergarten wing phase of the schedule in 29 days. This is a significant improvement from the original schedule duration of 56 construction days.

Floors 2 and 3 SIPS Utilization

The design of floors 2 and 3 are similar to one another with a few minor differences. The floor plan for the second floor addition can be seen in *Figure 3.4*, and the floor plan for the third floor addition can be seen in *Figure 3.5* on the following page. Each of the floor plans feature similarly sized classrooms that were designed to have the same functions. The corridor layout is not identical, but is similar. There is a teacher's workroom and a resources room on each floor, along with closets that are placed in identical locations. The main difference comes with the inclusion of the special education suite on the third floor. This room does not take away much space from the remainder of the floor plan however, and does not distract too much from the consistency in floor plan design when comparing the second and third floor.

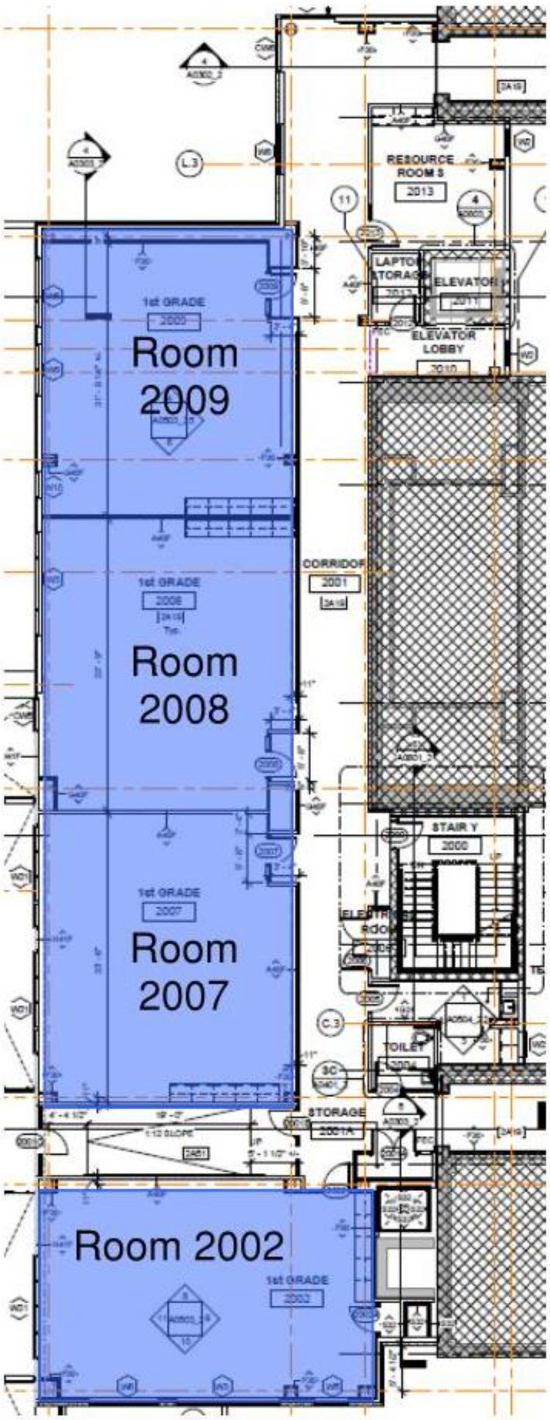


Figure 3.4: Second story floor plan

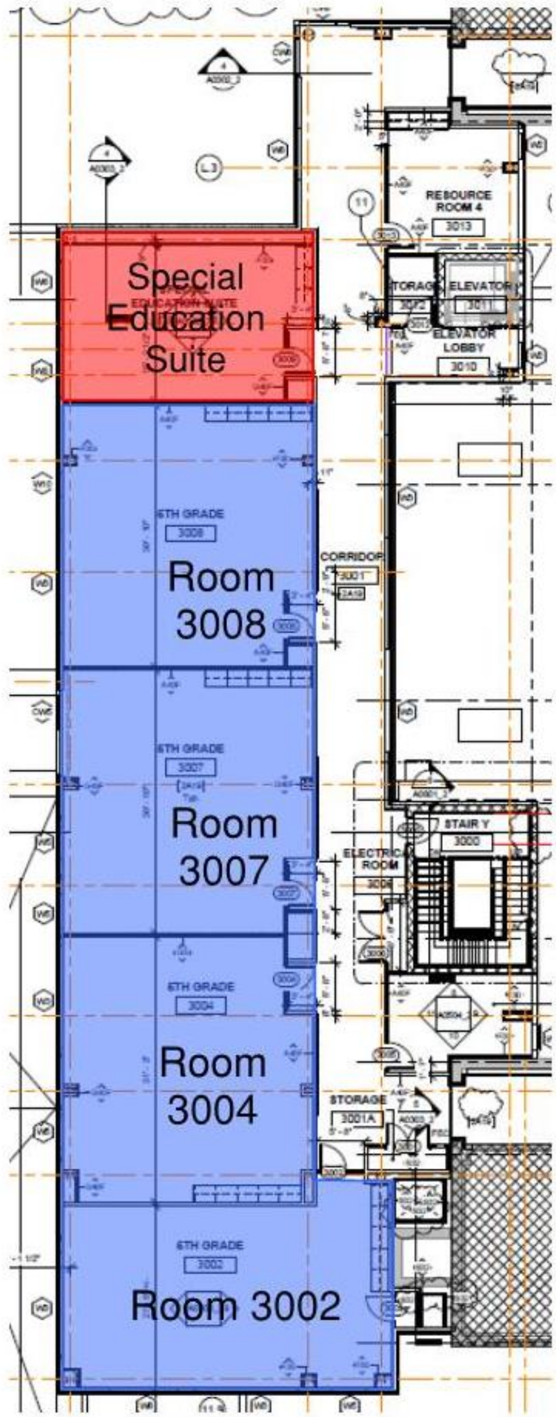


Figure 3.5 Third story floor plan

In *Figures 3.4 and 3.5* the classrooms color-coded in blue have all been identified as similar to each other. The classroom in red is the special education suite. This classroom is similar as well, but has smaller dimensions. Regardless, this space was treated the same as the other classrooms on floors two and three. There are other small rooms and offices dispersed between the two floors, however these rooms are very dissimilar to the other classrooms. Because each of these rooms are so small, they were combined into one category of rooms and should follow the same process as the other rooms. These rooms are depicted on the comprehensive SIPS schedule in *Figure 3.6.*

Tables 3.2 and 3.3 display the sequencing of the second and third floor SIPS. Each floor has essentially the same sequence as the pre-kindergarten wing. The only difference comes because of the omission of classroom bathrooms from the second and third story floor plans. There are minor differences in the durations per room. This is because the second floor was calculated based on the construction of five rooms while the third floor was calculated based on the construction of 6 rooms. The original schedule provided by Tompkins Builders is nearly identical for the second and third floor. Tompkins projected that the second floor would be completed within 58 days, and the third floor would be completed within 60 days. By implementing SIPS, each of these floors will take 32 days to complete. This includes both the room and hallway spaces as well.

Table 3.2: Floor 2 SIPS durations

ID	Activity	Days to Complete (All 6 rms)	Days to Complete 1 room	Duration per Room (days)	Actual Duration Per room (days)
1	Layout	3	0.60	2.60	2.5
	Door Frames	3	0.60		
	Wall Framing	10	2.00		
2	Plumbing R/I	10	2.00	2.00	2
	Electrical R/I	10	2.00		
	Duct R/I	10	2.00		
	Mech Pipe R/I & Units	10	2.00		
	Sprinkler Main R/I	5	1.00		
3	One-Side	4	0.80	1.60	1.5
	Insulation	4	0.80		
	Frame Bulkheads	4	0.80		
	Sprinkler Laterals	4	0.80		
4	Wall Close-In	5	1.00	3.00	3
	Grid	10	2.00		
	Prime & First Coat	5	1.00		
	Frame Hard Lids	5	1.00		
5	Casework/Cabniets	5	1.00	2.60	2.5
	Tack/Marker Boards	5	1.00		
	Close-in Hard Lids	3	0.60		
6	Devices and Fixtures Trim-out	10	2.00	2.60	2.5
	Drop Tile	3	0.60		
7	Room Floors	5	1.00	2.80	3
	Finish Coat Paint	5	1.00		
	FFE	4	0.80		
	Tile Bathrooms	4	4.00	4.0	1.0
	Bathroom Tiles	5	5.00	5.0	1.0
***	Corridor Floors	5	5.00	5.0	5.0
Total Duration				17.2	17.0

One aspect that may have helped accelerate the second and third floor bathrooms is the fact that there are no bathrooms in the classrooms like there were in the pre-kindergarten wing. There is actually only a small individual bathroom on the second floor of phase two, and there are not any bathrooms on the third floor of phase two at all. Tompkins schedule failed to adjust the schedule duration for the tasks that were concerned with the bathrooms (bathroom tile and tile bathrooms tasks). To adjust for this, the tasks related to the bathroom on the second floor were given new durations of 1 day rather than 4 days, as it was schedule previously. Bathroom tile and tile bathroom tasks were each omitted from the third floor SIPS schedule.

Table 3.3: Floor 3 SIPS durations

ID	Activity	Days to Complete (All 6 rms)	Days to Complete 1 room	Duration per Room (days)	Actual Duration Per room (days)
1	Layout	3	0.50	2.17	2.0
	Door Frames	2	0.33		
	Wall Framing	10	1.67		
2	Plumbing R/I	10	1.67	1.67	1.5
	Electrical R/I	10	1.67		
	Duct R/I	10	1.67		
	Mech Pipe R/I & Units	10	1.67		
	Sprinkler Main R/I	5	0.83		
3	One-Side	4	0.67	1.33	1.5
	Insulation	4	0.67		
	Frame Bulkheads	5	0.83		
	Sprinkler Laterals	4	0.67		
4	Wall Close-In	5	0.83	1.67	1.5
	Grid	5	0.83		
	Prime & First Coat	5	0.83		
	Frame Hard Lids	4	0.67		
5	Casework/Cabniets	5	0.83	1.67	1.5
	Tack/Marker Boards	1	0.17		
	Close-in Hard Lids	4	0.67		
6	Devices and Fixtures Trim-out	10	1.67	2.17	2.0
	Drop Tile	3	0.50		
7	Room Floors	5	0.83	2.33	2.5
	Finish Coat Paint	5	0.83		
	FFE	4	0.67		
***	Corridor Floors	5	5.00	5.0	5.0
Total Duration				13.0	12.5

Putting the Schedule Together

Once durations for specific rooms and extraneous activities were determined, the schedule was put together. The short-interval production schedules followed the model that is identified by *Figure 3.3*. The relationship between the pre-kindergarten wing and the second floor was a finish-to-start relationship from sequence 1 (layout, door frames, and wall framing). This relationship is identified in the schedule as a start-to-start relationship between Room 1020 and Room 202. A two-day lag was assigned to this relationship to account for the two days that it should take for the layout, wall framing, and door framing of room 1020. The relationship between the second and third floor is also a start-to-start relationship. There is a seven-day lag between the two rooms to limit the amount of overlap between two like sequences.

Because of the fast-track nature of the schedule, there are a lot of occasions where there overlap exists between construction tasks. Multiple crews will be required when this type of overlap occurs. To be exact, this happens 96 times in the proposed schedule using short-interval production scheduling. Initially this may have seemed like a lot of overlap and that more crews would be needed in order to meet this type of schedule compared to the existing schedule. However, after comparing the additional crews required for the proposed SIPS driven schedule to the existing schedule that was used by the Tompkins team, the existing schedule used more additional crews than the proposed schedule. Tompkins Builders' schedule used an additional 104 additional crews to create overlap on their schedule and to help meet the strict project deadline.

After learning that the two projects used a similar amount of crews, the SIPS schedule was created using the relationships that were just discussed. As mentioned in the introduction of this analysis, the first floor of the main building was essentially scheduled independently of the pre-kindergarten wing, the second floor, and the third floor. The full redeveloped schedule can be seen as *Figure 2.6* on the proceeding page. A larger version of the schedule can also be found in Appendix B.

The schedule begins on Thursday, September 9, 2015 just as it does in the existing schedule used by the Tompkins Builders. The critical path (identified in red in *Figure 3*.6) goes through each of the classroom spaces that are SIPS controlled. It is essential that each room is completed in the projected amount of days in order for the project to stay on schedule. If the critical path can be followed, the interior construction and move-in of phase two can be concluded by Tuesday, December 1, 2015. This would translate into a total duration of 64 construction days. The original schedule for the interior construction and move-in of phase two lasted 79 construction days. Utilizing SIPS could eliminate ***fifteen*** days from the original schedule.

ID	Task Name	Duration	Start	Finish
0	**Stanton Elementary**	**64 days**	**Thu 9/3/15**	**Tue 12/1/15**
1	**Pre-Kindergarten Wing**	**31 days**	**Thu 9/3/15**	**Thu 10/15/15**
2	Room 1017	13.5 days	Thu 9/3/15	Tue 9/22/15
3	Room 1011	13.5 days	Mon 9/7/15	Thu 9/24/15
4	Room 1004	13.5 days	Thu 9/10/15	Tue 9/29/15
5	Room 1007	13.5 days	Mon 9/14/15	Thu 10/1/15
6	Room 1014	13.5 days	Thu 9/17/15	Tue 10/6/15
7	Room 1020	13.5 days	Mon 9/21/15	Thu 10/8/15
8	Corridor Floors	5 days	Fri 10/9/15	Thu 10/15/15
9	**Main BLDG: 1st Floor**	**59 days**	**Thu 9/3/15**	**Tue 11/24/15**
10	Layout	2 days	Thu 9/3/15	Fri 9/4/15
11	Door Frames	2 days	Thu 9/3/15	Fri 9/4/15
12	Wall Framing	10 days	Thu 9/3/15	Wed 9/16/15
13	Mech Pipe R/I	10 days	Thu 9/3/15	Wed 9/16/15
14	Plumbing R/I	10 days	Thu 9/3/15	Wed 9/16/15
15	Sprinkler Main R/I	5 days	Thu 9/3/15	Wed 9/9/15
16	Duct R/I	10 days	Thu 9/3/15	Wed 9/16/15
17	Electrical R/I	10 days	Thu 9/3/15	Wed 9/16/15
18	One-Side	4 days	Thu 10/1/15	Tue 10/6/15
19	Insulation	4 days	Wed 10/7/15	Mon 10/12/15
20	Frame Bulkheads	4 days	Wed 10/7/15	Mon 10/12/15
21	Sprinkler Laterals	4 days	Wed 10/7/15	Mon 10/12/15
22	Wall Close-In	3 days	Fri 10/9/15	Tue 10/13/15
23	Grid	10 days	Wed 10/14/15	Tue 10/27/15
24	Bathroom Tile	6 days	Wed 10/14/15	Wed 10/21/15
25	Frame Hard Lids	5 days	Wed 10/14/15	Tue 10/20/15
26	Prime & First Coat	4 days	Wed 10/14/15	Mon 10/19/15
27	Tile Bathrooms	4 days	Wed 10/14/15	Mon 10/19/15
28	Casework/Cabinets	5 days	Mon 10/19/15	Fri 10/23/15
29	Tack/Marker Boards I	4 days	Tue 10/20/15	Fri 10/23/15
30	Close-in Hard Lids	3 days	Wed 10/21/15	Fri 10/23/15
31	Corridor Floors	5 days	Mon 10/26/15	Fri 10/30/15
32	Drop Tile	2 days	Wed 10/28/15	Thu 10/29/15
33	Room Floors	5 days	Fri 10/30/15	Thu 11/5/15
34	Finish Coat Paint	3 days	Fri 11/6/15	Tue 11/10/15
35	Devices and Fixtures Trim-out	10 days	Wed 11/11/15	Tue 11/24/15
36	FFE	4 days	Wed 11/11/15	Mon 11/16/15
37	**Main BLDG: 2nd Floor**	**32 days**	**Thu 9/24/15**	**Mon 11/9/15**
38	Room 2002	17 days	Thu 9/24/15	Mon 10/19/15
39	Room 2007	17 days	Tue 9/29/15	Wed 10/21/15
40	Room 2008	17 days	Thu 10/1/15	Mon 10/26/15
41	Room 2009	17 days	Tue 10/6/15	Wed 10/28/15
42	Rooms 2005, 2012, 2(	17 days	Thu 10/8/15	Mon 11/2/15
43	Tile Bathroom	1 day	Mon 11/2/15	Tue 11/3/15
44	Bathroom Tile	1 day	Mon 11/2/15	Tue 11/3/15
45	Corridor Flooring	5 days	Mon 11/2/15	Mon 11/9/15
46	**Main BLDG: 3rd Floor**	**31.5 days**	**Mon 10/19/15**	**Tue 12/1/15**
47	Room 3002	12.5 days	Mon 10/19/15	Wed 11/4/15
48	Room 3004	12.5 days	Wed 10/21/15	Fri 11/6/15
49	Room 3007	12.5 days	Fri 10/23/15	Tue 11/10/15
50	Room 3008	12.5 days	Tue 10/27/15	Thu 11/12/15
51	Room 3009	12.5 days	Thu 10/29/15	Mon 11/16/15
52	Rooms 3005, 3012, 3(	12.5 days	Mon 11/2/15	Wed 11/18/15
53	Hallway Flooring	5 days	Thu 11/19/15	Wed 11/25/15
54	Punchlist	4 days	Thu 11/26/15	Tue 12/1/15
55	Move-in	4 days	Thu 11/26/15	Tue 12/1/15

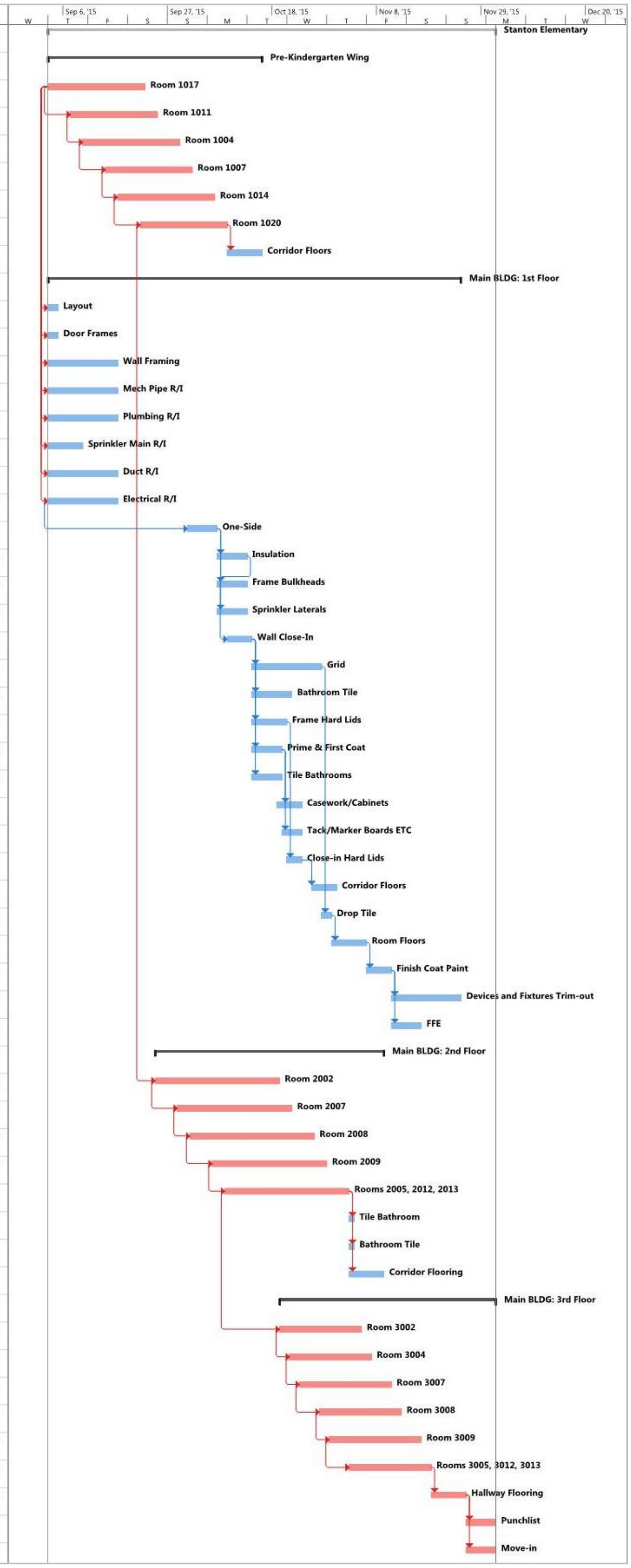


Figure 3.6: Proposed schedule using SIPS for the Pre-kindergarten wind and the second and third floors

Cost Analysis

The SIPS schedule that was used shortens the schedule mostly by means of modifying the relationships between construction tasks. However, there were instances where cutting off time to complete a sequence of events led to a lesser amount of construction time for the schedule as a whole. For example, in *Table 3.3*, the difference between the 'Duration per Room' and 'Actual Duration per Room' total days is 13 days minus 12.5 days. This is a difference of 0.5 construction days per room. The original schedule, when sequenced the way it was for this SIPS analysis, would take an average of thirteen days to complete construction for each room on the third floor. With the proposed schedule, it should take half of a day less per room. This translates into 3 days less than originally anticipated (6 rooms times 0.5 days). After performing the same calculations for floors one and two, the total amount of time saved was 5 days. This schedule savings would result in a total of five less days of labor costs. Unfortunately it is difficult to identify exactly which crews would be responsible for working during the parts of the five days that were eliminated from the schedule in this manner.

In contrast, it is possible that workers may require overtime pay when they would not have required as much overtime pay in the original schedule since some of the tasks were planned to be constructed in a shorter amount. SIPS does allow for a workers learning curve, which could help workers perform the tasks in the scheduled amount of time towards the end of a short-interval production schedule. However, how this curve relates to the amount of overtime that workers would receive was not calculated during this analysis.

As mentioned in the "Putting the Schedule Together" section, the short interval production-oriented schedule uses an estimated total of 96 additional crews. The existing schedule uses an estimated 104 times. These numbers are very close to one another, however the results include variable crew types. A whole analysis on crew types, quantity of worker in the crew, and the hourly rate of these workers would have to be performed to provide semi-accurate projections on cost savings (or cost increases) as a result of the additional crews used in the proposed schedule compared to the number of additional crews used in the existing project schedule.

In general terms, there is a potential for costs savings, but given all the variables in the different cost savings scenarios, it is difficult to determine a quantitative values for these savings without running an intense analysis of crew sizes and hourly rates, learner's working curve calculations and scheduling relationships between the sequence tasks. The variability of crew sizes and labor hours makes it difficult to identify a number for cost savings.

Conclusion

The utilization of short-interval production scheduling creates an opportunity for a time savings of fifteen construction day s on the Stanton Elementary School Project. This is substantial, and would eliminate 19% of the time required to complete the interior construction and move-in of phase two of the project. There is also an opportunity for cost savings, however it is difficult to say exactly how much could be saved. The scheduling savings alone should be enough to consider a SIPS approach as a superior option to the existing project schedule technique. This time savings is especially important given the strict construction deadlines set in place by the project owner. The Stanton Elementary School Project team should consider short-interval production scheduling techniques to cut down on the interior construction portion of the phase two schedule.

4 Construction Depth III
Piping Value Engineering

Introduction

While the previous two analyses were based mostly on improving the project schedule, this piping analysis will focus on the costs side of the project. As previously stated, a major issue throughout the course of this ongoing project was project financing. Because of this, the owner and the construction team looked for a variety of value engineering tactics that could help reduce the overall cost of the project. One method of value engineering that was not approached includes substituting PVC piping for the copper piping. While copper piping may be a desirable choice in the field of construction, PVC is also an adequate material for a piping system. This construction depth will focus on replacing the existing copper piping system with PVC piping for the domestic water piping in both phase one and phase two of the building construction.

The major driver for the substitution of copper piping with PVC piping systems is as a value engineering solution. To determine how utilizing PVC piping system provides cost benefits, a detailed estimate was developed for both PVC piping and copper piping as it applies to the existing domestic water piping design. In addition to the initial cost estimate, estimates considering system maintenance and recycling payback were created. Inconsistencies in available maintenance cost data led to the exclusion of that estimate from this report. This will be further described in the Maintenance costs section of the report.

In addition to considering the cost of the required system maintenance, the scheduling implications are considered based on the frequency that each system will need to undergo maintenance and/or repair. These claims are backed with RS Means scheduling data for maintenance and research about the durability of each system.

Cost Analysis

Initial System Costs

A comprehensive list of assumptions was required to facilitate an initial cost estimate. The complete list can be viewed in Appendix C. In general, all cost data were derived from RS Means 2016 cost data. Copper piping was assumed to be type L copper as identified in the construction documents. In contrast, all PVC piping was considered to be schedule 40 piping. While it is possible that schedule 80 piping would be used if a PVC piping system was used, it is unknown what percentage of the piping would be comprised of this piping thickness compared to schedule 40 piping. A location factor of 0.985 was applied for Washington D.C. The fully detailed cost estimate for both PVC piping and copper piping can be viewed on the proceeding two pages with *Figures 4.1 and 4.2*.

Domestic Water Piping Estimate: Existing Copper Piping

RS Means No.	Item	Qty.	Unit	Material	Total Material	Labor	Total Labor	Equipment	Total	Total Cost
22 11 1323 2140	1/2" Type L Copper Piping	1036.0	LF	$ 3.68	$ 3,812.48	$ 5.85	$ 6,060.60	$ -	$ 9.53	$ 9,873.08
22 11 1323 2180	3/4" Type L Copper Piping	801.2	LF	$ 5.25	$ 4,206.30	$ 6.25	$ 5,007.50	$ -	$ 11.50	$ 9,213.80
22 11 1323 2200	1" Type L Copper Piping	1421.5	LF	$ 7.40	$10,519.10	$ 6.95	$ 9,879.43	$ -	$ 14.35	$ 20,398.53
22 11 1323 2220	1-1/4" Type L Copper Piping	61.3	LF	$ 10.05	$ 616.07	$ 8.00	$ 490.40	$ -	$ 18.05	$ 1,106.47
22 11 1323 2240	1-1/2" Type L Copper Piping	122.3	LF	$ 12.60	$ 1,540.98	$ 9.10	$ 1,112.93	$ -	$ 21.70	$ 2,653.91
22 11 1323 2260	2" Type L Copper Piping	631.5	LF	$ 18.40	$11,619.60	$ 11.30	$ 7,135.95	$ -	$ 29.70	$ 18,755.55
22 11 1323 2300	3" Type L Copper Piping	404.6	LF	$ 37.00	$14,970.20	$ 15.20	$ 6,149.92	$ -	$ 52.20	$ 21,120.12
22 11 1323 2340	4" Type L Copper Piping	362.7	LF	$ 57.50	$20,855.25	$ 22.00	$ 7,979.40	$ -	$ 79.50	$ 28,834.65
22 11 1325 0480	1/2" Tee	37	EA	$ 1.92	$ 71.04	$ 36.50	$ 1,350.50	$ -	$ 38.42	$ 1,421.54
22 11 1325 0500	3/4" Tee	80	EA	$ 4.64	$ 371.20	$ 39.50	$ 3,160.00	$ -	$ 44.14	$ 3,531.20
22 11 1325 0510	1" Tee	56	EA	$ 13.95	$ 781.20	$ 47.50	$ 2,660.00	$ -	$ 61.45	$ 3,441.20
22 11 1325 0520	1-1/4" Tee	7	EA	$ 19.25	$ 134.75	$ 52.50	$ 367.50	$ -	$ 71.75	$ 502.25
22 11 1325 0530	1-1/2 " Tee	12	EA	$ 29.00	$ 348.00	$ 59.00	$ 708.00	$ -	$ 88.00	$ 1,056.00
22 11 1325 0540	2" Tee	24	EA	$ 46.00	$ 1,104.00	$ 67.50	$ 1,620.00	$ -	$ 113.50	$ 2,724.00
22 11 1325 0560	3" Tee	8	EA	$ 122.00	$ 976.00	$ 122.00	$ 976.00	$ -	$ 244.00	$ 1,952.00
22 11 1325 0580	4" Tee	12	EA	$ 286.00	$ 3,432.00	$ 171.00	$ 2,052.00	$ -	$ 457.00	$ 5,484.00
22 11 1325 0617	1"x1/2" Red Tee	2	EA	$ 21.00	$ 42.00	$ 43.00	$ 86.00	$ -	$ 64.00	$ 128.00
22 11 1325 0620	2"x3/4" Red Tee	2	EA	$ 40.00	$ 80.00	$ 59.00	$ 118.00	$ -	$ 99.00	$ 198.00
22 11 1325 0622	3"x1-1/4" Red Tee	1	EA	$ 103.00	$ 103.00	$ 107.00	$ 107.00	$ -	$ 210.00	$ 210.00
22 11 1325 0623	4"x1-1/2" Red Tee	2	EA	$ 220.00	$ 440.00	$ 142.00	$ 284.00	$ -	$ 362.00	$ 724.00
22 11 1325 0100	1/2" 90 Deg. Elbow	77	EA	$ 1.13	$ 87.01	$ 23.50	$ 1,809.50	$ -	$ 24.63	$ 1,896.51
22 11 1325 0120	3/4" 90 Deg. Elbow	105	EA	$ 2.53	$ 265.65	$ 25.00	$ 2,625.00	$ -	$ 27.53	$ 2,890.65
22 11 1325 0130	1" 90 Deg. Elbow	100	EA	$ 6.20	$ 620.00	$ 29.50	$ 2,950.00	$ -	$ 35.70	$ 3,570.00
22 11 1325 0140	1-1/4" 90 Deg. Elbow	4	EA	$ 9.20	$ 36.80	$ 31.50	$ 126.00	$ -	$ 40.70	$ 162.80
22 11 1325 0150	1-1/2" 90 Deg. Elbow	9	EA	$ 14.35	$ 129.15	$ 36.50	$ 328.50	$ -	$ 50.85	$ 457.65
22 11 1325 0160	2" 90 Deg. Elbow	23	EA	$ 26.00	$ 598.00	$ 43.00	$ 989.00	$ -	$ 69.00	$ 1,587.00
22 11 1325 0180	3" 90 Deg. Elbow	8	EA	$ 67.50	$ 540.00	$ 77.50	$ 620.00	$ -	$ 145.00	$ 1,160.00
22 11 1325 0200	4" 90 Deg. Elbow	24	EA	$ 148.00	$ 3,552.00	$ 94.50	$ 2,268.00	$ -	$ 242.50	$ 5,820.00
22 11 1325 0745	3/4"x1/2" Reducer	10	EA	$ 4.17	$ 41.70	$ 22.00	$ 220.00	$ -	$ 26.17	$ 261.70
22 11 1325 0747	1"x3/4" Reducer	14	EA	$ 5.95	$ 83.30	$ 24.50	$ 343.00	$ -	$ 30.45	$ 426.30
22 11 1325 0747	1"x1/2" Reducer	16	EA	$ 5.95	$ 95.20	$ 24.50	$ 392.00	$ -	$ 30.45	$ 487.20
22 11 1325 0749	1-1/2"x1" Reducer	2	EA	$ 11.05	$ 22.10	$ 29.50	$ 59.00	$ -	$ 40.55	$ 81.10
22 11 1325 0751	2"x1/2" Reducer	1	EA	$ 23.00	$ 23.00	$ 34.00	$ 34.00	$ -	$ 57.00	$ 57.00
22 11 1325 0751	2"x3/4" Reducer	1	EA	$ 23.00	$ 23.00	$ 34.00	$ 34.00	$ -	$ 57.00	$ 57.00
22 11 1325 0751	2"x1" Reducer	2	EA	$ 23.00	$ 46.00	$ 34.00	$ 68.00	$ -	$ 57.00	$ 114.00
22 11 1325 0753	3"x1" Reducer	5	EA	$ 49.50	$ 247.50	$ 61.00	$ 305.00	$ -	$ 110.50	$ 552.50
22 11 1325 0753	3"x1-1/4" Reducer	2	EA	$ 49.50	$ 99.00	$ 61.00	$ 122.00	$ -	$ 110.50	$ 221.00
22 11 1325 0755	4"x3/4" Reducer	3	EA	$ 101.00	$ 303.00	$ 107.00	$ 321.00	$ -	$ 208.00	$ 624.00
22 11 1325 0755	4"x1" Reducer	3	EA	$ 101.00	$ 303.00	$ 107.00	$ 321.00	$ -	$ 208.00	$ 624.00
22 11 1325 0755	4"x1-1/2" Reducer	1	EA	$ 101.00	$ 101.00	$ 107.00	$ 107.00	$ -	$ 208.00	$ 208.00
22 11 1325 0755	4"x2" Reducer	1	EA	$ 101.00	$ 101.00	$ 107.00	$ 107.00	$ -	$ 208.00	$ 208.00
22 11 1325 0755	4"x3" Reducer	1	EA	$ 101.00	$ 101.00	$ 107.00	$ 107.00	$ -	$ 208.00	$ 208.00
22 11 1325 0781	2" Cap	1	EA	$ 12.80	$ 12.80	$ 21.50	$ 21.50	$ -	$ 34.30	$ 34.30
22 11 1325 0793	3" Cap	1	EA	$ 174.00	$ 174.00	$ 39.00	$ 39.00	$ -	$ 213.00	$ 213.00
22 11 1325 1250	1/2" Cross	3	EA	$ 18.00	$ 54.00	$ 47.50	$ 142.50	$ -	$ 65.50	$ 196.50
22 11 1325 1260	3/4" Cross	5	EA	$ 35.00	$ 175.00	$ 50.00	$ 250.00	$ -	$ 85.00	$ 425.00
22 11 1325 1270	1" Cross	7	EA	$ 59.50	$ 416.50	$ 59.00	$ 413.00	$ -	$ 118.50	$ 829.50
22 11 1325 0020	Silver Solder, add 15 % to Fittings	-	-	-	-	15% of Labor Total		$ -	-	$ 4,291.65
22 11 1329 6210	1/2" Manual Ball Valve	11	EA	$ 43.50	$ 478.50	$ 18.50	$ 203.50	$ -	$ 62.00	$ 682.00
22 11 1329 6220	3/4" Manual Ball Valve	3	EA	$ 61.00	$ 183.00	$ 24.50	$ 73.50	$ -	$ 85.50	$ 256.50
22 11 1329 6230	1" Manual Ball Valve	7	EA	$ 75.00	$ 525.00	$ 26.00	$ 182.00	$ -	$ 101.00	$ 707.00
22 11 1329 6240	1-1/4" Manual Ball Valve	2	EA	$ 122.00	$ 244.00	$ 32.00	$ 64.00	$ -	$ 154.00	$ 308.00
22 11 1329 6260	2" Manual Ball Valve	3	EA	$ 269.00	$ 807.00	$ 43.00	$ 129.00	$ -	$ 312.00	$ 936.00
22 11 1329 6680	4" Manual Butterfly Valve	7	EA	$ 241.00	$ 1,687.00	$ 171.00	$ 1,197.00	$ -	$ 412.00	$ 2,884.00
22 07 1910 1016	1/2" Insulation, 1" Wall Thickness	1036.0	LF	$ 1.65	$ 1,709.40	$ 3.34	$ 3,460.24	$ -	$ 4.99	$ 5,169.64
22 07 1910 1018	3/4" Insulation, 1" Wall Thickness	801.2	LF	$ 1.72	$ 1,378.06	$ 3.49	$ 2,796.19	$ -	$ 5.21	$ 4,174.25
22 07 1910 1022	1" Insulation, 1" Wall Thickness	1421.5	LF	$ 1.77	$ 2,516.06	$ 3.66	$ 5,202.69	$ -	$ 5.43	$ 7,718.75
22 07 1910 1024	1-1/4" Insulation, 1" Wall Thickness	61.3	LF	$ 1.82	$ 111.57	$ 3.75	$ 229.88	$ -	$ 5.57	$ 341.44
22 07 1910 1026	1-1/2" Insulation, 1" Wall Thickness	122.3	LF	$ 1.90	$ 232.37	$ 3.75	$ 458.63	$ -	$ 5.65	$ 691.00
22 07 1910 1028	2" Insulation, 1" Wall Thickness	631.5	LF	$ 2.32	$ 1,465.08	$ 3.84	$ 2,424.96	$ -	$ 6.16	$ 3,890.04
22 07 1910 1032	3" Insulation, 1" Wall Thickness	404.6	LF	$ 2.55	$ 1,031.73	$ 4.27	$ 1,727.64	$ -	$ 6.82	$ 2,759.37
22 07 1910 1034	4" Insulation, 1" Wall Thickness	362.7	LF	$ 3.14	$ 1,138.88	$ 5.15	$ 1,867.91	$ -	$ 8.29	$ 3,006.78
									Subtotal Cost	$ 194,517.42
									Add 0.985 Location Factor	$ 191,599.66

Figure 4.1: Copper piping estimate for the domestic water piping system

Domestic Water Piping Estimate: Proposed PVC Piping

RS Means No.	Item	Qty.	Unit	Material	Total Material	Labor	Total Labor	Equipment	Total	Total Cost
22 11 1374 1860	1/2" Plastic Piping, PVC SCH 40	1036.0	LF	$ 4.96	$ 5,138.56	$ 8.75	$ 9,065.00	$ -	$ 13.71	$ 14,203.56
22 11 1374 1870	3/4" Plastic Piping	801.2	LF	$ 5.30	$ 4,246.36	$ 9.30	$ 7,451.16	$ -	$ 14.60	$ 11,697.52
22 11 1374 1880	1" Plastic Piping	1421.5	LF	$ 5.95	$ 8,457.93	$ 10.30	$14,641.45	$ -	$ 16.25	$ 23,099.38
22 11 1374 1890	1-1/4" Plastic Piping	61.3	LF	$ 6.70	$ 410.71	$ 11.30	$ 692.69	$ -	$ 18.00	$ 1,103.40
22 11 1374 1900	1-1/2" Plastic Piping	122.3	LF	$ 7.00	$ 856.10	$ 13.15	$ 1,608.25	$ -	$ 20.15	$ 2,464.35
22 11 1374 1910	2" Plastic Piping	631.5	LF	$ 8.25	$ 5,209.88	$ 14.45	$ 9,125.18	$ -	$ 22.70	$ 14,335.05
22 11 1374 1930	3" Plastic Piping	404.6	LF	$ 13.00	$ 5,259.80	$ 16.10	$ 6,514.06	$ -	$ 29.10	$ 11,773.86
22 11 1374 1940	4" Plastic Piping	362.7	LF	$ 16.60	$ 6,020.82	$ 17.75	$ 6,437.93	$ -	$ 34.35	$ 12,458.75
22 11 1376 3180	1/2" Tee	43	EA	$ 0.63	$ 27.09	$ 21.50	$ 924.50	$ -	$ 22.13	$ 951.59
22 11 1376 3190	3/4" Tee	90	EA	$ 0.73	$ 65.70	$ 25.00	$ 2,250.00	$ -	$ 25.73	$ 2,315.70
22 11 1376 3200	1" Tee	70	EA	$ 1.36	$ 95.20	$ 28.50	$ 1,995.00	$ -	$ 29.86	$ 2,090.20
22 11 1376 3210	1-1/4" Tee	7	EA	$ 2.11	$ 14.77	$ 32.00	$ 224.00	$ -	$ 34.11	$ 238.77
22 11 1376 3220	1-1/2 " Tee	12	EA	$ 2.57	$ 30.84	$ 35.50	$ 426.00	$ -	$ 38.07	$ 456.84
22 11 1376 3230	2" Tee	24	EA	$ 3.74	$ 89.76	$ 35.00	$ 840.00	$ -	$ 38.74	$ 929.76
22 11 1376 3250	3" Tee	8	EA	$ 16.20	$ 129.60	$ 56.00	$ 448.00	$ -	$ 72.20	$ 577.60
22 11 1376 3260	4" Tee	12	EA	$ 29.50	$ 354.00	$ 70.50	$ 846.00	$ -	$ 100.00	$ 1,200.00
22 11 1376 4862	1"x1/2" Red Tee	2	EA	$ 4.84	$ 9.68	$ 39.00	$ 78.00	$ -	$ 43.84	$ 87.68
22 11 1376 4862	2"x3/4" Red Tee	2	EA	$ 4.84	$ 9.68	$ 39.00	$ 78.00	$ -	$ 43.84	$ 87.68
22 11 1376 4864	3"x1-1/4" Red Tee	1	EA	$ 9.50	$ 9.50	$ 55.50	$ 55.50	$ -	$ 65.00	$ 65.00
22 11 1376 4868	4"x1-1/2" Red Tee	2	EA	$ 26.00	$ 52.00	$ 70.50	$ 141.00	$ -	$ 96.50	$ 193.00
22 11 1376 2760	1/2" 90 Deg. Elbow	77	EA	$ 0.50	$ 38.50	$ 14.20	$ 1,093.40	$ -	$ 14.70	$ 1,131.90
22 11 1376 2770	3/4" 90 Deg. Elbow	105	EA	$ 0.57	$ 59.85	$ 16.55	$ 1,737.75	$ -	$ 17.12	$ 1,797.60
22 11 1376 2780	1" 90 Deg. Elbow	100	EA	$ 1.01	$ 101.00	$ 18.95	$ 1,895.00	$ -	$ 19.96	$ 1,996.00
22 11 1376 2790	1-1/4" 90 Deg. Elbow	4	EA	$ 1.79	$ 7.16	$ 21.50	$ 86.00	$ -	$ 23.29	$ 93.16
22 11 1376 2800	1-1/2" 90 Deg. Elbow	9	EA	$ 1.94	$ 17.46	$ 23.50	$ 211.50	$ -	$ 25.44	$ 228.96
22 11 1376 2810	2" 90 Deg. Elbow	23	EA	$ 3.03	$ 69.69	$ 23.50	$ 540.50	$ -	$ 26.53	$ 610.19
22 11 1376 2830	3" 90 Deg. Elbow	8	EA	$ 11.05	$ 88.40	$ 37.00	$ 296.00	$ -	$ 48.05	$ 384.40
22 11 1376 2840	4" 90 Deg. Elbow	24	EA	$ 19.75	$ 474.00	$ 47.00	$ 1,128.00	$ -	$ 66.75	$ 1,602.00
22 11 1376 3712	3/4"x1/2" Reducer	10	EA	$ 0.53	$ 5.30	$ 15.05	$ 150.50	$ -	$ 15.58	$ 155.80
22 11 1376 3713	1"x3/4" Reducer	14	EA	$ 0.96	$ 13.44	$ 17.20	$ 240.80	$ -	$ 18.16	$ 254.24
22 11 1376 3713	1"x1/2" Reducer	16	EA	$ 0.96	$ 15.36	$ 17.20	$ 275.20	$ -	$ 18.16	$ 290.56
22 11 1376 3713	1-1/2"x1" Reducer	2	EA	$ 1.37	$ 2.74	$ 21.50	$ 43.00	$ -	$ 22.87	$ 45.74
22 11 1376 3716	2"x1/2" Reducer	1	EA	$ 12.27	$ 12.27	$ 21.50	$ 21.50	$ -	$ 33.77	$ 33.77
22 11 1376 3716	2"x3/4" Reducer	1	EA	$ 12.27	$ 12.27	$ 21.50	$ 21.50	$ -	$ 33.77	$ 33.77
22 11 1376 3716	2"x1" Reducer	2	EA	$ 12.27	$ 24.54	$ 21.50	$ 43.00	$ -	$ 33.77	$ 67.54
22 11 1376 3717	3"x1" Reducer	5	EA	$ 12.00	$ 60.00	$ 42.50	$ 212.50	$ -	$ 54.50	$ 272.50
22 11 1376 3717	3"x1-1/4" Reducer	2	EA	$ 12.00	$ 24.00	$ 42.50	$ 85.00	$ -	$ 54.50	$ 109.00
22 11 1376 3717	4"x3/4" Reducer	3	EA	$ 12.00	$ 36.00	$ 42.50	$ 127.50	$ -	$ 54.50	$ 163.50
22 11 1376 3717	4"x1" Reducer	3	EA	$ 12.00	$ 36.00	$ 42.50	$ 127.50	$ -	$ 54.50	$ 163.50
22 11 1376 3717	4"x1-1/2" Reducer	1	EA	$ 12.00	$ 12.00	$ 42.50	$ 42.50	$ -	$ 54.50	$ 54.50
22 11 1376 3717	4"x2" Reducer	1	EA	$ 12.00	$ 12.00	$ 42.50	$ 42.50	$ -	$ 54.50	$ 54.50
22 11 1376 3717	4"x3" Reducer	1	EA	$ 12.00	$ 12.00	$ 42.50	$ 42.50	$ -	$ 54.50	$ 54.50
29 11 1376 3650	2" Cap	1	EA	$ 1.56	$ 1.56	$ 12.90	$ 12.90	$ -	$ 14.46	$ 14.46
29 11 1376 3670	3" Cap	1	EA	$ 5.35	$ 5.35	$ 20.50	$ 20.50	$ -	$ 25.85	$ 25.85
22 11 1329 6210	1/2" Manual Ball Valve	11	EA	$ 43.50	$ 478.50	$ 18.50	$ 203.50	$ -	$ 62.00	$ 682.00
22 11 1329 6220	3/4" Manual Ball Valve	3	EA	$ 61.00	$ 183.00	$ 24.50	$ 73.50	$ -	$ 85.50	$ 256.50
22 11 1329 6230	1" Manual Ball Valve	7	EA	$ 75.00	$ 525.00	$ 26.00	$ 182.00	$ -	$ 101.00	$ 707.00
22 11 1329 6240	1-1/4" Manual Ball Valve	2	EA	$ 122.00	$ 244.00	$ 32.00	$ 64.00	$ -	$ 154.00	$ 308.00
22 11 1329 6260	2" Manual Ball Valve	3	EA	$ 269.00	$ 807.00	$ 43.00	$ 129.00	$ -	$ 312.00	$ 936.00
22 11 1329 6680	4" Manual Butterfly Valve	7	EA	$ 241.00	$ 1,687.00	$ 171.00	$ 1,197.00	$ -	$ 412.00	$ 2,884.00
22 07 1910 1016	1/2" Insulation, 1" Wall Thickness	1036.0	LF	$ 1.65	$ 1,709.40	$ 3.34	$ 3,460.24	$ -	$ 4.99	$ 5,169.64
22 07 1910 1018	3/4" Insulation, 1" Wall Thickness	801.2	LF	$ 1.72	$ 1,378.06	$ 3.49	$ 2,796.19	$ -	$ 5.21	$ 4,174.25
22 07 1910 1022	1" Insulation, 1" Wall Thickness	1421.5	LF	$ 1.77	$ 2,516.06	$ 3.66	$ 5,202.69	$ -	$ 5.43	$ 7,718.75
22 07 1910 1024	1-1/4" Insulation, 1" Wall Thickness	61.3	LF	$ 1.82	$ 111.57	$ 3.75	$ 229.88	$ -	$ 5.57	$ 341.44
22 07 1910 1026	1-1/2" Insulation, 1" Wall Thickness	122.3	LF	$ 1.90	$ 232.37	$ 3.75	$ 458.63	$ -	$ 5.65	$ 691.00
22 07 1910 1028	2" Insulation, 1" Wall Thickness	631.5	LF	$ 2.32	$ 1,465.08	$ 3.84	$ 2,424.96	$ -	$ 6.16	$ 3,890.04
22 07 1910 1032	3" Insulation, 1" Wall Thickness	404.6	LF	$ 2.55	$ 1,031.73	$ 4.27	$ 1,727.64	$ -	$ 6.82	$ 2,759.37
22 07 1910 1034	4" Insulation, 1" Wall Thickness	362.7	LF	$ 3.14	$ 1,138.88	$ 5.15	$ 1,867.91	$ -	$ 8.29	$ 3,006.78

Total Cost	$ 143,492.38
Add 0.985 Location Factor	$ 141,340.00

Figure 4.2: PVC piping estimate for the domestic water piping system

As seen in the figures, the initial cost of the existing domestic water piping system copper piping was approximately***$191,600***. The initial cost of the same system, but with PVC Piping came out to be ***$141,340***. This is an initial cost savings of ***$50,260***, which is approximately 0.16% of the total project costs. With these numbers, initial cost savings of the domestic water piping system would be 26% of the original system costs.

Maintenance Costs

Maintenance Costs were difficult to identify for both systems. RS Means data for maintenance costs was insufficient, as cost data was not provided for the majority of the fittings and piping dimensions that would be necessary to complete an accurate maintenance cost analysis. The same was true when analyzing maintenance costs for the PVC piping. Inconsistencies also arose when comparing the two systems, for the same data was not available for common piping and fitting sizes when comparing both material types.

Despite the insufficiency in cost data that would allow for an accurate estimate comparing the two maintenance costs, replacement time durations were sufficient to draw a comparative analysis. RS Means data for standard replacement durations can be viewed by *Table 4.1*. RS Means projects that both copper and PVC piping systems will have maintenance issues with fitting connections, and could require maintenance within ten years of the initial installation. Copper piping and fittings require maintenance as early as within 20 to 25 years. Similarly PVC piping projects to require replacement every 30 years according to RS Means. Very little information is provided regarding PVC fittings; however, the information that is provided indicates that fittings could undergo maintenance within ten years of initial installation. In general, RS Means tends to conclude that PVC and Copper piping requires similar maintenance with regard to maintenance frequency.

RS Means tends to undervalue the potential durability of both piping materials. General opinion in the construction field tends to agree that both copper and PVC piping systems are capable of lasting 75 years or more. Regardless, the systems are very similar when comparing durability and life expectancy. The major differences occur in the cost of each material: copper is more expensive initially and will be more expensive to replace.

Table 4.1: RS Means Replacement Duration Comparison Copper and PVC Domestic Water Piping

RS Means No.	System Description	Frequency (Years)	Crew
Copper Piping			
D2023 110 0010	Resolder Joint *Measure, cut & ream both ends* *Solder fitting*	10	1 PLUM
D2023 110 0020	Replace 3/4"copper pipe and fittings *Remove old pipe* *Install copper tube with couplings and hangers*	20	2 PLUM
D2023 110 0030 – D2023 110 0080	Replace (1" – 8") copper pipe and fittings *Remove old pipe* *Install (1" – 8") copper tube with couplings and hangers*	25	2 PLUM
PVC Piping			
D2023 130 0210	Reglue joint, install 1-1/2" Tee *Cut existing pipe, install tee 1-1/2"* *Inspect joints*	10	1 PLUM
D2023 130 0310	Reglue joint, install 2" Tee *Cut existing pipe, install tee 2"* *Inspect joints*	10	Q-1
D2023 130 2030 – D2023 130 2230	Replace 1000' PVC pipe (1" – 1-1/2") diameter *Remover broken pipe* *Install 1000' new PVC pipe 2" diameter* *Inspect joints*	30	1 PLUM
D2023 130 2330	Replace 1000' PVC pipe 2" diameter *Remover broken pipe* *Install 1000' new PVC pipe 2" diameter* *Inspect joints*	30	Q-1

Copper Recycling Costs

While PVC piping is typically discarded following demolition, copper piping can continue to hold value, as it can be scrapped and recycled. The scrapping of copper and reimbursement for recycling copper must be considered when determining the worth of a copper piping system in comparison to an alternative PVC piping system.

Table 4.2 and *Table 4.3* display the calculations used to determine the overall scrap potential of the existing copper domestic water piping. *Table 4.3* shows more concern toward calculating the overall weight of the copper piping. Weights for copper fittings were not included in the below calculations. Total piping lengths in linear feet are provided for each piping diameter present in the domestic water piping system. Each pipe length is multiplied by its unit weight per linear foot to determine the overall weight of piping by its diameter size. The piping unit weight is based on type L copper tubing, which is the piping thickness that is present in the existing piping system. Summing the total weights of each pipe size provides the overall weight of the copper piping present in the domestic water piping system, which is approximately *5,227 pounds*.

Table 4.3 utilizes the total weight from *Table 4.2* to determine the potential total reimbursement of the domestic water piping system for copper scrapping. The current price of copper scrapping in the United States is an average of $1.968 per pound. Multiplying the total weight by the cost per pound of scrapped copper leads to a total projected reimbursement of ***$10,286.04***.

Table 4.2: Copper Weight Calculations

Pipe Size	Total Pipe Length (LF)	Weight (lbs/ft)	Total Weight (lbs)
1/2"	756	0.285	215.5
3/4"	556.2	0.455	253.1
1”	1140.5	0.655	747.0
1-1/4”	52.8	0.884	46.7
1-1/2”	88.8	1.14	101.2
2”	552.5	1.75	966.9
3”	389.6	3.33	1297.4
4”	297.2	5.38	1598.9
Total Copper Weight (lbs)			5226.64

Table 4.3: Copper Scrap Recycling Reimbursement Calculations

Total Weight (lbs)	Cost Per Pound	Total Scrap Cost
5226.64	$1.968/lb	***$10,286.04***

The projected reimbursement of $10,286.04 is based on the 2016 value of the US Dollar. This allows for simple comparison to the detailed estimate prices for both the copper piping and PVC piping estimate of the domestic water piping system. The detailed estimate conclude that the expected cost of a copper piping system would be approximately ***$191,599.66*** with a potential payback of ***$10,286.05*** if the copper piping is recycled when the piping system would be replaced. The PVC estimate concludes that the cost of such a system would be approximately ***$141,340.00*** with a negligible payback as a result of recycling the PVC piping.

Impact on Schedule

After performing analysis on the amount of man hours that would be required for both systems, PVC piping emerged as the quicker option. The existing copper piping system was projected to require 1,334 labor hours while the proposed PVC system was projected to require 1,228 labor hours. This is a difference of 106 hours, or approximately 12 construction days (based on eight hour work days). It is difficult to say how much of an impact on the schedule this would make, since the schedule was very busy in the summer and not as busy during the school year. Regardless, replacing the copper piping with PVC piping for the domestic water piping system would not add to the already busy construction schedule. Calculations for the scheduling comparisons of each of these systems are displayed by *Figures 4.3 and 4.4* in Appendix C.

Conclusion

Table 4.4 below identifies some of the key design considerations for each system and identifies which is preferred in each situation. In general, copper piping is more expensive and takes longer to install. While copper piping does offer the opportunity for recycling costs, this return on costs in nowhere near enough to account for the cost savings provided by a switch to a PVC piping system. Maintenance costs could unfortunately not be accurately determined based on the cost data provided in RS Means. However, RS Means did indicate that PVC piping (not including fittings) is likely to last 30 years before requiring maintenance compared

Table 4.4: Copper vs. PVC Summary

Design Consideration	**Copper**	**PVC**	**Best Solution**	**Savings by using PVC**
Initial Cost	$ 191,600.00	$ 141,340.00	PVC	$ 50,260.00
Payback when replaced and recycled	$ 10,286.04	-	Copper	$ (10,286.04)
Maintenance Cost Projections	Inconsistent data makes it difficult to determine exact costs		PVC	N/A
Maintenance Frequency According to RS Means	Connections: 10 years	N/A	Either	N/A
	Fittings: 20 years	Fittings: 10 years		N/A
	Piping: 20 years	Piping: 30 years		N/A
Maintenance Frequency According to Construction Industry from Research	50 to 75 years, as high as 100 years	50 to 75 years, as high as 100 years	Either	N/A
Safety Concerns	Soldering Overhead	Overhead Placement	PVC	Safety

In addition to PVC being cheaper and quicker to install, it is also involves a safer installation process. Dealing with installing pipe can be unsafe and dangerous to workers for piping that is being installed overhead. Copper piping is especially dangerous when overhead installation occurs because of the soldering that is necessary to connect piping. PVC does not require soldering for its connections and is less of a safety hazard in that regard. Based on the reasons described, the domestic water piping system should be redesigned as a PVC piping system.

5 Research Topic
BIM Planning On Small Projects

Introduction

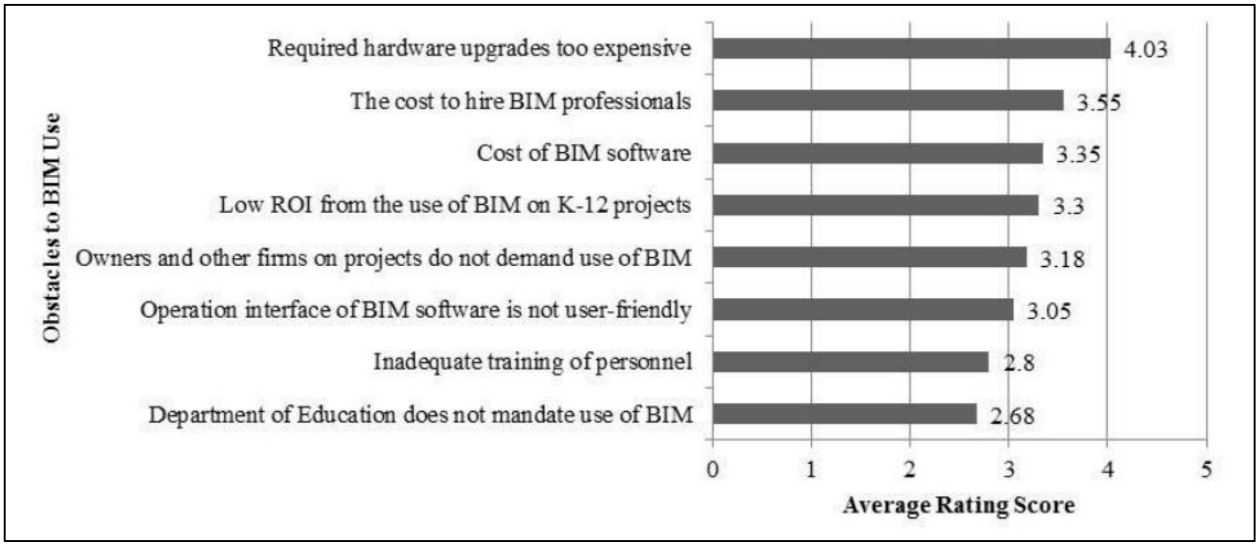
As stated many times already, the Stanton Elementary School Project suffered from issues with project funding and a very strict scheduling timeline. One construction practice that has essentially become standard that could have helped with planning throughout the course of the project is building information modeling (BIM). BIM techniques were utilized on this project; however, it appears that more could have been done to push through with the BIM approach. The project team did not feel the need to follow a BIM execution plan because they were worried that it would take up too much time. Determining the worth of a complete BIM execution plan compared to its benefits on a project is something that may be difficult to do in the short amount of time that is allotted to project planning. As a result, BIM execution planning on this project, a project with a majority of scheduling and financial constraints, was not utilized to its fullest potential. The limited amount of BIM execution used on the Stanton Elementary School project led to further research on how BIM can be effective on smaller projects.

It is a common misconception in the construction industry that BIM is most effective on larger projects and smaller projects cannot see the same types of benefits from BIM. The goal of this research is to determine the most applicable uses of BIM technology and see how these applications can be administered to a smaller project like the Stanton Elementary School project in a way that benefits the project without becoming too time consuming. The research performed is intended to benefit small projects in a hypothetical situation, but can also be used in construction practice for smaller projects.

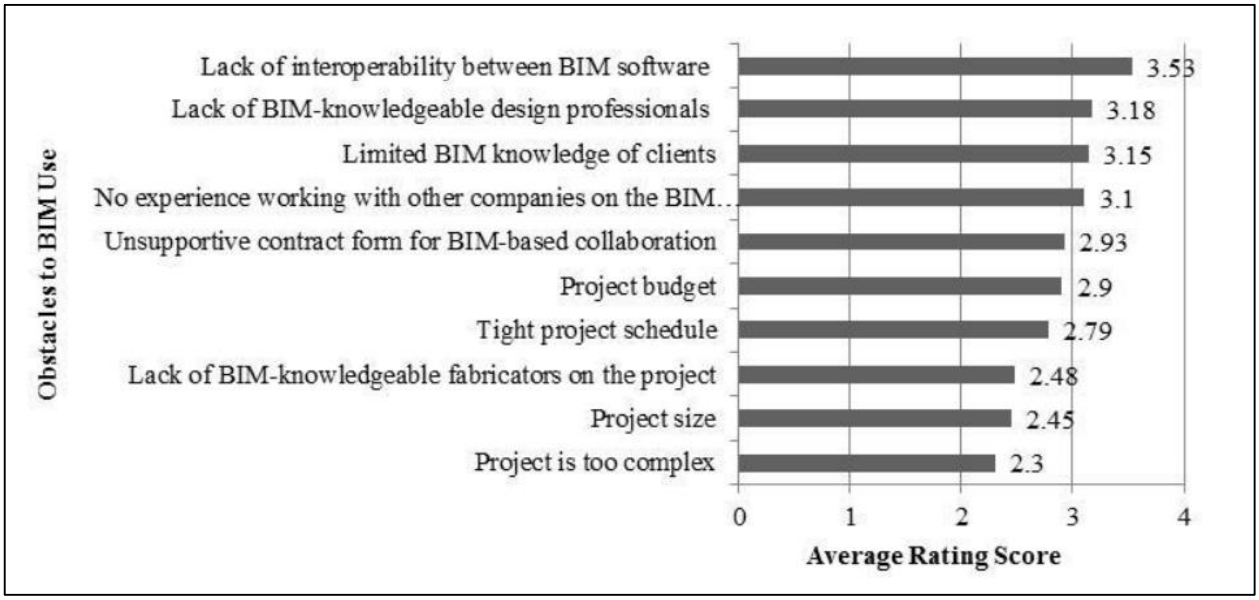
Research of this topic was performed by looking at a variety of case studies and scholarly articles that are focused on how BIM benefited smaller projects. These studies and articles also provided an interpretation with regard to why BIM is more unpopular with smaller projects. A survey-based research study titled *Implementation of BIM on K-12 Educational Facility Projects in Florida* was also analyzed and used to interpret the successes and failures of BIM execution for kindergarten through 12th grade projects. In addition, Penn State's existing BIM Research plans were referenced and used as a guide to BIM project planning for the proposed BIM execution planning guide included in this thesis.

Myths against BIM Implementation on Small Projects

Many of the researched articles and studies referenced that there is a common misconception that BIM is strictly beneficial as for larger projects only. In a 2012 study performed analyzing how BIM is implemented on educational buildings in Florida, surveys were to a variety of construction managers, engineering firms, and architectural firms to determine how they used BIM, if at all, for these types of projects. One of the surveys was specific to why companies decided not to use BIM for educational facility projects. Another survey attempts to identify types of project factors that prevented the use of BIM on educational facility projects. When answering the survey questions, respondents were asked to use a 5-point scale that indicated the level of truth to each reason behind not using BIM. The scale awarded one point if the topic was not likely at all to prevent BIM usage, two points if it was somewhat likely, three points if it was moderately likely, four points if it was very likely, and five points if it was extremely likely. *Figure 5.1* and *Figure 5.2* identify potential reasons that BIM was not used on projects in Florida in 2012 based on the survey results. Some of these reasons are expanded upon after *Figures 5.1 and 5.2* by using information from the same report and using information from other case studies and articles that were concerned with the same topic.



(Image source: "Implementation of Building Information Modeling on K-12 Educational Facility Projects in Florida")
Figure 5.1: Business factors that prevented the use of BIM on K-12 projects in Florida in 2012



(Image source: "Implementation of Building Information Modeling on K-12 Educational Facility Projects in Florida")
Figure 5.2: Project factors that prevented the use of BIM on K-12 projects in Florida in 2012

Cost of BIM Implementation

Many firms that refuse to use BIM on its projects because of the concern that the added costs that factor into BIM usage will not offer an adequate return of investment. Concerns stem from added costs of purchasing BIM software, the cost of required hardware updates to support BIM, and the costs that come with hiring professionals with BIM experience. Similar thinking provides reasons for firms to miss out on the benefits that BIM provides when they work on smaller projects, or in the case of this study, kindergarten through twelfth grade projects.

Complexity of BIM Process

Some owners do not see the benefit of BIM on smaller projects because of the large amount of detail that is put into a project by using BIM. While this is a benefit for large projects, firms may view this as a waste of time for smaller projects. For small firms that are not willing to use BIM processes, there is some concern about the software being too complex and not user-friendly. Overall, firms are worried that the relationship between BIM complexity and project size can harm project productivity.

Training Time

This concern goes along with the concern regarding BIM complexity. If a staff is not well-trained for BIM processes, then using BIM will take longer and be more ineffective. Having a lack of expertise does not allow for BIM to be as effective as it should be. Additionally, firms that currently do not use BIM in construction do not believe that the benefits do not outweigh the costs and time that it takes for training.

Lack of Client Demand

Project owners may not always be aware of the benefits of BIM and do not force that it is used on their projects. This allows firms to go through the project without using BIM processes if that is how they choose to perform the work.

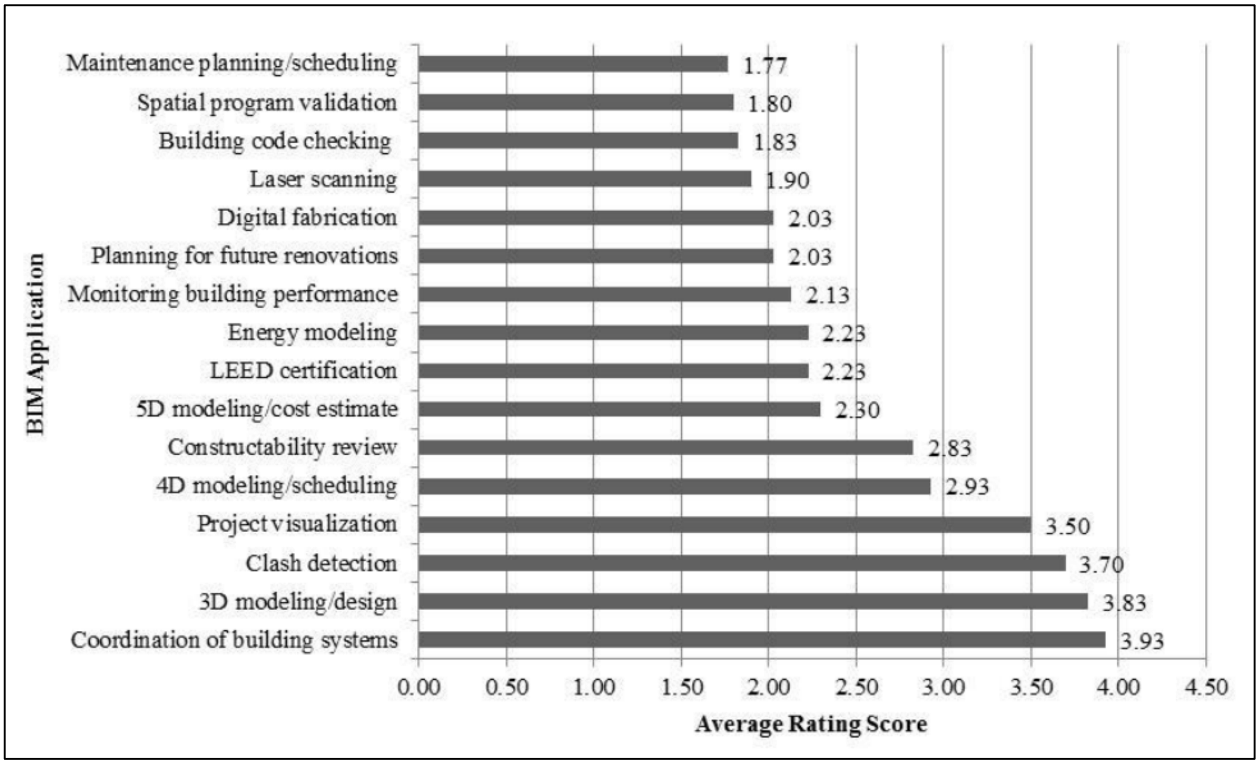
Reasons for BIM Implementation on Small Projects

While a lot of the reasons listed in the above section may seem valid, construction managers and designers who hold these views may not be well-informed of the benefits that BIM can bring to a project. After the initial costs and training occurs, there are a considerable amount of benefits to using BIM. As the Florida study provided survey information identifying reasoning as to why firms are unlikely to use BIM on kindergarten through twelfth grade educational facilities, the study also included surveys that identified the main uses of BIM on these types of projects. These results can be depicted by *Figures 5.3 and 5.4* on the following page.

Figure 5.3 identifies that BIM implementation helps in a variety of ways, mostly centered on project quality, scheduling, and greater cost estimate accuracies. In addition, an average score of 2.23 indicates that the return of investment of is slightly to moderately beneficial. *Figure 5.4* identifies strong correlations between various BIM applications and project benefits. Items such as constructability review, 4D modeling and scheduling, project visualization, clash detection, 3D modeling and design, and coordination of building systems all received fairly high scores with regard to how they help a kindergarten to twelfth grade project.

(Image source: "Implementation of Building Information Modeling on K-12 Educational Facility Projects in Florida")

Figure 5.3: Business benefits companies experienced due to the use of BIM on K-12 projects



(Image source: "Implementation of Building Information Modeling on K-12 Educational Facility Projects in Florida")

Figure 5.4: Benefits of using specific BIM application on K-12 projects

In addition to the findings of the Florida study focused on educational buildings, other research was found supporting benefits of BIM usage for small projects. A presentation sponsored by the American Institute of Architects (AIA) titled *BIM for Small Projects: Case Studies in Innovative BIM Use by Small Firms* identifies its own beliefs on the benefits that BIM brings to the table for small projects. In addition to the benefits already discussed, this presentation indicated that the following items are benefits of using BIM on smaller projects:

- More time spent on design.
- Increased feedback on design options.
- Design becomes primary commodity versus construction documentation.
- Once training is complete, faster turnaround on CDs.
- Forces personnel to be less specialized
- Aids in creating contracts documents
- Opportunities for 3D walkthrough

In the previous section, one of the major concerns was training time. In *BIM for Small Projects: Case Studies in Innovative BIM Use by Small Firms*, one of the benefits from BIM is that training increases the turnaround on construction documents. So while training may take time in the beginning of the process, the implementation of BIM with trained workers makes up for lost time because it allows for work to be performed quicker.

In an *Owner's Perspective* article, project manager and article author Patrick Wilson discusses his experience with BIM and explains that he has seen how BIM on small projects can provide opportunities for smaller firms to expand its BIM knowledge. The article also explains how Patrick Wilson and his team only work on projects that require BIM usage. Before the project starts, his team takes the time to train subcontractors in BIM methods if they do not have prior experience. The team does this because they worry that making BIM mandatory will deter some contractors from bidding. This is a unique approach to ensuring that BIM is used on a project. Not only does it force subcontractors to use BIM techniques, but it also trains them in BIM and helps in creating a construction workforce that is less specialized.

Recommended BIM Practices for Small Projects

From the research information discussed in the previous section, the following items have been identified as practices that are essential on small projects with BIM execution:

- Coordinating building systems and clash detection
- 3D model design
- Project visualization applications coming from 3D modeling
- Constructability review

The items listed above were the items that were found most important on kindergarten through twelfth grade projects in Florida. In addition to the items listed, implementing 4D modeling to help with the project schedule serves as an effective planning method on BIM projects. Ensuring that all subcontractors are capable of implementing BIM processes is also important. For BIM execution to be successful, it will be important that all parties involved are trained and capable of using BIM.

Additionally, multiple sources identified that the most effective delivery methods for a BIM-driven project are either design build or integrated project delivery (IPD) methods. These methods allow for the most collaborative effort and allows for easier paths for communication. Under optimal circumstances, the project owner would recognize this relationship, and push for one of these collaborative delivery methods.

It may also be beneficial to identify items that were not as successful for smaller projects and educational buildings. As previously determined, one of the issues that firms have with using BIM on small projects is the because of the complexity of the BIM process in relation to small scale of the project. One way to help eliminate this misconception (other than educating these firms on the benefits of BIM for all sized projects) is to identify potential items that are not as essential to BIM execution. Some of these potential items (based on the Florida study) are listed below:

- Maintenance planning/scheduling
- Spatial program validation
- Building code checking
- Laser scanning
- Digital fabrication
- Planning for future renovations
- Monitoring building performance
- Energy modeling
- LEED certification
- 5D modeling/cost estimate

Each of these items received a rating of 2.3 or less on the scale identified before. This means that firms who used BIM on educational projects in Florida collectively deemed these items as less than moderately beneficial to the project. On the other side of things, the items identified at the beginning of this section should be recognized as essential to the BIM process for small projects.

In addition to the consideration of the BIM design elements that were considered from research findings (whether effective or ineffective) the Penn State BIM execution guidelines should be closely followed for small projects. *Table 5.1* on the following page depicts the key elements of the Penn State University BIM execution planning approach.

The Penn State BIM planning approach focuses on identifying project goals, team information, standard project procedures, and other pieces of information that allow for the entire project team to be on the same page. It allows for a collaborative environment and one where communication is made easy. Since documentation of team project goals and methods combined with individual responsibilities are known at the onset of the project, the BIM process moves a lot more smoothly.

Table 5.1: Penn State BIM Execution Planning

BIMex Section	Section Title
Section A	BIM Project Execution Plan Overview
Section B	Project Information
Section C	Key Project Contacts
Section D	Project Goals/BIM Uses
Section F	Organizational Roles/Staffing
Section G	BIM Process Design
Section H	BIM Information Exchanges
Section I	Collaboration Procedures
Section J	Quality Control
Section K	Technological Infrastructure Needs
Section L	Model Structure
Section M	Project Deliverables
Section N	Delivery Strategy Contract
Section O	Attachments

Conclusions

Based on what was learned from the research and the BIM practices that are promoted by Penn State, a list of items that are especially important for BIM to be successful on small projects is provided in *Table 5.2*. In addition to the list provided, other BIM practices, especially the ones provided, may also be used on small projects. The list provided in *Table* 5.2 serves as a proposed minimum BIMex plan for construction managers that may still be wary about using BIM on smaller projects. In addition to the BIM uses that are proposed in *Table 5.2*, BIM planning methods from *Table 5.1* should also be used for small projects.

Table 5.2: Recommended Ibex minimum requirements for BIM on small projects

Building Systems Analysis
Site Utilization Planning
Construction System Design (Virtual Mock-up)
3D Control and Planning (Digital Layout)
3D coordination
Sustainability (LEED) Evaluation
Design Reviews
Phase Planning
Cost Estimation
Existing Conditions Modeling

While all methods of BIM use are effective and have their own benefits, some of the research, especially the research performed in Florida for kindergarten through twelfth grade educational facilities, show that not all approaches are desirable for small scale projects. A description of the BIM use items from *Table* 5.2 is provided in Appendix D for more information on these processes. This information was published by Penn State University. Additional BIM uses that did not make the *Table 5.2* are provided in Appendix D as well.

6 Structural Breadth

Pre-Kindergarten Wing Foundation Redesign

Introduction

The new addition to the Stanton Elementary School added a noticeable amount of classroom space and took a large amount of space from the existing site. If the school were to ever see another building expansion, it is very likely that this expansion would have to occur vertically. *Figure 6.1* helps identify that the school site has been essentially maximized by the existing building addition. The parking lot cannot really be made smaller, especially with the increase in classrooms and need for more faculty as a result of the school's expansion. Roads occupy the site on three sides, and the fourth (southernmost side) is occupied by the school's athletic fields. The most sensible location for this type of expansion would occur at the site of the pre-kindergarten wing.

Figure 6.1 Site Logistics including pre-kindergarten wing identifiaction

The pre-kindergarten wing is only one story tall and houses six classrooms. This space occupies an area of approximately 8,400 square feet (60 feet by 140 feet). This leaves room for a considerable amount of additional classroom spaces if two stories were to be added to this section of the building. With an addition 8,400 square feet of spaces, twelve to twenty additional classrooms could be added to the building.

The existing building foundation system is a helical pile and pile cap system. This is used throughout the phase two renovation consistently in conjunction with continuous footings around the perimeter of the phase two building addition. The design initially called for a spread footing foundation system; however unsuitable soils forced the project team to adjust the design to the existing pile and pile cap system. Because of the unsuitable soils, the building's foundations will remain a pile and pile cap system for in the redesign.

The purpose of this structural breadth is to determine if it would be feasible to add the additional load of two stories on top of the existing foundations and to revamp the foundation design to allow for heavier loading conditions if needed. In the end, the goal is to have an analysis of what the added cost and schedule implications would look like and how the project would be affected by these factors.

Determining Column Loading

Structural analysis began by calculating the tributary area for the columns that would be affected by the foundation redesign. For the sake of analysis, the second and third stories that would be added on top of the existing structure were assumed to have the same floor plan design as the first floor. Once column tributary areas were known, calculations for loading could begin. The following assumptions were made based on the loading conditions provided in the construction documents for phase 2 of construction:

- Live Loads
  - Typical classroom = 65 PSF (includes partition loading)
  - First floor corridors = 100 PSF
  - Second floor Corridors = 80 PSF
  - Roof load = 20 PSF
- Dead Loads
  - 40 PSF assumed for all levels, including roof
- Snow Loads
  - 30 PSF

The above loading conditions were then used in LRFD calculations to determine the loading on each column. *Table 6.1* in Appendix E depicts how each calculation was performed for specific columns. Once column loading conditions were known, the *AISC Steel Construction Manual, 14th ed.* was used to determine if the existing building columns would support the loading conditions of a two a three-story pre-kindergarten wing. The existing columns were sufficient, and would not need to be changed to support the new building loading conditions. Column sizing for floors two and three were determined to be W8x31. The W8x31 columns will be spliced at a height of 16 feet. These columns will be 26 feet in height to combine to 42 feet. This height assumption was made because the main building is 42 feet in height.

The combination of the column self-weight with the loading conditions of each floor were then summed to determine the total loading on the foundations. Specific loading calculations are located in *Table 6.2* in Appendix E. The *Table 6.2* calculations identify column tributary areas, first floor loading conditions, second floor loading conditions, third floor loading conditions, roof loading conditions, column sizing and self-weights, total loading on columns, and total pile cap loading.

Once column loading was determined, the loading conditions created by the proposed three story structure could be compared to the existing loading conditions. Surprisingly, the two loading situations were very similar. *Table 6.3* goes on to show each of the loading conditions at specific pile cap locations and whether or not the proposed building loading will comply with the existing pile and pile cap bearing capacities.

Table 6.3: Loading Conditions and Design Comparisons

Column	Total Load on Footing (kip)	Existing Loading (kip)	Existing Design	# of Piles	Existing Loading Potential (kip)	Is Existing Design Sufficient?	Recommended Design
D.5-20	50.6	65	P3	3	120	YES	Remain the Same
D.5-19	162.7	175	P5	5	200	YES	Remain the Same
D.5-18	162.7	175	P5	5	200	YES	Remain the Same
D.5-17	162.7	175	P5	5	200	YES	Remain the Same
D.5-16	162.7	175	P5	5	200	YES	Remain the Same
D.5-15	162.7	175	P5	5	200	YES	Remain the Same
D.5-14	172.0	175	P5	5	200	YES	Remain the Same
B.8-20	74.7	85	P3	3	120	YES	Remain the Same
B.8-19	241.9	225	P7	7	280	YES	Remain the Same
B.8-18	241.9	225	P7	7	280	YES	Remain the Same
B.8-17	241.9	225	P7	7	280	YES	Remain the Same
B.8-16	241.9	225	P7	7	280	YES	Remain the Same
B.8-15	241.9	225	P7	7	280	YES	Remain the Same
B.8-14	261.9	210	P6	6	240	NO	Change to P7
Aa.1-20	50.6	65	P3	3	120	YES	Remain the Same
Aa.1-19	162.7	175	P5	5	200	YES	Remain the Same
Aa.1-18	162.7	175	P5	5	200	YES	Remain the Same
Aa.1-17	162.7	175	P5	5	200	YES	Remain the Same
Aa.1-16	162.7	175	P5	5	200	YES	Remain the Same
Aa.1-15	162.7	175	P5	5	200	YES	Remain the Same
Aa.1-14	172.0	175	P5	5	200	YES	Remain the Same
A.9-20	74.7	85	P3	3	120	YES	Remain the Same
A.9-19	241.9	225	P7	7	280	YES	Remain the Same
A.9-18	241.9	225	P7	7	280	YES	Remain the Same
A.9-17	241.9	225	P7	7	280	YES	Remain the Same
A.9-16	241.9	225	P7	7	280	YES	Remain the Same
A.9-15	241.9	225	P7	7	280	YES	Remain the Same
A.9-14	261.9	225	P6	6	240	NO	Change to P7

From *Table 5.3*, the column labeled 'Total Load on Footing' is the load that the pile cap would be experiencing from the proposed three-story redesign. The column labeled 'Existing Loading' is the loading for which the pile cap was originally designed based on the existing single-story pre-kindergarten wing. The column labeled 'Existing Loading Potential' identifies the maximum design potential loading of the pile cap. The column labeled 'Is Existing Design Sufficient?' is used to compare the existing loading values to the proposed loading values. Twenty-six of the twenty-eight pile caps used in the pre-kindergarten wing would be sufficient for proposed two-story addition. Two pile caps, located at columns B.8-14 and A.9-14, do not have the required bearing capacity to support the increased column loading that would occur as a result of adding two stories to the structure.

For the pile caps located at B.8-14 and A.9-14, the design bearing capacity is exceeded by 21.9 kips. The design for each of these pile caps should be upgraded to pile cap P7 as shown in the construction drawings. *Figure 6.2* identifies the differences in design between pile cap P6 and P7.

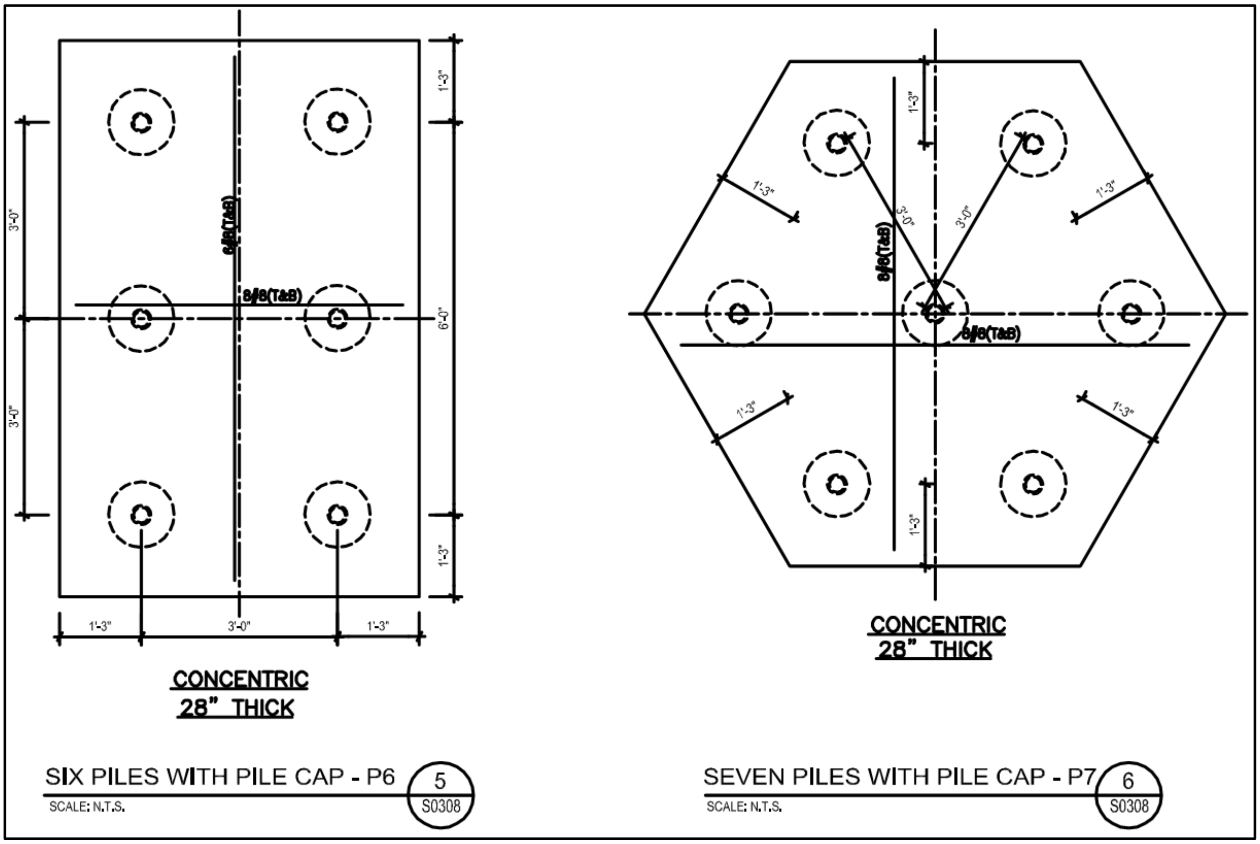


Figure 6.2: Pile cap design for P6 and P7 pile caps

Pile cap P6 has a square foot area of about 38 ft^2, six piles, and a bearing capacity of 240 kips. Pile cap P7 has a square foot area of about 52 ft^2, seven piles, and a bearing capacity of 280 kips. With a bearing capacity of 280 kips, pile cap design P7 is capable of supporting the 261.9 kip loading conditions that it would face at column locations B.8-14 and A.9-14.

Revised Design: Maintain the same pile cap design at all locations ***except*** at locations B.8-14 and A.9-14. Column locations B.8-14 and A.9-14 should upgrade to pile cap design P7.

Cost Analysis

Pile cap P7 is larger than pile cap P6 and includes an additional helical pile. As a result, the cost of the foundations will increase. To depict this increase, estimates of both pile cap systems were developed. RS Means cost data was used for concrete, concrete placement, formwork, and rebar cost calculations. Helical pile costs were derived from cost information provided by Tompkins Builders. A major assumption was made in performing the helical pile cost derivations. The helical pile cost per pile was assumed to be $1,134.62. This assumption came from dividing the total cost of the contract that Tompkins held with the helical piles subcontractor by the total number of piles on the project. RS Means does not have cost data for helical piles, most likely as a result of the complexity and variability of helical pile systems. Additionally, it is difficult to determine labor costs for an item that can experience such variability in installation time based on the onsite soil conditions. The $1,134.62 cost is assumed to include material, labor, and equipment costs.

Existing Foundation System Estimate

RS Means No.	Item	Qty.	Unit	Material	Material Total	Labor	Labor Total	Equipment	Equipment Total	Total
03 30 5320 3825	3000 psi concrete	101.00	CY	207	$ 20,907.00	120	$ 12,120.00	0.73	$ 73.73	$ 33,100.73
03 31 1370 2400	Concrete Placement	101.00	CY			34.5	$ 3,484.50	1.15	$ 116.15	$ 3,600.65
03 11 1325 3000	Formwork	1604	SFCA	2.85	$ 4,570.61	5.05	$ 8,098.80			$ 12,669.41
03 21 1160 0550	#8 Rebar	6.79	TON	960	$ 6,520.78	470	$ 3,192.47			$ 9,713.25
(From Tompkins)	Helical Piles	154	EA	N/A		N/A		N/A		$ 174,730.77

Total $ 233,814.80

Total with 0.985 Location Factor ***$ 230,307.58***

Figure 6.3: Existing foundation system detailed estimate

Proposed Foundation System Estimate

RS Means No.	Item	Qty.	Unit	Material	Material Total	Labor	Labor Total	Equipment	Equipment Total	Total
03 30 5320 3825	3000 PSI Concrete	104.00	CY	207	$ 21,528.00	120	$ 12,480.00	0.73	$ 75.92	$ 34,083.92
03 31 1370 2400	Concrete Placement	104.00	CY			34.5	$ 3,588.00	1.15	$ 119.60	$ 3,707.60
03 11 1325 3000	Formwork	1607	SFCA	2.85	$ 4,579.48	5.05	$ 8,114.51			$ 12,693.98
03 21 1160 0550	#8 Rebar	6.86	TON	960	$ 6,582.30	470	$ 3,222.58			$ 9,804.88
(From Tompkins)	Helical Piles	156	EA	N/A		N/A		N/A		$ 177,000.00

Total $ 237,290.38

Total with 0.985 Location Factor ***$ 233,731.03***

Figure 6.4: Proposed foundation system detailed estimate

The complete detailed cost estimates for both the existing pile cap foundation system and the proposed pile cap foundation system are provided in *Figure 6.3* and *Figure 6.4* respectively. The existing pile cap foundation system is projected to cost approximately ***$230,308*** compared to the proposed foundation design cost of ***$233,731***. Upgrading the foundation systems would cost about ***$3,423***, which is a ***1.46%*** increase in pile cap foundation cost for only the pre-kindergarten wing foundations. This is a fairly insignificant cost increase.

Scheduling Implications

The small amount of concrete that is required to increase the bearing capacity of pile caps located at B.8-14 and A.9-14 will have an extremely minimal effect of the schedule. The additional two piles that are required for the proposed design will have slightly more of an impact but will also be fairly minimal. RS Means data was used to consider scheduling durations for concrete, formwork, and rebar placement. Information from Tompkins Builders phase two schedule was used to determine the helical pile installation duration.

Drilling of 260 helical piles lasted 67 construction days. This is a rate of about 3.9 helical piles per day. Two additional piles are required for the proposed design, which translates into a duration of about 0.5 construction days. A total expected duration of 67.5 days was derived for the proposed foundation design pile cap installation. The remainder of scheduling durations can be seen in *Table 6.4* and *Table 6.5*. The proposed pile cap foundation design is projected to be 0.6 construction days longer than the existing design. None of the items listed are a part of the schedule's critical path.

Table 6.4: Scheduling calculations for existing pile cap system

Existing Foundation System Estimate

RS Means No.	RS Means	Item	Qty.	Unit		Crew	Daily Ouput	Labor Hours		Total (days)
03 30 5320 3825	Concrete In Place, Footings (300 psi), spread from 1 C.Y.	3000 psi concrete	101	CY		C-14C	43	2.605		2.35
03 11 1325 3000	Forms in place, footings, file	Formwork	1604	SFCA		C-1	290	0.11		5.53
03 21 1160 0550	Reinforcing in Place, Slab	#8 Rebar	6.79	TON		4 Rodman	3.6	8.889		1.89
(From Tompkins)	From Tompkins Builders	Helical Piles	154	EA		N/A	N/A	N/A		67.00
Total										76.77

Table 6.5: Scheduling calculations for proposed pile cap system redesign

Proposed Foundation System Estimate

RS Means No.	RS Means	Item	Qty.	Unit		Crew	Daily Ouput	Labor Hours		Total (days)
03 30 5320 3825	Concrete In Place, Footings (300 psi), spread from 1 C.Y.	3000 PSI Concrete	104	CY		C-14C	43	2.605		2.42
03 11 1325 3000	Forms in place, footings, file	Formwork	1607	SFCA		C-1	290	0.11		5.54
03 21 1160 0550	Reinforcing in Place, Slab	#8 Rebar	6.86	TON		4 Rodman	3.6	8.889		1.90
(From Tompkins)	From Tompkins Builders	Helical Piles	156	EA		N/A	N/A	N/A		67.52
Total										77.38

Conclusion

Initially, it may seem surprising that the existing pile caps design is so similar to a proposed foundation design that would allow for two additional stories. There are a number of factors that may play into why the calculated loading conditions for a three-story building were so close to the loading conditions used to design the existing foundations.

1. The existing building loading was heavily influenced by factors of safety. This is extremely likely, as the previous foundation design called for spread footings that were nearly half the size of the respective pile caps.
2. Unsuitable soils may have played a role in this potential overdesign. The soil bearing capacity of 3000 psi that was used was derived from the helical pile data and reports. It is possible that the design professional considered a lower soil-bearing capacity that could have potentially influenced the size of the pile caps, making them much larger than they would have needed to be for the existing building loading conditions.
3. The green roof over the existing pre-kindergarten wing could have played a major role in column loading for this existing foundation design. If a future vertical expansion of the pre-kindergarten wing were to occur, the existing green roof would be demolished. The loading for the proposed foundation redesign did not consider loading for a green roof. For the purpose of this breath analysis, the assumption was made that the green roof would not be replaced in a future building addition.

Generally speaking, the redesign that is necessary to generate a foundation system that is capable of supporting 3 stories is very minimal. This process requires the modification of only two pile cap designs, adding only three cubic yard of concrete, 128 pounds of additional number 8 reinforcing bars, and two additional helical piles. This translates into a minimal added cost of $3,423 and about 0.6 construction days. Understanding that the schedule and the existing budget have very little room to be adjusted on this project, an exception should be made for the foundation systems. This system will allow for future vertical expansion, at a very minimal cost. If expansion were to occur in the future, an incredible amount of time and money would be saved by having a foundation system that can already support the additional building loading. This is a change that should be made. The owner should pay for the foundation redesign to allow for vertical expansion over the pre-kindergarten wing if it were to ever occur at a later date.

7 Acoustical Breadth
Classroom Acoustical Analysis

Introduction

The intent of the following acoustical breadth analysis is to determine if the existing building partitions act as appropriate acoustical barriers for classrooms. One of the main goals of the Stanton Elementary School building addition and renovation was to improve the building environment in a way that would benefit students and enhance students' learning experiences. Improving upon the building's acoustical design would act as a major step towards achieving that goal.

There are a number of potential noise distractions that could hinder students' abilities to learn. Specific background noise distractions will be identified in the analysis section for each room within the acoustical report. Rooms covered in this analysis were chosen specifically because of the types of noise distractions they could face. The following rooms were analyzed in this acoustical breadth:

- Room 108 – Pre-kindergarten Classroom
- Room 215 – Library
- Room 205 – 2nd Grade Classroom
- Room 319 – Music Room
- Room 1017 – Pre-kindergarten Classroom

The process of analysis was based on the sound transmission class (STC) ratings of the walls separating the selected classrooms from adjacent spaces. STC ratings use transmission loss data at one-third octave bands to identify the effectiveness that an object has in preventing noise to travel through the object under question. For this analysis, STC ratings were either identified directly from what was provided in the construction documents or by making assumptions based on the makeup of the wall compared to model partitions provided by *NRC Gypsum Board Walls: Transmission Lass Data*. Additional STC and transmission loss data were derived from the *Architectural Acoustics: Principles and Design* textbook by Mehta, Johnson, and Rocafort.

In a situation where walls featured multiple types of materials or partitions, the composite STC of the wall was calculated using transmission loss data for each partition type. These types of calculations used equations 5.1 and 5.2, along with the typical method for determining STC of a wall with one-third octave band transmission loss data. In the below equations, (TL) is transmission loss, (τ) is the transmission coefficient, and (S) is the surface area of a partition. Tables for specific calculations based on wall type and classroom can be found in Appendix F.

$$\text{TL} = 10 \log 1/\tau \qquad (5.1)$$

$$\text{TL}_{\text{comp}} = \frac{S_T}{(\tau_1 S_1 + \tau_2 S_2 + \ldots + \tau_n S_n)} \qquad (5.2)$$

Recommended STC values were determined based on spaces that were adjacent to each wall. This information was taken from *ANSI/ASA S12.60-2010/Part 1* data outlining standard acoustical performance criteria, design requirements, and guidelines for schools. Specifically, *Table 7.1* below was utilized to obtain recommended wall STC values. Once recommended values were determined, a comparison was drawn based on the actual and recommended partition sound transmission classes. Recommended STC values related to the actual wall STC vales are depicted for each room in *Tables 7.2a* to *7.2e* in Appendix F.

Table 7.1: Limits on A- and C-weighted sound levels of background noise and reverberation times in unoccupied furnished learning spaces

Learning space [a)]	**Greatest one-hour average A- and C-weighted sound level of exterior-source background noise** [b), f)] **(dB)**	**Greatest one-hour average A- and C-weighted sound level of interior-source background noise** [c), f)] **(dB)**	**Maximum permitted reverberation times for sound pressure levels in octave bands with midband frequencies of 500, 1000, and 2000 Hz (s)**
Core learning space with enclosed volume ≤ 283 m^3 (≤ 10 000 ft^3)	35 / 55	35 / 55	0.6 s [e)]
Core learning space with enclosed volume > 283 m^3 and ≤ 566 m^3 (> 10 000 ft^3 and ≤ 20 000 ft^3)	35 / 55	35 / 55	0.7 s
Core learning spaces with enclosed volumes > 566 m^3 (> 20 000 ft^3) and all ancillary learning spaces	40 / 60 [d)]	40 / 60 [d)]	No requirement

a) See 3.1.1.1 and 3.1.1.2 for definitions of core and ancillary learning spaces.

b) The greatest one-hour average A- and C-weighted interior-source and the greatest one-hour average A- and C-weighted exterior-source background noise levels are evaluated independently and will normally occur at different locations in the room and at different times of day.

c) See 5.2.2 for other limits on interior-source background noise level.

d) See 5.2.3 for limits in corridors adjacent to classrooms.

e) See 5.3.2 for requirement that core learning spaces ≤ 283 m^3 (≤ 10 000 ft^3) shall be readily adaptable to allow reduction in reverberation time to 0.3 s.

f) The design location shall be at a height of 1 m above the floor and no closer than 1 m from a wall, window, or fixed object such as HVAC equipment or supply or return opening. See A.1.3 for measurement location.

(Table 1 from ANSI/ASA S12.260-2010/Part 1)

Acoustical Analysis by Room

Room 108 Analysis

Room 108 is a pre-kindergarten classroom and was part of the building renovation that takes place in phase one of the project. *Figure 7.1* shows the layout of classroom 108 and identifies each wall for the reader's reference throughout the course of this analysis. The room's exterior walls are outlined in red, and the interior walls are outlined in blue. The Stanton Elementary School has 10 pre-kindergarten classrooms in total, making this room ideal analysis. Additionally, this space could potentially face acoustical issues that can cause unwanted background noise resulting from many different sources such as:

- The stairwell adjacent to wall A
- The hallway adjacent to wall A
- The individual restrooms adjacent to wall C
- Traffic on Naylor Road (adjacent to wall A)
- The athletic fields near wall F

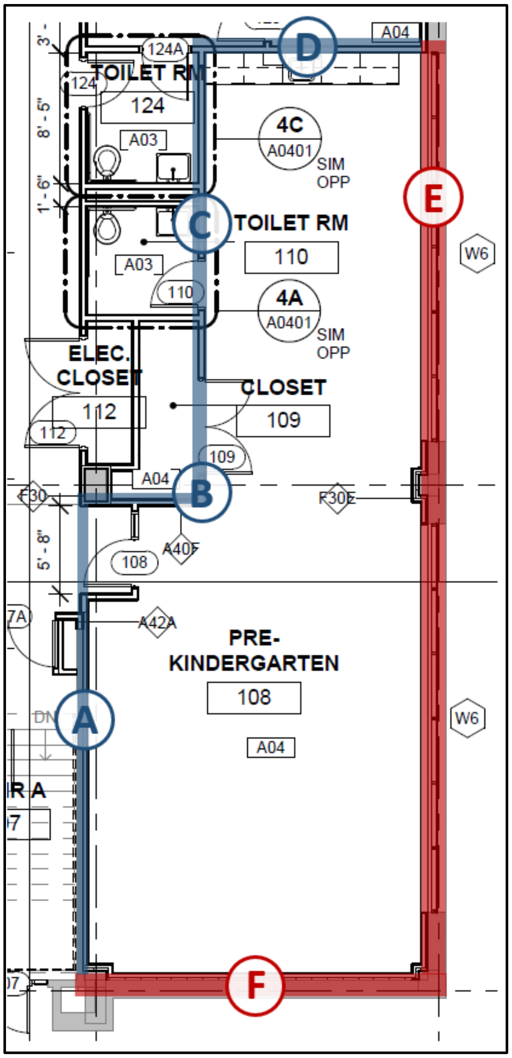


Figure 7.1: Pre-kindergarten room 108 in phase 1 of construction

All of the above sources ended up playing a role in the analysis with the exception of the noise coming from the school athletic fields. After further investigation, it was determined that the athletic fields were not within a range that would affect students in room 108. The full analysis and determining factors of the recommended wall STC values can be seen in *Table 7.2a* in Appendix F. In general, walls A, B, D, F, and the floor-ceiling assembly below room 108 all met the acoustical design recommendations. Walls C and E and the floor-ceiling assembly above room 108 did not meet the acoustics recommendations and a further analysis was performed to provide recommendations to improve upon the existing acoustical deficiencies.

Wall E could potentially be threatened by exterior noise from traffic coming from Naylor Road, which is directly adjacent to the building. This is especially concerning given the large amount of window space that is present on this façade. The windows used on this project featured aluminum mullions and ¼-inch laminated glass. These windows have an STC-35 rating. The acoustical rating of exterior wall E suffers as a result of the high percentage of window coverage on this wall (68% of the wall is glazing).

The minimum STC requirement for an exterior wall of an educational building is STC-35. Due to the proximity of Naylor Road, the STC for exterior wall E should be a minimum of STC-40. This assumption was made because this wall is within 30-50 feet of Naylor Road. *ANSI/ASA S12.260-2010/Part* 1 states that a classroom within 30 to 50 feet of a playground area used for recess should have a minimum of STC-40 partitions separating the classroom from outside. The assumption was made that playground noise would be similar to traffic noise. After performing calculations for the wall's composite STC value, it was determined that exterior wall E only maintains a sound transmission class of 36. (Supporting calculations for composite walls can be found in Appendix F). This falls short of the minimum recommendation of STC-40.

Wall C is an STC-49 rated wall, which is typically sufficient for a classroom. However, this wall separates the classroom from restrooms, and requires an STC-53 wall to meet design recommendations. The floor assembly is also short of recommended sound transmission class ratings. The art room is directly below room 108. In most circumstances, an art room would require an STC-50 barrier when adjacent to other classroom spaces. The circumstances are different here, as the Stanton Elementary School art room has a kiln. Kilns can reach up to 90 dB in volume, which is similar to that of a mechanical room. Such a situation calls for an STC-60 barrier between the two spaces. The existing floor-ceiling barrier design is estimated to have an STC of 53, which is short of the recommended STC of 60.

Room 108 Recommendations

Most importantly, a higher composite STC rating should be present for the wall E partition that separates the classroom from the outside environment, which is very close to Naylor Road. Given the high percentage of windows present within this partition, the most sensible method of improving STC rating would be to utilize windows with higher STC values. Typical windows are about STC-35, which is what the Stanton Elementary School features. Sound proof windows of a similar design range from STC-48 to STC 56. Implementing a sound proof window with an STC value of 48 would be sufficient. The window and wall value would each be above the recommended value of STC-40. Therefore, the composite assembly STC rating would also be greater than STC-40.

Wall C falls just short of the recommended STC rating. The building has multiple existing wall designs that match or exceed STC-53. Changing wall C from a type A40F partition (STC-49) to a type A42A partition (STC-56) would satisfy the sound transmission class recommendations provided for a partition between a classroom and a restroom space. Detailed drawings of project partition types can be seen in Appendix F.

Finally, the floor-ceiling design should be improved to meet the design recommendations of STC-60. Lack of consistent data and research in these types of assemblies makes it difficult to identify the most appropriate solution, for it is nearly impossible to match the most sensible solutions (that could be associated with the project) to assemblies that have reasonable STC ratings. The existing floor-ceiling system is a composite deck with 4 inches of concrete, a 1'-8" air plenum space, and acoustical ceiling tiles. The most accurate representation of the floor-ceiling assembly that could be found was simply a 6" thick concrete slab. This STC value was determined to be 53. This type of design could be enhanced by adding insulation between acoustical ceiling tiles and composite decking space. This type of design would increase the sound transmission class rating to STC-60. Again, there is variability in the recommended system and what would actually be feasible based on the structural system that is existing in the building. However, this provides the most feasible solution compared to other methods.

Room 215 Analysis

Room 215 is home to the elementary school library. *Figure 7.2* shows the layout of room. As in *Figure 7.1*, the room's exterior walls are outlined in red while the interior walls are outlined in blue. It is generally accepted that library spaces should be as quiet as possible. It is important for students to be able to have a quiet environment to visit, which is why the library acoustical analysis was performed. The library is between two classroom spaces, and is adjacent to a hallway on one side of the room and adjacent to Naylor Road on the other side of the room. Possible noise disturbances to this space could stem from:

- Naylor road
- The hallway
- Adjacent classrooms

The full analysis and determining factors of the recommended wall STC values can be seen in *Table 7.2b* in Appendix F. None of the walls met the recommended STC values; however, the floor-ceiling assemblies were acoustically adequate for the spaces below and above the library. Further analysis was performed to provide recommendations for improving upon the existing acoustical deficiencies for the library interior and exterior walls.

Wall A is a composite wall featuring glazing with an STC-35 rating that covers nearly forty percent of the wall. This heavily reduces the STC rating of the wall to STC-39. This is well below the recommended minimum requirement of STC-45 for walls between hallways and classroom spaces. Wall C is similar in the regard that it too is a composite wall. This composite wall separates the classroom from the outdoor environment, and should have a minimum STC requirement of STC-40. Due to the large percentage of glazing across wall C (68% of the total wall surface area), this wall falls short of acoustical design recommendations, and is only STC-36 rated.

Walls B and D are essentially sufficient, but barely miss the recommended mark. Each of these walls are between the library and a classroom space. The recommended STC for such a partition is STC-50. Each of these walls have a sound transmission class of 49.

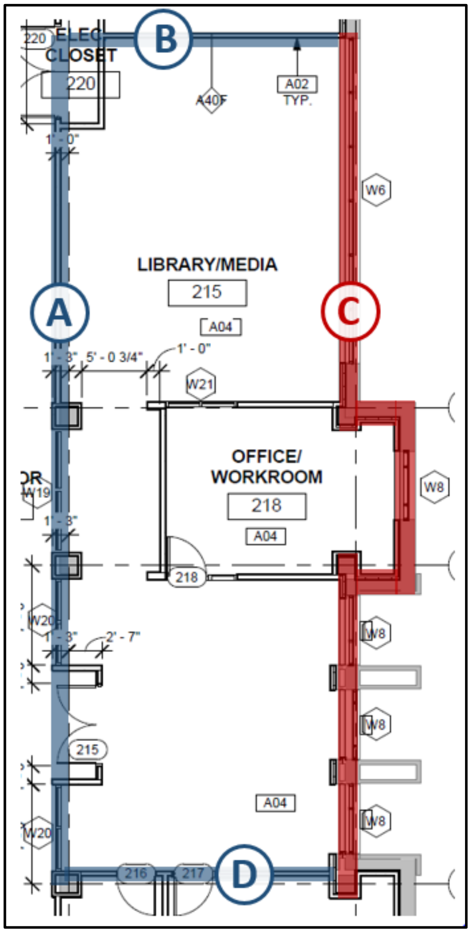


Figure 7.2: Pre-kindergarten room 215 in phase 1 of construction

Room 215 Recommendations

Wall type A is insufficient by a fairly large margin when compared to the STC recommendations. This is largely a result of the high amount of glazing that is a part of this partition. While the interior glazing may provide an aesthetically pleasing design, it may be beneficial to eliminate this aspect of design from wall A. Wall A should consist of the typical gypsum on top of metal studs design with fiberglass insulation that is featured throughout the building. Glazing should be eliminated from the wall completely. This would increase the wall STC from STC-39 to STC-49. This is a much more adequate acoustical design.

Wall type C again suffers from the large amount of glazing that covers the overall partition surface area. Because wall C is an exterior wall, it would be best to replace the existing windows with better STC-rated windows. This will allow for the same amount of natural daylight to enter the space and will also provide better acoustical efficiency. Soundproof windows would increase the window STC rating from 35 to 48. The wall sound transmission class (STC-45) and window sound transmission class would each exceed the recommendation of STC-40.

Walls B and D are very close to the recommended STC ratings for adjacent classroom spaces. The STC difference is only one, which is nearly negligible. However, since the space is extra sensitive outside noise, the walls could benefit from increasing the STC rating. These walls should be changed from partition type A40F (STC-49) to partition type A42A (STC-56).

Room 205 Analysis

Room 205 is a second grade classroom that is a part of the phase on building renovation. This room was chosen to serve as a room that does not face many threats of background noise. While this room has a view of the athletic fields where recess is held, it is not close enough to be affected by outside noise from the field. Room 205 is surrounded by a hallway, stairwell, athletic fields, another second grade classroom, and a dean's room. Above the room is another classroom and below it is a classroom, a coaches room, and an individual restroom. *Figure 7.3* displays the layout of the room and how each wall is identified throughout the report.

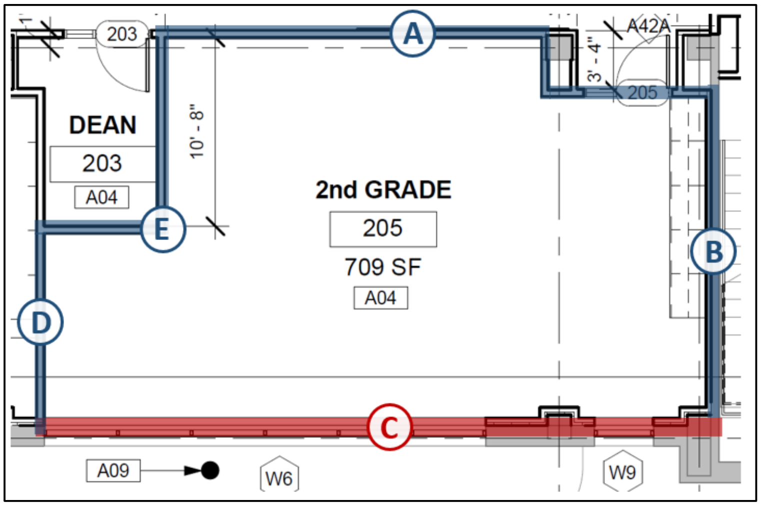


Figure 7.3: 2nd grade classroom in phase 1 of construction

After determining recommended sound transmission class ratings for each of the walls based on adjacent spaces, the conclusion was made that the partitions were acoustically sufficient. Recommendations were not necessary for room 205 since each room was already acoustically efficient. The full analysis of second grade classroom 205 can be viewed on *Table 7.2c* in Appendix F. This room could be used as a model for typical classrooms.

Room 319 Analysis

Room 319 is home to the school's music room. For the most part, the location of this classroom with respect to other classrooms is efficient from an acoustical design perspective. The issue with the music room is not that the room may experience unwanted background noise from other sources, but that the music room will be home to potential unwanted noise for other spaces. The room is surrounded by two hallways (on walls A and C as seen in *Figure 7.4*, and elevator shaft, a resource room, and the outside environment. Below the room is a classroom and above it is the roof. The acoustical design is fairly efficient when considering the spaces that are adjacent to the

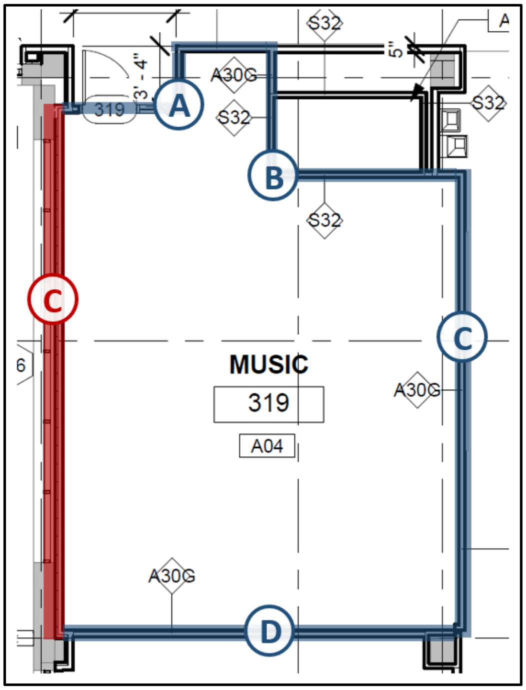


Figure 7.4: Music Room 319 in phase 1 of construction

music room. Walls A, C, D and E all met acoustical design requirements. The full analysis can be viewed on *Table 7.2d* in Appendix F.

The main issue came with the floor-ceiling assembly. Because the floor-ceiling assembly separates a classroom space from a music room, the assembly needed to meet a sound transmission class of 60. These recommendations were not met, as the estimated STC rating of the building's floor-ceiling assembly is approximately STC-53. In addition to this deficiency, the elevator shaft walls (walls B) had a surprisingly low sound transmission class of 38. While there is no recommendation for partitions between elevators and classrooms, the general assumption was made that this partition should have the same STC rating as a hallway. While it may not matter if elevator passengers hear the background noise coming from the music room, the concern is that sound could travel through the elevator space from the music room and affect other nearby locations. STC-45 partitions would help reduce this potential background noise level, which is part of the reason as to why this assumption was made.

Room 319 Recommendations

Improvements to the elevator shaft walls and floor-ceiling assembly acoustical design should occur. The elevator shaft walls' (walls B) low rating of STC-38 is most likely as a result of the omission of insulation from the wall design. The existing wall type, 3/4-inch gypsum wall board on each side with metal studs spaced 24 inches on center (or partition type S32 as identified by the construction documents), should be replaced with the wall design that is used for the other walls within the music room, 5/8" gypsum wall board on each side of metal studs spaced 24 inches on center with sound attenuation batts (partition type A30G as identified by the construction documents). This wall type is STC-45 rated, and would meet the recommended acoustical design.

The issue of the floor-ceiling assembly should be treated similarly to how it was treated for room 108. The design of this assembly should be improved to meet the design recommendations of STC-60. The existing floor-ceiling system is a composite deck with 4 inches of concrete, a 1' – 8" air plenum space, and acoustical ceiling tiles. As previously discussed, the most accurate representation of the floor-ceiling assembly that could be found was simply a 6-inch thick concrete slab. This STC value was determined to be 53. This type of design could be enhanced by adding acoustical insulation between acoustical ceiling tiles and composite decking space. This type of design would increase the sound transmission class rating of STC-60. Again, there is variability in the recommended system and what would actually be feasible based on the structural system that is existing in the building. However, this provides the most feasible solution compared to other methods.

Room 1017 Analysis

Room 1017 is home to a pre-kindergarten classroom that was constructed in phase 2 of the project. *Figure 7.5* shows the layout of classroom 1017 and identifies each wall that was analyzed. This space could suffer acoustically from background noise sourcing from:

- The hallway adjacent to walls A and B
- The individual restrooms adjacent to wall D
- The athletic fields near wall C

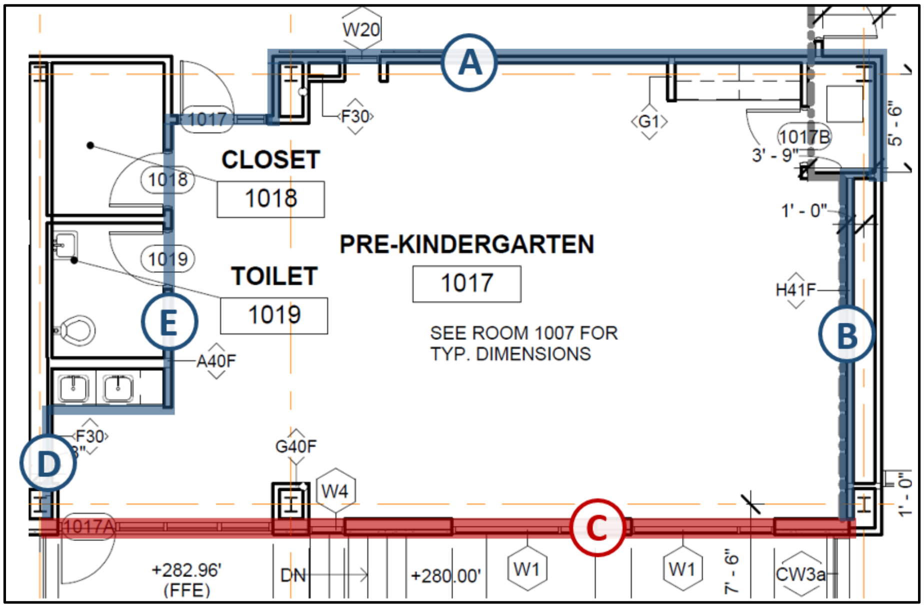


Figure 7.5: Pre-kindergarten room 1017 in phase 2 of construction

After further analysis, all of these considerations factored into the overall acoustical design requirements. Walls A and B offered sufficient acoustical design while Class C, D, and E failed to meet the design recommendations.

Exterior wall C followed the pattern typical exterior walls on this building and failed to meet acoustical requirements as a result of a large amount of glazing covering the wall's surface area. Wall C falls within a range of 30 to 50 feet from the school's athletic fields. These fields are used during school hours for recess, and as a result can be a potential source of unwanted background noise.

Wall D fails to meet the acoustical design recommendations for a partition separating two classroom spaces. The wall has a sound transmission class of STC-45 which is short of the recommended STC-50 value. Wall E fails to meet the requirement for a partition between bathrooms and a classroom space. This type of partition should be STC-53 but is only STC-49.

Room 1017 Recommendations

The biggest concern with this space comes as a result of the poor acoustical consideration for the exterior wall (wall C). The large window surface is the acoustical downfall of the design. The large surface of the glazing will control in STC ratings; therefore, this is the variable that should be changed in design. The existing windows with an STC-35 rating should be replaced by a sound proof window with an STC rating of 48. This type of window combined with the existing exterior wall structure with an STC-rating approximated at STC-44 will form a composite wall that exceeds the recommended STC-40 rating.

Wall D and wall E should also be modified to meet the recommended acoustical design. Wall D should be modified to an A30F partition (as identified in the construction documents and depicted in *Figure 7.12* in Appendix F) with an STC of 51. This change will allow the wall to meet the recommendations of an STC-50 partition for a wall separating two classroom spaces. Wall E should be modified to an A42A partition with an STC-56 rating. This meets the recommendations of an STC-53 partition for a wall separating a classroom space from a bathroom space.

Cost Analysis

A brief cost analysis was performed based on each of the recommendations that were made for each particular room. *Tables 7.3a – 7.3e* identify the cost influence as a result of improving the rooms' acoustical design.

Table 7.3a: Cost analysis of room 108 acoustical design recommendations

Room 108: Pre-Kindergarten Classroom						
	Partition	Existing Design		Recommended Design		
Location	Type	Design	Cost	Design	Cost	Cost Increase
Wall C	Wall	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - 3.5" thick, 5/8" GWB	$ -	Add 1/2" gypsum layer on each side of wall	$ 211.14	$ 211.14
Wall E	Glazing	STC-35 Rated Window, 1/4" thick	$ 5,460.00	STC-45 Windows, add 2" Air space and 3/16" thick pane	$ 9,800.00	$ 4,340.00
Ceiling/Floor Assembly	Floor Assembly	Carpeting, Composite Decking with 4" concrete, 1'-9" plenum, acoustical ceiling tile	$ -	Add 3" fiberglass insulation within plenum space	$ 64.00	$ 64.00
Total Cost Added						*$ 4,615.14*

Table 7.3b: Cost analysis of room 205 acoustical design recommendations

Room 215: Library						
	Partition	Existing Design		Recommended Design		
Location	Type	Design	Cost	Design	Cost	Cost Increase
Wall A	Glazing	STC-35 Rated Window, 1/4" thick	$ 2,552.14	STC-45 Windows, add 2" Air space and 3/16" thick pane	$ 1,343.66	$ (1,208.48)
Wall B	Wall	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - 3.5" thick, 5/8" GWB		Add 1/2" gypsum layer on each side of wall	$ 222.36	$ 222.36
Wall C	Glazing	STC-35 Rated Window, 1/4" thick	$ 4,567.60	STC-45 Windows, add 2" Air space and 3/16" thick pane	$ 8,300.00	$ 3,732.40
Wall D	Wall	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - 3.5" thick, 5/8" GWB	$ -	Add 1/2" gypsum layer on each side of wall	$ 252.96	$ 252.96
Total Cost Added						*$ 2,999.24*

Table 7.3c: Cost analysis of room 215 acoustical design recommendations

Room 205: 2nd Grade Classroom						
	Partition	Existing Design		Recommended Design		
Location	Type	Design	Cost	Design	Cost	Cost Increase
No recommendations for this space. Partition costs will remain the same.						

Table 7.3d: Cost analysis of room 319 acoustical design recommendations

Room 319: Music Room						
	Partition	Existing Design		Recommended Design		
Location	Type	Design	Cost	Design	Cost	Cost Increase
Wall B	Wall	3/4" GWB on Interior Side, "CH Type Studs - Metal Studs 24" OC, 1" GWB on Shaft Side	$ -	Add 1/2" gypsum layer on each side of wall	$ 111.60	$ 111.60
Ceiling/Floor Assembly	Floor Assembly	Carpeting, Composite Decking with 4" concrete, 1'-9" plenum, acoustical ceiling tile	$ -	Add 3" fiberglass insulation within plenum space	$ 384.00	$ 384.00
Total Cost Added						*$ 495.60*

Table 7.3e: Cost analysis of room 1017 acoustical design recommendations

Room 1017: Pre-Kindergarten Classroom						
	Partition	Existing Design		Recommended Design		
Location	Type	Design	Cost	Design	Cost	Cost Increase
Wall C	Glazing	STC-35 Rated Window, 1/4" thick	$ 2,479.40	STC-45 Windows, add 2" Air space and 3/16" thick pane	$ 3,911.60	$ 1,432.20
Wall D	Wall	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - 3.5" thick, 5/8" GWB	$ -	Add 1/2" gypsum layer on each side of wall	$ 104.04	$ 104.04
Wall E	Wall	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - 3.5" thick, 5/8" GWB	$ -	Add 1/2" gypsum layer on each side of wall	$ 278.46	$ 278.46
Total Cost Added						*$ 1,814.70*

In general each acoustical design improvement results in a cost increase. As depicted in *Table 7.3b*, the replacement of the window in the library with a wall partition actually saves costs; however, this is the only instance in which cost savings occur.

In general, the improvement from standard single pane windows with an STC-35 rating to a double pane window with an STC-45 rating is the greatest difference in cost. Unfortunately this is a necessary cost if the owner is interested in meeting acoustical design recommendations. Since the window space takes up such a large portion of the wall percentages for the building exterior walls, they are the controlling factor in STC determination. Based on the calculations used to determine differences in costs for single pane versus double pane windows, improving to double pane glazing increased the cost of windows by approximately 79%. It is extremely likely that all exterior windows facing Naylor Road will need higher STC rated windows.

Conclusion

The majority of the classroom spaces that were analyzed experience some type of deficiency. The most typical acoustical blunder occurred as a result of the high surface area of poor acoustically rated windows. In addition, it appears that a lot of the existing walls within the building were not considered for acoustical analysis at the time of design. Most of the walls have inappropriate partitions based on conditions provided by the adjacent spaces. These acoustical issues should have been considered and evaluated before the design was finalized and constructed.

The acoustical analysis that was performed in this report should be expanded upon so that each classroom is analyzed. If the project owner is serious about having the highest quality environment for students to learn, then the acoustical recommendations provided the analysis sections of this breadth should be followed. This includes but is not limited to:

- Increasing wall STC values when the existing value is not compliant with the recommendations provided in this report.
    - If the wall does not include sound attenuating batt insulation, add this type of insulation to determine if the STC has improved to the required level.
    - If the wall does include sound attenuating batt insulation and is still acoustically insufficient, add ½-inch gypsum wall board to each side of the existing partition.
- Increasing floor-ceiling assembly STC values by adding sound attenuating batt insulation in the plenum space to decrease sound transmission.
- Increasing exterior composite wall STC values by utilizing sound proof windows instead of the STC-35 windows that are currently used in the project
- Increasing interior composite wall STC values by minimizing the surface area of windows within the wall.

Material costs will undeniably increase by improving the acoustical systems, especially by replacing the existing windows. At the beginning of the project, the owner should have requested for an acoustical analysis of classroom partitions to be executed. At this point, the entire building is constructed, and it is not logical to make changes to the existing partitions.

8 Thesis Conclusions

Construction Depth I: Project Phasing Analysis

The purpose of the construction phasing analysis was to identify a solution that would help create some flexibility within the project schedule through re-phasing. Identifying that phase two in the original construction plan (building addition) could be performed prior to phase one (building renovation) without scheduling consequences was very important to this analysis. In addition to preserving the original schedule duration, savings in project costs and scheduling time could be observed as a result of eliminating the need for temporary rooms and partitions to be built as a part of the building renovation. The main goal of achieving additional scheduling flexibility was met. By revamping the schedule to push the renovation phase from the summer of 2014 to the summer of 2015, six days of float were added to the schedule. The idea of rephrasing to perform the building addition prior to the building renovation would be beneficial and should be recommended.

Construction Depth II: Short-Interval Production Scheduling

The purpose of the short-interval production scheduling analysis was to eliminate time from the project schedule. Phase one of construction was deemed unsuitable for SIPS given the variability in the layout of classrooms based on the floor plan of each floor. A SIPS approach was determined to be beneficial for phase two of construction and was used to shorten the schedule by a total of fifteen construction days. Given the strict and demanding nature of the existing project schedule, cutting down the schedule by fifteen days is especially beneficial. This scheduling improvement is done by using a fast track approach and does not require additional crews to perform the expected work. Because of the notable time savings that a short-interval production schedule would create, the schedule provided in section 3 of the report should be recommended.

Construction Depth III: Piping Value Engineering

The purpose of the piping value engineering analysis was to cut down on piping costs for the domestic water system. Both copper and PVC piping systems offer durable solutions to piping and are effective options. The owner constantly faced issues with project financing throughout the course of the project, and as a result project manager was often looking for value engineering solutions to cut down on project costs. Using PVC piping instead of copper piping for the domestic water system would save approximately $50,000 in initial costs. This translates into roughly a 26% savings. Because of the ongoing issues with project financing, the cooper piping system should be switched to PVC piping for the domestic water system.

Structural Breadth: Pre-kindergarten Foundation Redesign

The purpose of the foundation redesign structural breadth was to develop a foundation design that would allow for a two-story building addition in the future. After calculating loading conditions for the proposed two-story addition, it became apparent that the existing foundation system was over-designed. The majority of the existing foundations could support the loading conditions of a two-story building addition without any type of re-design. Only two pile caps required a new design. This would result in additional material and labor costs of less than $4000. Despite the ongoing project financing issues, $4,000 would be a very minimal added cost. The addition of two stories over top of the existing pre-kindergarten wing would enable an addition of twelve to twenty classrooms. That is a significant addition, and if it were to happen in the future, this type of addition would come at a reduced cost with an adequate foundation system already in place. The foundation redesign that is proposed in section 5 of the report should be implemented to the Stanton Elementary School project.

Acoustical Breadth: Classroom Acoustical Analysis

The purpose of the classroom acoustical analysis breadth was to determine if the existing acoustical design was sufficient and to determine the effect on project costs for potential acoustical design changes. Many of the rooms were found to have deficiencies in acoustical design. Improving room acoustics comes at a cost that is unavoidable. If the owner is truly cares about the well-being of the Stanton Elementary School students and would like to provide the best environment possible, the recommendations made in section 7 of this report should be executed and further acoustical analysis of the building should occur. If the owner cares more about cost savings, then the recommendations made in section 7 of this report should not all be followed, for implementing these acoustical strategies could drive up the price of the project. From a project manager’s standpoint, these changes would not be recommended because of the undeniable cost increases that would result from acoustical redesign.

Appendix A: Project Phasing Analysis

Figures & Tables

Figure 2.2: Front-loaded schedule with building addition phase preceding the renovation phase

ID	Task Name	Duration	Start	Finish
0	**Stanton Elementary**	**478 days?**	**Fri 6/20/14**	**Mon 1/4/16**
1	**Addition (Phase 2)**	**283.75 days**	**Fri 6/20/14**	**Mon 4/6/15**
2	Phase 2 Foundations to Grade (from phase 1)	96 days	Fri 6/20/14	Thu 8/7/14
3	Mobilization, Site work, Ext Demo	184 days	Thu 8/7/14	Wed 4/1/15
4	Foundations	63 days	Thu 9/18/14	Tue 12/16/14
5	Structure	32 days	Tue 12/2/14	Thu 1/15/15
6	**Pre-Kindergarten Wing**	**57 days**	**Thu 12/18/14**	**Fri 3/6/15**
7	Pre-K Wing Envelope	24 days	Mon 12/22/14	Fri 1/23/15
8	Pre-K Wing	56 days	Thu 12/18/14	Fri 3/6/15
9	**Main Building**	**68 days**	**Thu 1/1/15**	**Mon 4/6/15**
10	Main Building Envelope	47 days	Tue 1/13/15	Thu 3/19/15
11	1st Floor	60 days	Thu 1/1/15	Thu 3/26/15
12	2nd Floor	58 days	Wed 1/7/15	Mon 3/30/15
13	3rd Floor	60 days	Mon 1/12/15	Mon 4/6/15
14	**Renovation (Phase 1)**	**195 days?**	**Mon 4/6/15**	**Mon 1/4/16**
15	Mobilization	6 days	Mon 4/6/15	Tue 4/14/15
16	**Demolition and Abatement**	**48 days**	**Wed 4/8/15**	**Mon 6/15/15**
17	3rd Floor	24 days	Wed 4/8/15	Tue 5/12/15
18	2nd Floor	26 days	Mon 4/20/15	Tue 5/26/15
19	1st Floor	24 days	Thu 4/30/15	Wed 6/3/15
20	Basement	24 days	Tue 5/12/15	Mon 6/15/15
21	**Interior Construction**	**74 days**	**Tue 5/12/15**	**Mon 8/24/15**
22	3rd Floor	52 days	Tue 5/12/15	Thu 7/23/15
23	2nd Floor	48 days	Tue 5/26/15	Fri 7/31/15
24	1st Floor	52 days	Wed 6/3/15	Fri 8/14/15
25	Basement	50 days	Mon 6/15/15	Mon 8/24/15
26	**Interior Finishes**	**37 days**	**Mon 7/20/15**	**Wed 9/9/15**
27	3rd Floor	15 days	Mon 7/20/15	Mon 8/10/15
28	2nd Floor	15 days	Tue 7/28/15	Tue 8/18/15
29	1st Floor	15 days	Tue 8/11/15	Tue 9/1/15
30	Basement	15 days	Wed 8/19/15	Wed 9/9/15
31	Exterior Skin	96 days	Mon 5/4/15	Tue 9/15/15
32	Comminsioning and Closeout	42 days	Mon 7/20/15	Wed 9/16/15
33	Phase B Site Work	78 days	Wed 9/16/15	Mon 1/4/16
34				

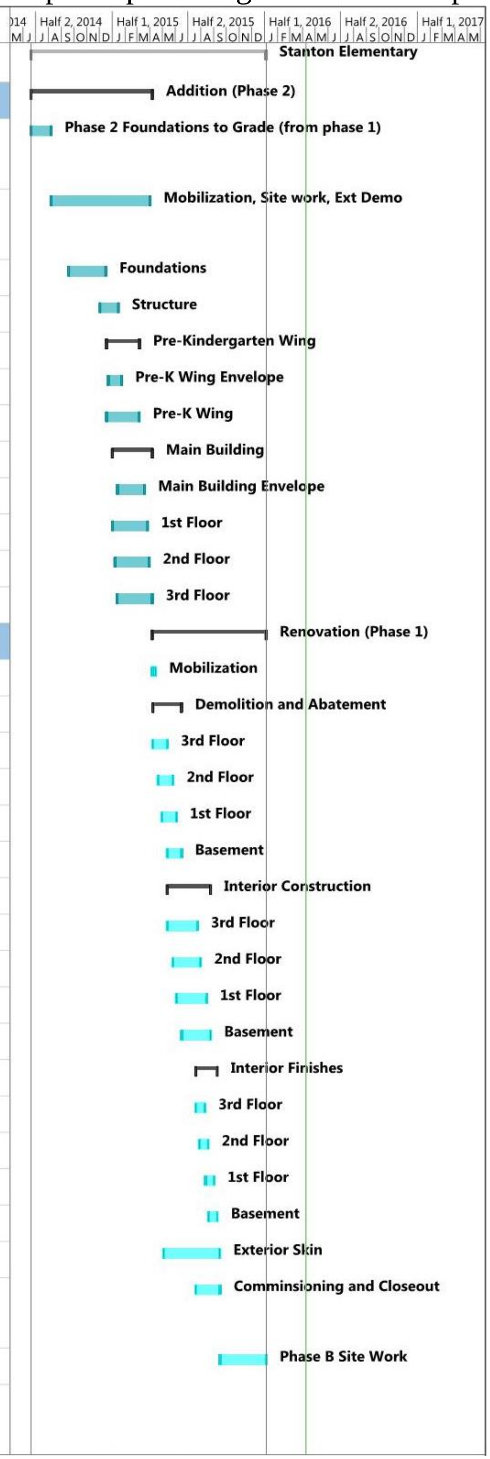
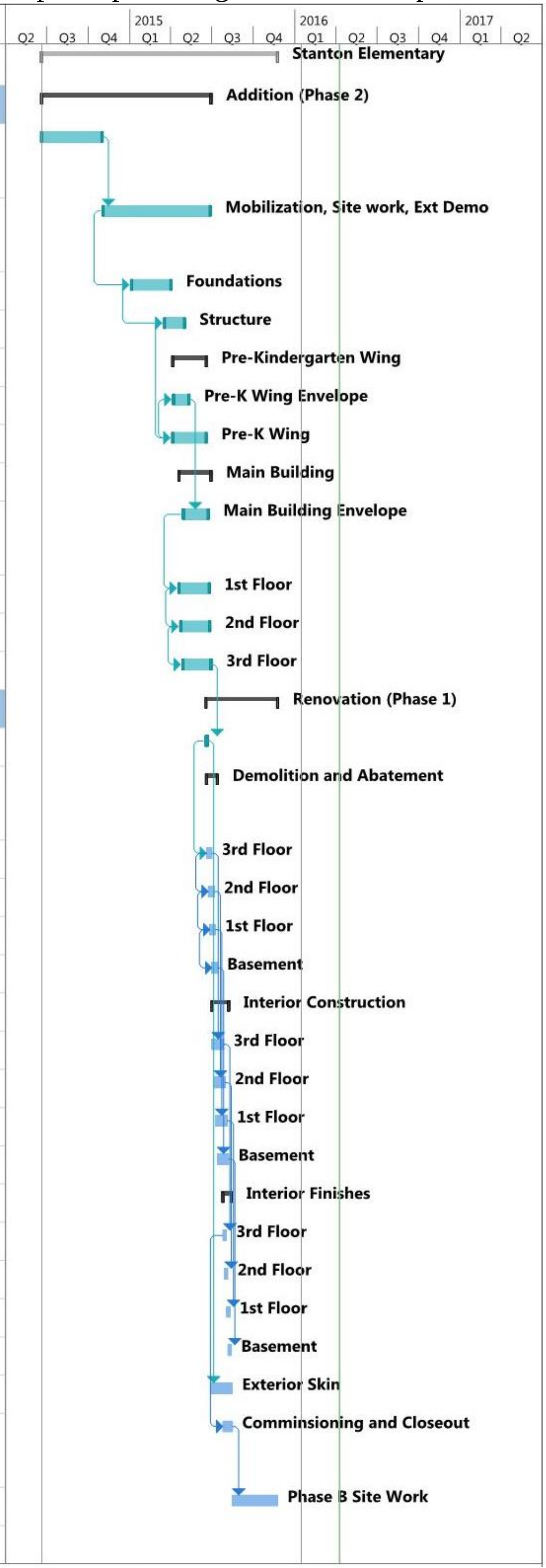


Figure 2.3: Back-loaded schedule with building addition phase preceding the renovation phase

ID	Task Name	Duration	Start	Finish
0	**Stanton Elementary**	**456 days?**	**Fri 6/20/14**	**Mon 11/23/15**
1	**Addition (Phase 2)**	**283 days**	**Fri 6/20/14**	**Mon 6/29/15**
2	Phase 2 Foundations to Grade (from phase 1)	96 days	Fri 6/20/14	Fri 10/31/14
3	Mobilization, Site work, Ext Demo	184 days	Mon 11/3/14	Sat 6/27/15
4	Foundations	63 days	Mon 1/5/15	Wed 4/1/15
5	Structure	32 days	Thu 3/19/15	Fri 5/1/15
6	**Pre-Kindergarten Wing**	**56 days**	**Mon 4/6/15**	**Thu 6/18/15**
7	Pre-K Wing Envelope	24 days	Wed 4/8/15	Mon 5/11/15
8	Pre-K Wing	56 days	Mon 4/6/15	Thu 6/18/15
9	**Main Building**	**67 days**	**Mon 4/20/15**	**Mon 6/29/15**
10	Main Building Envelope	47 days	Thu 4/30/15	Tue 6/23/15
11	1st Floor	60 days	Mon 4/20/15	Thu 6/25/15
12	2nd Floor	58 days	Fri 4/24/15	Fri 6/26/15
13	3rd Floor	60 days	Wed 4/29/15	Mon 6/29/15
14	**Renovation (Phase 1)**	**195 days?**	**Thu 6/18/15**	**Mon 11/23/15**
15	Mobilization	6 days	Thu 6/18/15	Sun 6/21/15
16	**Demolition and Abatement**	**48 days**	**Fri 6/19/15**	**Mon 7/13/15**
17	3rd Floor	24 days	Fri 6/19/15	Wed 7/1/15
18	2nd Floor	26 days	Tue 6/23/15	Mon 7/6/15
19	1st Floor	24 days	Sat 6/27/15	Thu 7/9/15
20	Basement	24 days	Wed 7/1/15	Mon 7/13/15
21	**Interior Construction**	**74 days**	**Wed 7/1/15**	**Fri 8/7/15**
22	3rd Floor	52 days	Wed 7/1/15	Mon 7/27/15
23	2nd Floor	48 days	Mon 7/6/15	Thu 7/30/15
24	1st Floor	52 days	Thu 7/9/15	Tue 8/4/15
25	Basement	50 days	Mon 7/13/15	Fri 8/7/15
26	**Interior Finishes**	**37 days**	**Sun 7/26/15**	**Thu 8/13/15**
27	3rd Floor	15 days	Sun 7/26/15	Sun 8/2/15
28	2nd Floor	15 days	Wed 7/29/15	Wed 8/5/15
29	1st Floor	15 days	Mon 8/3/15	Mon 8/10/15
30	Basement	15 days	Thu 8/6/15	Thu 8/13/15
31	Exterior Skin	96 days	Sun 6/28/15	Sat 8/15/15
32	Comminsioning and Closeout	42 days	Sun 7/26/15	Sat 8/15/15
33	Phase B Site Work	78 days	Sun 8/16/15	Mon 11/23/15
34				



Appendix B: Short Interval Production Scheduling

Figures & Tables

Room	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Typical Room		1		2		3		4		5			6		7		

Figure 3.7: Second floor typical schedule for a typical classroom

Table 3.2: Second Floor SIPS durations

ID	Activity	Days to Complete (All 6 rms)	Days to Complete 1 room	Duration per Room (days)	Actual Duration Per room (days)
1	Layout	3	0.60	2.60	2.5
	Door Frames	3	0.60		
	Wall Framing	10	2.00		
2	Plumbing R/I	10	2.00	2.00	2
	Electrical R/I	10	2.00		
	Duct R/I	10	2.00		
	Mech Pipe R/I & Units	10	2.00		
	Sprinkler Main R/I	5	1.00		
3	One-Side	4	0.80	1.60	1.5
	Insulation	4	0.80		
	Frame Bulkheads	4	0.80		
	Sprinkler Laterals	4	0.80		
4	Wall Close-In	5	1.00	3.00	3
	Grid	10	2.00		
	Prime & First Coat	5	1.00		
	Frame Hard Lids	5	1.00		
5	Casework/Cabniets	5	1.00	2.60	2.5
	Tack/Marker Boards	5	1.00		
	Close-in Hard Lids	3	0.60		
6	Devices and Fixtures Trim-out	10	2.00	2.60	2.5
	Drop Tile	3	0.60		
7	Room Floors	5	1.00	2.80	3
	Finish Coat Paint	5	1.00		
	FFE	4	0.80		
Total Duration				17.2	17.0

Figure 3.8: Third floor typical schedule for a typical classroom

Room	1	2	3	4	5	6	7	8	9	10	11	12	13

Typical Room	1	2	3	4	5	6	7

Table 3.3: Third floor SIPS durations

ID	Activity	Days to Complete (All 6 rms)	Days to Complete 1 room	Duration per Room (days)	Actual Duration Per room (days)
1	Layout	3	0.50	2.17	2.0
	Door Frames	2	0.33		
	Wall Framing	10	1.67		
2	Plumbing R/I	10	1.67	1.67	1.5
	Electrical R/I	10	1.67		
	Duct R/I	10	1.67		
	Mech Pipe R/I & Units	10	1.67		
	Sprinkler Main R/I	5	0.83		
3	One-Side	4	0.67	1.33	1.5
	Insulation	4	0.67		
	Frame Bulkheads	5	0.83		
	Sprinkler Laterals	4	0.67		
4	Wall Close-In	5	0.83	1.67	1.5
	Grid	5	0.83		
	Prime & First Coat	5	0.83		
	Frame Hard Lids	4	0.67		
5	Casework/Cabniets	5	0.83	1.67	1.5
	Tack/Marker Boards	1	0.17		
	Close-in Hard Lids	4	0.67		
6	Devices and Fixtures Trim-out	10	1.67	2.17	2.0
	Drop Tile	3	0.50		
7	Room Floors	5	0.83	2.33	2.5
	Finish Coat Paint	5	0.83		
	FFE	4	0.67		
Total Duration				13.0	12.5

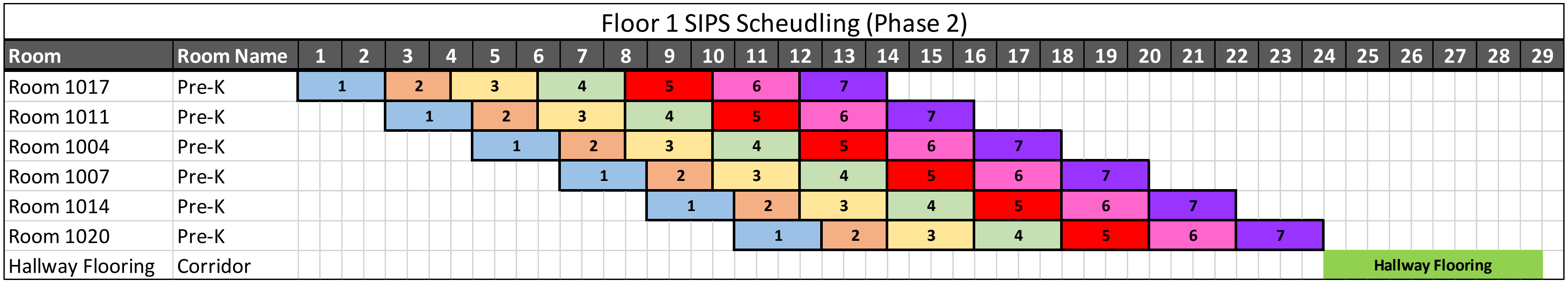


Figure 3.3 First floor pre-kindergarten wing SIPS

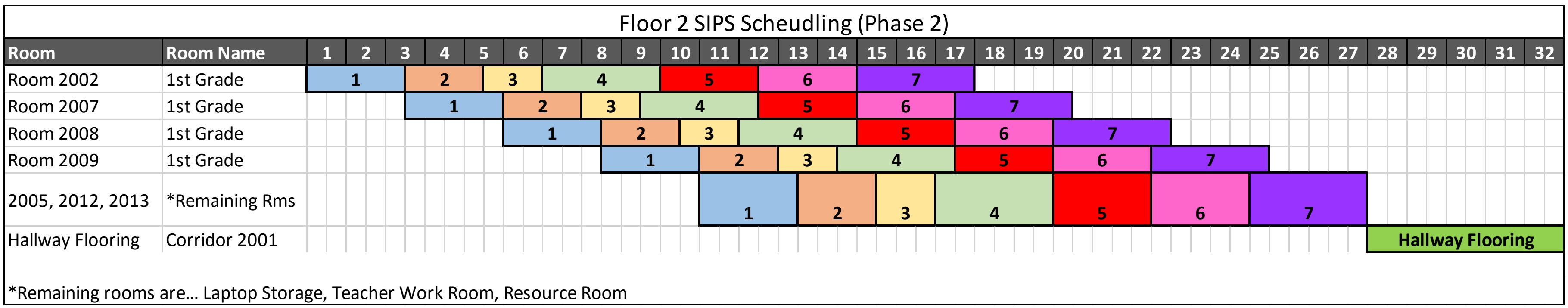


Figure 3.9: Second floor SIPS

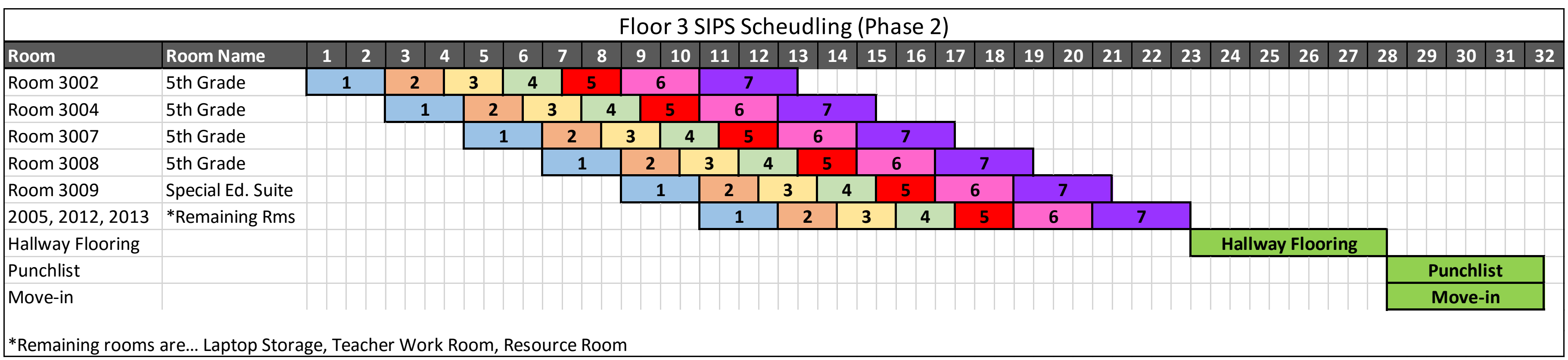


Figure 3.10: Third Floor SIPS

Appendix C: Piping Value Engineering

List of Assumptions

1. General Assumptions
    a. Estimate Data provided by 2016 RS Means Plumbing Costs data.
    b. Riser height determined by average floor to floor height of 13’8” for floors one to three. Riser height determined by floor to floor height for basement floor (only applicable during phase one takeoffs) of 11’3”.
    c. Plenum space assumed to be 3’8” for floors one to three. Plenum space determined to be 1’8” for plenum between basement and floor one.
    d. The following assumptions were made for vertical piping connecting to fixtures:
        i. Vertical piping run connecting to lavatories was considered to be 6”
        ii. Vertical piping run connecting to sinks and lavatories was considered to be 21”.
    e. Pipe measurements that included a pipe connection to elbows and reducers were reduced by 2 inches to account for space taken up by each of these fittings. Pipe measurements that included a pipe connection to tees, reducing tees, crosses, and valves were reduced by 4 inches to account for space taken up by each of these fittings and valves. These assumptions were made for all pipe diameter sizes.
    f. All reducers assumed to be concentric reducers.
    g. Location factor for Washington D.C. of 0.985 was utilized material and labor costs.
    h. The following assumptions were made for manual valves.
        i. Manual valves ranging from 1/2" to 2” in size were considered to be ball valves.
        ii. Manual valves 4” in size were considered to be butterfly valves as a result of RS Means cost data not including ball valves compatible to piping greater than 2” inches in diameter.
        iii. The same material for valves was considered for copper the existing copper piping estimate and the recommended PVC piping estimate.
2. Copper Piping Domestic Water Assumptions
    a. As per the construction drawings, type L copper piping is used in the detailed copper piping estimate.
    b. Detailed estimate does not directly include hangers for copper piping. RS Means data ranging from 22 11 13.23 2140 to 22 11 1323 2340 is type L copper piping, with hangers at every 10 feet. Hangers are indirectly included in the estimate as a part of the piping data.
    c. Material costs for soldering not considered.

   d. Labor costs of soldering piping connections modeled by RS Means data number 22 11 13.25 0020. RS Means number 22 11 13.25 0020 indicates that cost of labor for fitting connections increases by 15%.
   e. RS Means data number 22 11 13.25 0020 specifies silver solder. This type of solder was assumed for the cost estimate.
   f. As per construction drawings, insulation of 1/2" thickness is required for domestic water piping. RS Means did not supply cost data for 1/2" insulation wall thickness. Insulation with 1" wall thickness was used as a substitution.
3. PVC Piping Assumptions
   a. PVC piping was considered to be Schedule 40 piping. While Schedule 80 piping would most likely be present to some degree, it is difficult to determine the quantity of schedule 80 piping compared to schedule 40 piping.
   b. As in copper piping estimate, hangers are assumed to be spaced at every 10 feet. Hanger are included in detailed estimate data for PVC piping from RS Means data ranging from 22 11 1374 1860 to 22 11 1374 1940.
   c. As per construction drawings, insulation of 1/2" thickness is required for domestic water piping. RS Means did not supply cost data for 1/2" insulation wall thickness. Insulation with 1" wall thickness was used as a substitution. PVC piping estimate utilized the same costs for insulation as existing copper piping.
   d. RS Means data does not include cost data for PVC cross fittings. Two tee fittings were used to model the cost of a cross fitting for PVC piping.
   e. RS Means data does not include cost data for 1" PVC reducing tees. 1" reducing tees were modeled as 2" reducing tees (22 11 13.76 4860).
   f. RS Means data does not include cost data for 3" PVC reducing fittings. 3" reducing fittings were modeled as 4" reducing fittings (22 11 1376 3717).
4. Piping Life Cycle Analysis
   a. Copper piping and PVC piping were considered to have similar lifespans.
   b. The lifespans of both copper and PVC piping were considered to be negligible in calculating replacement costs, for each material is capable of lasting past the building's expected lifespan (or prior to the building's next renovation).
   c. Current day pricing for copper scrap recycling was considered to be $1.968 per pound.
   d. Copper scrap recycling considered for pipe lengths or all sizes. Fittings not included in recycling costs
   e. Current day pricing for plastic scrap was considered to be negligible and was not considered.

Figures & Tables

RS Means No.	Item	Qty.	Unit	Crew	Daily Output	Labor Hours	Total Duration (Hours)
22 11 1374 1860	1/2" Plastic Piping, PVC SCH 40	1036.0	LF	1 Plum	54.00	0.148	153.5
22 11 1374 1870	3/4" Plastic Piping	801.2	LF	1 Plum	51.00	0.157	125.7
22 11 1374 1880	1" Plastic Piping	1421.5	LF	1 Plum	46.00	0.174	247.2
22 11 1374 1890	1-1/4" Plastic Piping	61.3	LF	1 Plum	42.00	0.190	11.7
22 11 1374 1900	1-1/2" Plastic Piping	122.3	LF	1 Plum	36.00	0.222	27.2
22 11 1374 1910	2" Plastic Piping	631.5	LF	Q-1	59.00	0.271	85.6
22 11 1374 1930	3" Plastic Piping	404.6	LF	Q-1	53.00	0.302	61.1
22 11 1374 1940	4" Plastic Piping	362.7	LF	Q-1	48.00	0.333	60.5
22 11 1376 3180	1/2" Tee	43	EA	1 Plum	22.20	0.360	15.5
22 11 1376 3190	3/4" Tee	90	EA	1 Plum	19.00	0.421	37.9
22 11 1376 3200	1" Tee	70	EA	1 Plum	16.70	0.479	33.5
22 11 1376 3210	1-1/4" Tee	7	EA	1 Plum	14.80	0.541	3.8
22 11 1376 3220	1-1/2 " Tee	12	EA	1 Plum	13.30	0.602	7.2
22 11 1376 3230	2" Tee	24	EA	Q-1	24.20	0.661	7.9
22 11 1376 3250	3" Tee	8	EA	Q-1	15.20	1.053	4.2
22 11 1376 3260	4" Tee	12	EA	Q-1	12.10	1.322	7.9
22 11 1376 4862	1"x1/2" Red Tee	2	EA	Q-1	22.00	0.727	0.7
22 11 1376 4862	2"x3/4" Red Tee	2	EA	Q-1	22.00	0.727	0.7
22 11 1376 4864	3"x1-1/4" Red Tee	1	EA	Q-1	15.30	1.046	0.5
22 11 1376 4868	4"x1-1/2" Red Tee	2	EA	Q-1	12.10	1.322	1.3
22 11 1376 2760	1/2" 90 Deg. Elbow	77	EA	1 Plum	33.30	0.240	18.5
22 11 1376 2770	3/4" 90 Deg. Elbow	105	EA	1 Plum	28.60	0.280	29.4
22 11 1376 2780	1" 90 Deg. Elbow	100	EA	1 Plum	25.00	0.320	32.0
22 11 1376 2790	1-1/4" 90 Deg. Elbow	4	EA	1 Plum	22.20	0.360	1.4
22 11 1376 2800	1-1/2" 90 Deg. Elbow	9	EA	1 Plum	20.00	0.400	3.6
22 11 1376 2810	2" 90 Deg. Elbow	23	EA	Q-1	36.40	0.440	5.1
22 11 1376 2830	3" 90 Deg. Elbow	8	EA	Q-1	22.90	0.699	2.8
22 11 1376 2840	4" 90 Deg. Elbow	24	EA	Q-1	18.20	0.879	10.5
22 11 1376 3712	3/4"x1/2" Reducer	10	EA	1 Plum	31.5	0.254	2.5
22 11 1376 3713	1"x3/4" Reducer	14	EA	1 Plum	27.50	0.291	4.1
22 11 1376 3713	1"x1/2" Reducer	16	EA	1 Plum	27.50	0.291	4.7
22 11 1376 3713	1-1/2"x1" Reducer	2	EA	1 Plum	22.00	0.364	0.7
22 11 1376 3716	2"x1/2" Reducer	1	EA	Q-1	40	0.400	0.2
22 11 1376 3716	2"x3/4" Reducer	1	EA	Q-1	40	0.400	0.2
22 11 1376 3716	2"x1" Reducer	2	EA	Q-1	40	0.400	0.4
22 11 1376 3717	3"x1" Reducer	5	EA	Q-1	20	0.800	2.0
22 11 1376 3717	3"x1-1/4" Reducer	2	EA	Q-1	20	0.800	0.8
22 11 1376 3717	4"x3/4" Reducer	3	EA	Q-1	20	0.800	1.2
22 11 1376 3717	4"x1" Reducer	3	EA	Q-1	20	0.800	1.2
22 11 1376 3717	4"x1-1/2" Reducer	1	EA	Q-1	20	0.800	0.4
22 11 1376 3717	4"x2" Reducer	1	EA	Q-1	20	0.800	0.4
22 11 1376 3717	4"x3" Reducer	1	EA	Q-1	20	0.800	0.4
29 11 1376 3650	2" Cap	1	EA	Q-1	66.1	0.242	0.1
29 11 1376 3670	3" Cap	1	EA	Q-1	41.6	0.385	0.2
22 11 1329 6210	1/2" Manual Ball Valve	11	EA	1 Plum	25.6	0.313	3.4
22 11 1329 6220	3/4" Manual Ball Valve	3	EA	1 Plum	19.2	0.417	1.3
22 11 1329 6230	1" Manual Ball Valve	7	EA	1 Plum	18.1	0.442	3.1
22 11 1329 6240	1-1/4" Manual Ball Valve	2	EA	1 Plum	14.7	0.544	1.1
22 11 1329 6260	2" Manual Ball Valve	3	EA	1 Plum	11	0.727	2.2
22 11 1329 6680	4" Manual Butterfly Valve	7	EA	Q-1	5	3.200	11.2
22 07 1910 1016	1/2" Insulation, 1" Wall Thickness	1036.0	LF	Q-14	230	0.070	36.0
22 07 1910 1018	3/4" Insulation, 1" Wall Thickness	801.2	LF	Q-14	220	0.073	29.1
22 07 1910 1022	1" Insulation, 1" Wall Thickness	1421.5	LF	Q-14	210	0.076	54.2
22 07 1910 1024	1-1/4" Insulation, 1" Wall Thickness	61.3	LF	Q-14	205	0.078	2.4
22 07 1910 1026	1-1/2" Insulation, 1" Wall Thickness	122.3	LF	Q-14	205	0.078	4.8
22 07 1910 1028	2" Insulation, 1" Wall Thickness	631.5	LF	Q-14	200	0.800	25.3
22 07 1910 1032	3" Insulation, 1" Wall Thickness	404.6	LF	Q-14	180	0.089	18.0
22 07 1910 1034	4" Insulation, 1" Wall Thickness	362.7	LF	Q-14	150	0.107	19.3

Total Duration 1227.8

Figure 4.3: PVC piping total labor hours based on crews

RS Means No.	Item	Qty.	Unit	Crew	Daily Output	Labor Hours	Total Duration
22 11 1323 2140	1/2" Type L Copper Piping	1036.0	LF	1 Plum	81	0.099	102.3
22 11 1323 2180	3/4" Type L Copper Piping	801.2	LF	1 Plum	76	0.105	84.3
22 11 1323 2200	1" Type L Copper Piping	1421.5	LF	1 Plum	68	0.118	167.2
22 11 1323 2220	1-1/4" Type L Copper Piping	61.3	LF	1 Plum	58	0.138	8.5
22 11 1323 2240	1-1/2" Type L Copper Piping	122.3	LF	1 Plum	53	0.154	18.5
22 11 1323 2260	2" Type L Copper Piping	631.5	LF	1 Plum	42	0.190	120.3
22 11 1323 2300	3" Type L Copper Piping	404.6	LF	Q-1	56	0.286	57.8
22 11 1323 2340	4" Type L Copper Piping	362.7	LF	Q-1	39	0.410	74.4
22 11 1325 0480	1/2" Tee	37	EA	1 Plum	13	0.615	22.8
22 11 1325 0500	3/4" Tee	80	EA	1 Plum	12	0.667	53.3
22 11 1325 0510	1" Tee	56	EA	1 Plum	10	0.800	44.8
22 11 1325 0520	1-1/4" Tee	7	EA	1 Plum	9	0.889	6.2
22 11 1325 0530	1-1/2 " Tee	12	EA	1 Plum	8	1.000	12.0
22 11 1325 0540	2" Tee	24	EA	1 Plum	7	1.143	27.4
22 11 1325 0560	3" Tee	8	EA	Q-1	7	2.286	9.1
22 11 1325 0580	4" Tee	12	EA	Q-1	5	3.200	19.2
22 11 1325 0617	1"x1/2" Red Tee	2	EA	1 Plum	11	0.727	1.5
22 11 1325 0620	2"x3/4" Red Tee	2	EA	1 Plum	8	1.000	2.0
22 11 1325 0622	3"x1-1/4" Red Tee	1	EA	Q-1	8	2.000	1.0
22 11 1325 0623	4"x1-1/2" Red Tee	2	EA	Q-1	6	2.667	2.7
22 11 1325 0100	1/2" 90 Deg. Elbow	77	EA	1 Plum	20	0.400	30.8
22 11 1325 0120	3/4" 90 Deg. Elbow	105	EA	1 Plum	19	0.421	44.2
22 11 1325 0130	1" 90 Deg. Elbow	100	EA	1 Plum	16	0.500	50.0
22 11 1325 0140	1-1/4" 90 Deg. Elbow	4	EA	1 Plum	15	0.533	2.1
22 11 1325 0150	1-1/2" 90 Deg. Elbow	9	EA	1 Plum	13	0.615	5.5
22 11 1325 0160	2" 90 Deg. Elbow	23	EA	1 Plum	11	0.727	16.7
22 11 1325 0180	3" 90 Deg. Elbow	8	EA	Q-1	11	1.455	5.8
22 11 1325 0200	4" 90 Deg. Elbow	24	EA	Q-1	9	1.778	21.3
22 11 1325 0745	3/4"x1/2" Reducer	10	EA	1 Plum	21.5	0.372	3.7
22 11 1325 0747	1"x3/4" Reducer	14	EA	1 Plum	19.50	0.410	5.7
22 11 1325 0747	1"x1/2" Reducer	16	EA	1 Plum	19.50	0.410	6.6
22 11 1325 0749	1-1/2"x1" Reducer	2	EA	1 Plum	16	0.500	1.0
22 11 1325 0751	2"x1/2" Reducer	1	EA	1 Plum	14	0.571	0.6
22 11 1325 0751	2"x3/4" Reducer	1	EA	1 Plum	14	0.571	0.6
22 11 1325 0751	2"x1" Reducer	2	EA	1 Plum	14	0.571	1.1
22 11 1325 0753	3"x1" Reducer	5	EA	Q-1	14	1.143	2.9
22 11 1325 0753	3"x1-1/4" Reducer	2	EA	Q-1	14	1.143	1.1
22 11 1325 0755	4"x3/4" Reducer	3	EA	Q-1	8	2.000	3.0
22 11 1325 0755	4"x1" Reducer	3	EA	Q-1	8	2.000	3.0
22 11 1325 0755	4"x1-1/2" Reducer	1	EA	Q-1	8	2.000	1.0
22 11 1325 0755	4"x2" Reducer	1	EA	Q-1	8	2.000	1.0
22 11 1325 0755	4"x3" Reducer	1	EA	Q-1	8	2.000	1.0
22 11 1325 0781	2" Cap	1	EA	1 Plum	22	0.364	0.4
22 11 1325 0793	3" Cap	1	EA	Q-1	22	0.727	0.4
22 11 1325 1250	1/2" Cross	3	EA	1 Plum	10	0.800	2.4
22 11 1325 1260	3/4" Cross	5	EA	1 Plum	9.5	0.842	4.2
22 11 1325 1270	1" Cross	7	EA	1 Plum	8	1.000	7.0
22 11 1325 0020	Silver Solder, add 15 % to Fittings	*add 15% to duration of fittings installation for soldering*					63.8
22 11 1329 6210	1/2" Manual Ball Valve	11	EA	1 Plum	25.6	0.313	3.4
22 11 1329 6220	3/4" Manual Ball Valve	3	EA	1 Plum	19.2	0.417	1.3
22 11 1329 6230	1" Manual Ball Valve	7	EA	1 Plum	18.1	0.442	3.1
22 11 1329 6240	1-1/4" Manual Ball Valve	2	EA	1 Plum	14.7	0.544	1.1
22 11 1329 6260	2" Manual Ball Valve	3	EA	1 Plum	11	0.727	2.2
22 11 1329 6680	4" Manual Butterfly Valve	7	EA	Q-1	5	3.200	11.2
22 07 1910 1016	1/2" Insulation, 1" Wall Thickness	1036.0	LF	Q-14	230	0.070	36.0
22 07 1910 1018	3/4" Insulation, 1" Wall Thickness	801.2	LF	Q-14	220	0.073	29.1
22 07 1910 1022	1" Insulation, 1" Wall Thickness	1421.5	LF	Q-14	210	0.076	54.2
22 07 1910 1024	1-1/4" Insulation, 1" Wall Thickness	61.3	LF	Q-14	205	0.078	2.4
22 07 1910 1026	1-1/2" Insulation, 1" Wall Thickness	122.3	LF	Q-14	205	0.078	4.8
22 07 1910 1028	2" Insulation, 1" Wall Thickness	631.5	LF	Q-14	200	0.800	25.3
22 07 1910 1032	3" Insulation, 1" Wall Thickness	404.6	LF	Q-14	180	0.089	18.0
22 07 1910 1034	4" Insulation, 1" Wall Thickness	362.7	LF	Q-14	150	0.107	19.3

Total Duration 1333.6

Figure 4.3: PVC piping total labor hours based on crews

Appendix D: BIM Research Topic

Figures & Tables

Building (Preventative) Maintenance Scheduling

Description:

A process in which the functionality of the building structure (walls, floors, roof, etc) and equipment serving the building (mechanical, electrical, plumbing, etc) are maintained over the operational life of a facility. A successful maintenance program will improve building performance, reduce repairs, and reduce overall maintenance costs.

Potential Value:

- Plan maintenance activities proactively and appropriately allocate maintenance staff
- Track maintenance history
- Reduce corrective maintenance and emergency maintenance repairs
- Increase productivity of maintenance staff because the physical location of equipment/system is clearly understood
- Evaluate different maintenance approaches based on cost
- Allow facility managers to justify the need and cost of establishing a reliability centered maintenance program

Resources Required:

- Design review software to view Record Model and components
- Building Automation System (BAS) linked to Record Model
- Computerized Maintenance Management System (CMMS) linked to Record Model
- User-Friendly Dashboard Interface linked to Record Model to provide building performance information and/or other information to educate building users

Team Competencies Required:

- Ability to understand and manipulate CMMS and building control systems with Record Model
- Ability to understand typical equipment operation and maintenance practices
- Ability to manipulate, navigate, and review a 3D Model

Selected Resources:

- Campbell, D.A. (2007). BIM – Web Applications for AEC, Web 3D Symposium.
- Fallon, K. (2008). "Interoperability: Critical to Achieving BIM Benefits". AIA Edges Website: Singh, H.; W.H. Dunn (2008). Integrating Facilities Stovepipes for Total Asset Management (TAM). Journal of Building Information Modeling, Spring 2008. http://www.aia.ord/nwsltr_tap.cfm?pagename=tap_a_0704_interop
- ASHRAE (2003). HVAC design Manual for Hospitals and Clinics. Atlanta, GA. (2004). Federal energy Management Program. O&M Best Practices: A Guide to Achieving Operational Efficiency, Release 2.0. July 2004. www1.eere.energy.gov/femp/pds.OM_5.pdf
- Piotrowski, J. (2001). Pro-Active Maintenance for Pumps. Archives, February 2001, Pump-Zone.com

Figure 5.5: Building preventative maintenance scheduling information

Building Systems Analysis

Description:

A process that measures how a building's performance compares to the specified design. This includes how the mechanical system operates and how much energy a building uses. Other aspects of this analysis include, but are not limited to, ventilated facade studies, lighting analysis, internal and external CFD airflow, , and solar analysis.

Potential Value:

- Ensure building is operating to specified design and sustainable standards
- Identify opportunities to modify system operations to improve performance
- Create a "what if" scenario and change different materials throughout the building to show better or worse performance conditions

Resources Required:

- Building Systems Analysis Software (Energy, Lighting, Mechanical, Other)

Team Competencies Required:

- Ability to understand and manipulate CMMS and building control systems with Record Model
- Ability to understand typical equipment operation and maintenance practices
- Ability to manipulate, navigate, and review a 3D Model

Selected Resources:

- Ayat E. Osman, Robert Ries. " Optimization For Cogeneration Systems in Buildings Based on Life Cycle Assessment" May 2006, http://itocn.org/2006/20/
- "Building Performance Analysis Using Revit" 2007 Autodesk Inc., http://images.autodesk.com/adsk/files/building_performance_analysis_using_revit.pdf

Figure 5.6: Building systems analysis information

Asset Management

Description:

A process in which an organized management system is bi-directionally linked to a record model to efficiently aid in the maintenance and operation of a facility and its assets. These assets, consisting of the physical building, systems, surrounding environment, and equipment, must be maintained, upgraded, and operated at an efficiency which will satisfy both the owner and users in the most cost effective manner. It assists in financial decision-making, short-term and long-term planning, and generating scheduled work orders. Asset Management utilizes the data contained in a record model to populate an asset management system which is then used to determine cost implications of changing or upgrading building assets, segregate costs of assets for financial tax purposes, and maintain a current comprehensive database that can produce the value of a company's assets. The bi-directional link also allows users to visualize the asset in the model before servicing it potentially reducing service time.

Potential Value:

- Store operations, maintenance owner user manuals, and equipment specifications for faster access.
- Perform and analyze facility and equipment condition assessments
- Maintain up-to-date facility and equipment data including but not limited to maintenance schedules, warranties, cost data, upgrades, replacements, damages/deterioration, maintenance records, manufacturer's data, and equipment functionality
- Provide one comprehensive source for tracking the use, performance, and maintenance of a building's assets for the owner, maintenance team, and financial department
- Produce accurate quantity takeoffs of current company assets which aids in financial reporting, bidding, and estimating the future cost implications of upgrades or replacements of a particular asset.
- Allow for future updates of record model to show current building asset information after upgrades, replacements, or maintenance by tracking changes and importing new information into model.
- Aid financial department in efficiently analyzing different types of assets through an increased level of visualization
- Increase the opportunity for measurement and verification of systems during building occupation
- Automatically generate scheduled work orders for maintenance staff.

Resources Required:

- Asset Management system
- Ability to Bi-directional link facilities record model and Asset Management System.

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D Model (preferred but not required)
- Ability to manipulate an asset management system
- Knowledge of tax requirements and related financial software
- Knowledge of construction and the operation of a building (replacements, upgrades, etc.)
- Pre-design knowledge of which assets are worth tracking, whether the building is dynamic vs. static, and the end needs of the building to satisfy the owner

Selected Resources:

- CURT. (2010) BIM Implementation: An Owner's Guide to Getting Started
- NIST (2007) General Buildings Information Handover Guide: Principles, Methodology, and Case Studies<http://www.fire.nist.gov/bfrlpubs/build07/PDF/b07015.pdf>

Figure 5.7: Asset management information

Space Management and Tracking

Description:

A process in which BIM is utilized to effectively distribute, manage, and track appropriate spaces and related resources within a facility. A facility building information model allows the facility management team to analyze the existing use of the space and effectively apply transition planning management towards any applicable changes. Such applications are particularly useful during a project's renovation where building segments are to remain occupied. Space Management and Tracking ensures the appropriate allocation of spatial resources throughout the life of the facility. This use benefits from the utilization of the record model. This application often requires integration with spatial tracking software.

Potential Value:

- More easily identify and allocate space for appropriate building use
- Increase the efficiency of transition planning and management
- Proficiently track the use of current space and resources
- Assist in planning future space needs for the facility

Resources Required:

- Bi-directional 3D Model Manipulation; software and record model integration
- Space mapping and management input application (Mapguide, Maximo, etc.)

Team Competencies Required:

- Ability to manipulate, navigate, and review record model
- Ability to assess current space and assets and mange appropriately for future needs
- Knowledge of facility management applications
- Ability to effectively integrate the record model with the Facility Management's Application and appropriate software associated with the client's needs.

Selected Resources:

- Jason Thacker "Total Facilities Management." 2010. 19 Sept. 2010. Technology Associates International Corporation. Web. 19 Sept. 2010, <http://proceedings.esri.com/library/userconf/proc04/docs/pap1519.pdf>.
- Mapping Your Facilities Management Future. Aug. 2009 Web. 19 Sept. 2010. Acatech Solutions, <https://www.avatech.com/solutions/facilities-management/facilities-management-whitepapers.aspx>.
- Vacik, Nocolas A. and Patricia Huesca-Dorantes. "building a GIS Database for Space and Facilities Management." New Directions for Institutional Research, n120 p53-61 2003.

Figure 5.8: Space management and tracking information

Disaster Planning

Description:

A process in which emergency responders would have access to critical building information in the form of a model and information system. The BIM would provide critical building information to the responders that would improve the efficiency of the response and minimize the safety risks. The dynamic building information would be provided by a building automation system (BAS), while the static building information, such as floor plans and equipment schematics, would reside in a BIM model. These two systems would be integrated via a wireless connection and emergency responders would be linked to an overall system. The BIM coupled with the BAS would be able to clearly display where the emergency was located within the building, possible routes to the area, and any other harmful locations within the building.

Potential Value:

- Provide police, fire, public safety officials, and first responders access to critical building information in real-time
- Improve the effectiveness of emergency response
- Minimize risks to responders

Resources Required:

- Design review software to view Record Model and components
- Building Automation System (BAS) linked to Record Model
- Computerized Maintenance Management System (CMMS) linked to Record Model

Team Competencies Required:

- Ability to manipulate, navigate, and review BIM model for facility updates
- Ability to understand dynamic building information through BAS
- Ability to make appropriate decisions during an emergency

Selected Resources:

- **Building Information for Emergency Responders**. Systemics, Cybernetics and Informatics, 11th World Multi-Conference (WMSCI 2007). Proceedings. Volume 3. Jointly with the Information Systems Analysis and Synthesis: ISAS 2007, 13th International Conference. July 8-11, 2007, Orlando, FL, Callaos, N.; Lesso, W.; Zinn, C. D.; Yang, H., Editor(s) (s), 1-6 pp, 2007. Treado, S. J.; Vinh, A.; Holmberg, D. G.; Galler, M.

Figure 5.9: Disaster planning information

Record Modeling

Description:

Record Modeling is the process used to depict an accurate representation of the physical conditions, environment, and assets of a facility. The record model should, at a minimum, contain information relating to the main architectural, structural, and MEP elements. It is the culmination of all the BIM Modeling throughout the project, including linking Operation, Maintenance, and Asset data to the As-Built model (created from the Design, Construction, 4D Coordination Models, and Subcontractor Fabrication Models) to deliver a record model to the owner or facility manager. Additional information including equipment and space planning systems may be necessary if the owner intends to utilize the information in the future.

Potential Value:

- Aid in future modeling and 3D design coordination for renovation
- Improve documentation of environment for future uses, e.g., renovation or historical documentation
- Aid in the permitting process (e.g. continuous change vs. specified code.)
- Minimize facility turnover dispute (e.g. link to contract with historical data highlights expectations and comparisons drawn to final product.)
- Ability for embedding future data based upon renovation or equipment replacement
- Provide owner with accurate model of building, equipment, and spaces within a building to create possible synergies with other BIM Uses
- Minimize building turnover information and required storage space for this information
- Better accommodate owner's needs and wants to help foster a stronger relationship and promote repeat business
- Easily assess client requirement data such as room areas or environmental performance to as-designed, as-built or as-performing data.

Resources Required:

- 3D Model Manipulation Tools
- Compliant Model Authoring Tools to Accommodate Required Deliverable
- Access to Essential Information in Electronic Format
- Database of Assets and Equipment with Metadata (Based upon Owner's Capabilities)

Team Competencies Required:

- Ability to manipulate, navigate, and review 3D model
- Ability to use BIM modeling application for building updates
- Ability to thoroughly understand facility operations processes to ensure correct input of information
- Ability to effectively communicate between the design, construction, and facilities management teams

Selected Resources:

- Brown, J. L. (September 2009). Wisconsin Bets on BIM. *Civil Engineering* , 40-41.
- CRC for Construction Innovation. *Adopting BIM for Facilities Management - Solutions for Managing the Syndey Opera House.*
- Gregerson, J. (December 2009). For Owners, BIM Has Vim. *Buildings* , 26.
- Knight, D., Roth, S., & Rosen, S. (June 2010). Using BIM in HVAC Design. *ASHRAE Journal* , 24-34.
- Madsen, J. J. (July 2008). Build Smarter, Faster, and Cheaper with BIM. *Buildings* , 94-96.
- McKew, H. (July 2009). Owners, Please Demand More From Your IPD Team. *Engineered Systems* , 50.
- Woo, J., Wilsmann, J., & Kang, D. (2010). Use of As-Built Building Information Modeling. *Construction Research Congress 2010* , 538-548.

Figure 5.10: Record modeling information

Site Utilization Planning

Description:

A process in which BIM is used to graphically represent both permanent and temporary facilities on site during multiple phases of the construction process. It may also be linked with the construction activity schedule to convey space and sequencing requirements. Additional information incorporated into the model can include labor resources, materials with associated deliveries, and equipment location. Because the 3D model components can be directly linked to the schedule, site management functions such as visualized planning, short-term re-planning, and resource analysis can be analyzed over different spatial and temporal data.

Potential Value:

- Efficiently generate site usage layout for temporary facilities, assembly areas, and material deliveries for all phases of construction
- Quickly identify potential and critical space and time conflicts
- Accurately evaluate site layout for safety concerns
- Select a feasible construction scheme
- Effectively communicate construction sequence and layout to all interested parties
- Easily update site organization and space usage as construction progresses
- Minimize the amount of time spent performing site utilization planning

Resources Required:

- Design authoring software
- Scheduling software
- 4D model integration software
- Detailed existing conditions site plan

Team Competencies Required:

- Ability to create, manipulate, navigate, and review a 3D Model
- Ability to manipulate and assess construction schedule with a 3D model
- Ability to understand typical construction methods
- Ability to translate field knowledge to a technological process

Selected Resources:

- Chau, K.W.; M. Anson, and J.P. Zhang. (July/August 2004) "Four-Dimensional Visualization of Construction Scheduling and Site Utilization." Journal of Construction Engineering and Management. 598-606. ASCE. 5 September 2008. http://cedb.asce.org/cgi/WWWdisplay.cgi?0410956
- Dawood, Nashwam et al. (2005) "The Virtual Construction Site (VIRCON) Tools: An Industrial Evaluation." ITcon. Vol. 10 43-54. 8 September 2008. http://www.itcon.org/cgi-bin/works/Show?2005_5
- Heesom, David and Lamine Mahdjoubi. (February 2004) "Trends of 4D CAD Applications for Construction Planning." Construction Management and Economics. 22 171-182. 8 September 2008. http://www.tamu.edu/classes/choudhury/articles/1.pdf
- J.P. Zhang, M. Anson and Q. Wang. (2000) "A New 4D Management Approach to Construction Planning and Site Space Utilization." Proceedings of the Eighth International Conference on Computing in Civil and Building Engineering 279, 3 (2000) ASCE. Â 21 September 2010. http://dx.doi.org/10.1061/40513(279)3.
- J. H. Kang, S. D. Anderson, M. J. Clayton. (June 2007) "Empirical Study on the Merit of Web-Based 4D Visualization in Collaborative Construction Planning and Scheduling." J. Constr. Engrg. and Mgmt. Volume 133, Issue 6, pp. 447-461 ASCE. 20 September 2010. http://dx.doi.org/10.1061/(ASCE)0733-9364(2007)133:6(447)
- Timo Hartmann, Ju Gao and Martin Fischer. (October 2008) "Areas of Application for 3D and 4D Models." Journal of Construction Engineering and Management (Volumne 135, Issue 10): 776-785.
- Ting Huang, C.W. Kong, H.L. Guo, Andrew Baldwin, Heng Li. (August 2007) "A Virtual Prototyping System for Simulating Construction Processes." Automation in Construction (Volume 16, Issue 5):Pages 576-585, (http://www.sciencedirect.com/science/article/B6V20-4MFJT9J-1/2/45a7645cc1a6836c45317a012fbc181a)

Figure 5.11: Site utilization planning information

Construction System Design (Virtual Mockup)

Description:

A process in which 3D System Design Software is used to design and analyze the construction of a complex building system (e.g. form work, glazing, tie-backs, etc.) in order to increase planning.

Potential Value:

- Increase constructability of a complex building system
- Increase construction productivity
- Increase safety awareness of a complex building system
- Decrease language barriers

Resources Required:

- 3D System design software

Team Competencies Required:

- Ability to manipulate, navigate, and review 3D model
- Ability to make appropriate construction decisions using a 3D System Design Software
- Knowledge of typical and appropriate construction practices for each component

Selected Resources:

- Leventhal, Lauren." Delivering Instruction for Inherently-3D Construction Tasks: Lessons and Questions for Universal Accessibility". Workshop on Universal Accessibility of Ubiquitous Computing: Providing for the elderly.
- Khemlano (2007). AECbytes: Building the Future (October 18, 2007).

Figure 5.12: Construction System Design (Virtual Mockup)

Digital Fabrication

Description:

A process that uses digitized information to facilitate the fabrication of construction materials or assemblies. Some uses of digital fabrication can be seen in sheet metal fabrication, structural steel fabrication, pipe cutting, prototyping for design intent reviews etc. It assists in ensuring that the downstream phase of manufacturing has minimum ambiguities and enough information to fabricate with minimal waste. An information model could also be used with suitable technologies to assemble the fabricated parts into the final assembly.

Potential Value:

- Ensuring quality of information
- Minimize tolerances through machine fabrication
- Increase fabrication productivity and safety
- Reduce lead time
- Adapt late changes in design
- Reduced dependency on 2D paper drawings

Resources Required:

- Design Authoring Software
- Machine readable data for fabrication
- Fabrication methods

Team Competencies Required:

- Ability to understand and create fabrication models
- Ability to manipulate, navigate, and review a 3D model
- Ability to extract digital information for fabrication from 3D models
- Ability to manufacture building components using digital information
- Ability to understand typical fabrication methods

Selected Resources:

- Eastman, C. (2008) "BIM HANDBOOK A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors."
- Papanikolaou, D. (2008). "Digital Fabrication Production System Theory: towards an integrated environment for design and production of assemblies." Cuba, 484-488.
- Reifschneider, M. (2009). "Managing the quality if structural steel Building Information Modeling."
- Rundell, R. (2008). "BIM and Digital Fabrication (1-2-3 Revit Tutorial)."
- Sass, L. (2005). "A production system for design and construction with digital fabrication." MIT.
- Seely, J. C. (2004). "Digital Fabrication in the Architectural Design Process." Master Thesis, Massachusetts Institute of Technology.

Figure 5.13: Digital fabrication information

3D Control and Planning (Digital Layout)

Description:

A process that utilizes an information model to layout facility assemblies or automate control of equipment's movement and location. The information model is used to create detailed control points aid in assembly layout. An example of this is layout of walls using a total station with points preloaded and/or using GPS coordinates to determine if proper excavation depth is reached.

Potential Value:

- Decrease layout errors by linking model with real world coordinates
- Increase efficiency and productivity by decreasing time spent surveying in the field
- Reduce rework because control points are received directly from the model
- Decrease/Eliminate language barriers

Resources Required:

- Machinery with GPS capabilities
- Digital Layout Equipment
- Model Transition Software (what software takes model and converts it to usable information).

Team Competencies Required:

- Ability to create, manipulate, navigate and review 3D model
- Ability to interpret if model data is appropriate for layout and equipment control.

Selected Resources:

- Garrett, R. E. (2007, January-February). PennDOT About to Embrace GPS Technology. Retrieved 2010, from gradingandexcavation.com: http://www.gradingandexcavation.com/january-february-2007/penndot-gps-technology.aspx>.
- Strafaci, A. (2008, October). What Does BIM Mean for Civil Engineers? Retrieved 2010, from cenews.com: http://images.autodesk.com/emea_s_main/files/what_does_bim_mean_for_civil_engineers_ce_news_1008.pdf
- TEKLA International. (2008, October 28). Tekla Corporation and Trible to Improve Construction Field Layout Using Building Information Modeling. Retrieved 2010, from tekla.com: http://www.tekla.com/us/about-us/news/Pages/TeklaTrimble.aspx

Figure 5.14: 3D control and planning (digital layout) information

3D Coordination

Description:

A process in which Clash Detection software is used during the coordination process to determine field conflicts by comparing 3D models of building systems. The goal of clash detection is to eliminate the major system conflicts prior to installation.

Potential Value:

- Coordinate building project through a model
- Reduce and eliminate field conflicts; which reduces RFI's significantly compared to other methods
- Visualize construction
- Increase productivity
- Reduced construction cost; potentially less cost growth (i.e. less change orders)
- Decrease construction time
- Increase productivity on site
- More accurate as built drawings

Resources Required:

- Design Authoring Software
- Model Review application

Team Competencies Required:

- Ability to deal with people and project challenges
- Ability to manipulate, navigate, and review a 3D model
- Knowledge of BIM model applications for facility updates
- Knowledge of building systems.

Selected References:

- Staub-French S and Khanzode A (2007) **"3D and 4D Modeling for design and construction coordination: issues and lessons learned"** ITcon Vol. 12, pg. 381-407, http://www.itcon.org/2007/26
- Khanzode A, Fischer M, Reed D (2008) **"Benefits and lessons learned of implementing building virtual design and construction (VDC) technologies for coordination of mechanical, electrical, and plumbing (MEP) systems on a large healthcare project"**, ITcon Vol. 13, Special Issue **Case studies of BIM use** , pg. 324-342, http://www.itcon.org/2008/22

Figure 5.15: 3D Coordination information

Design Authoring

Description:

A process in which 3D software is used to develop a Building Information Model based on criteria that is important to the translation of the building's design. Two groups of applications are at the core of BIM-based design process are design authoring tools and audit and analysis tools.

Authoring tools create models while audit and analysis tools study or add to the richness of information in a model. Most of audit and analysis tools can be used for Design Review and Engineering Analysis BIM Uses. Design authoring tools are a first step towards BIM and the key is connecting the 3D model with a powerful database of properties, quantities, means and methods, costs and schedules.

Potential Value:

- Transparency of design for all stakeholders
- Better control and quality control of design, cost and schedule
- Powerful design visualization
- True collaboration between project stakeholders and BIM users
- Improved quality control and assurance

Resources Required:

- Design Authoring Software

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D model
- Knowledge of construction means and methods
- Design and construction experience

Selected References:

- Tardif, M. (2008). BIM: Reaching Forward, Reaching Back. AIArchitect This Week. Face of the AIA. AIArchitect

Figure 5.16: Design authoring information

Engineering Analysis (Structural, Lighting, Energy, Mechanical, Other)

Description:

A process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications. Development of this information is the basis for what will be passed on to the owner and/or operator for use in the building's systems (i.e. energy analysis, structural analysis, emergency evacuation planning, etc.). These analysis tools and performance simulations can significantly improve the design of the facility and its energy consumption during its lifecycle in the future.

Potential Value:

- Automating analysis and saving time and cost
- Analysis tools are less costly than BIM authoring tools, easier to learn and implement and less disruptive to established workflow
- Improve specialized expertise and services offered by the design firm
- Achieve optimum, energy-efficient design solution by applying various rigorous analyses
- Faster return on investment with applying audit and analysis tools for engineering analyses
- Improve the quality and reduce the cycle time of the design analyses

Resources Required:

- Design Authoring Tools
- Engineering analysis tools and software

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D Model
- Ability to assess a model through engineering analysis tools
- Knowledge of construction means and methods
- Design and construction experience

Selected References:

- Malin, N. (2008). BIM Companies Acquiring Energy Modeling Capabilities. http://greensource.construction.com/news/080403BIMModeling.asp
- Marsh, A. (2006). Ecotect as a Teaching Tool. http://naturalfrequency.com/articles/ecotectasteacher
- Marsh, A. (2006). Building Analysis: Work Smart, Not Hard. http://naturalfrequency.com/articles/smartmodelling
- Novitzki, B. (2008). Energy Modeling for Sustainability. http://continuingeducation.construction.com/article.php?L=5&C=399
- Stumpf, A., Brucker, B. (2008). BIM Enables Early Design Energy Analysis. http://www.cecer.army.mil/td/tips/docs/BIM-EnergyAnalysis.pdf
- PIER Building Program (2008). Estimating Energy Use Early and Often. www.esource.com/esource/getpub/public/pdf/cec/CEC-TB-13_EstEnergyUse.pdf
- Ecotect - Building Analysis for Designers. http://www.cabs-cad.com/ecotect.htm
- Khemlani (2007). AECbytes: Building the Future (October 18, 2007).

Figure 5.17: Engineering Analysis information

Facility Energy Analysis

Description:

The BIM Use of Facility Energy Analysis is a process in the facility design phase which one or more building energy simulation programs use a properly adjusted BIM model to conduct energy assessments for the current building design. The core goal of this BIM use is to inspect building energy standard compatibility and seek opportunities to optimize proposed design to reduce structure's life-cycle costs.

Potential Value:

- Save time and costs by obtaining building and system information automatically from BIM model instead of inputting data manually
- Improve building energy prediction accuracy by auto-determining building information such as geometries, volumes precisely from BIM model
- Help with building energy code verification
- Optimize building design for better building performance efficiency and reduce building life-cycle cost

Resources Required:

- Building Energy Simulation and Analysis Software(s)
- Well-adjusted Building 3D-BIM Model
- Detailed Local Weather Data
- National/Local Building Energy Standards (e.g. ASHRAE Standard 90.1)

Team Competencies Required:

- Knowledge of basic building energy systems
- Knowledge of compatible building energy standard
- Knowledge and experience of building system design
- Ability to manipulate, navigate, and review a 3D Model
- Ability to assess a model through engineering analysis tools

Selected References:

- ASHRAE. 2009. ASHRE Handbook-Fundamentals. Atlanta. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
- Crawley. D. B., Hand, J. W., et, 2008. Contrasting the capabilities of building energy performance simulation program. Building and Environment 43 (2008) 661-673.
- Bazjanac. V. 2008. IFC BIM-Based Methodology for Semi-Automated Building Energy Performance Simulation. Proceedings of CIB-W78 25th International Conferenceon Information Technology in Construction.
- Stumpf. A., Kim. H., Jenicek. E. 2009. Early Design Energy Analysis Using BIMS (Building Information Models). 2009 Construction Research Congress. ASCE.
- Cho. Y. K., Alaskar. S., and Bode.T.A. 2010. BIM-Integrated Sustainable Material and Renewable Energy Simulation. 2010 Construction Research Congress. ASCE.

Figure 5.18: Facility Energy Analysis information

Structural Analysis (Structural, Lighting, Energy, Mechanical, Other)

Description:

A process in which analytical modeling software utilizes the BIM design authoring model so to determine the behavior of a given structural system. With the modeling minimum required standards for structural design and analysis are used for optimization. Based on this analysis further development and reinfinement of the structural design takes place to create effective, efficient, and constructible structural systems. The development of this information is the basis for what will be passed onto the digital fabrication and construction system design phases.

This BIM Use does not need to be implemented from the beginning of the design to be beneficial. Often structural analysis is implemented at the connection design level to make fabrication quicker, more efficient and for better coordination during construction. Another application is that this relates and ties into is construction system design, examples include but not limited to: erection design, construction means and methods, and rigging. The application of this analysis tool allows for performance simulations that can significantly improve the design, performance, and safety of the facility over its lifecycle.

Potential Value:

- Save time and cost on creating extra models
- Easier transition BIM authoring tools allowing new firms implementing this use model
- Improve specialized expertise and services offered by the design firm
- Achieve optimum efficient design solutions by applying various rigorous analyses
- Faster return on investment with applying audit and analysis tools for engineering analyses
- Improve the quality of the design analyses
- Reduce the cycle time of the design analyses

Resources Required:

- Design Authoring Tools
- Structural Engineering analysis tools and software
- Design standards and codes
- Adequate hardware for running software

Team Competencies Required:

- Ability to create, manipulate, navigate, and review a 3D Structural Model
- Ability to assess a model through engineering analysis tools
- Knowledge of constructability methods
- Knowledge of analytical modeling techniques
- Knowledge of structural behavior and design
- Design experience
- Integration expertise pertaining to building systems as a whole
- Experience in structural sequencing methods

Selected References:

These references discuss current trends with BIM in structural engineering, limitations and shortcomings of this Use at the present, the potential future benefits, and the theory behind how this Use works.

- Ikerd, Will (2007) "**The Importance of BIM in Structural Engineering: The greatest change in over a century**" Structure Magazine, October 2007, pgs 37-40
- Burt, Bruce (2009) **"BIM Interoperability: the Promise and the Reality"** Structure Magazine, December 2009, pgs 19-21
- Faraone, Thomas, et al. (2009) **"BIM Resources for the AEC Community"** Structure Magazine, March 2009, pgs 32-33
- Eastman et al (2010) "**Exchange Model and Exchange Object Concepts for Implementation of National BIM Standards"**, Journal of Computing in Civil Engineering, (January/February 2010): 25-34. ASCE.
- Barak et al (2009) **"Unique Requirements of Building Information Modeling for CIP Reinforced Concrete",** Journal of Computing in Civil Engineering, (March/April 2009): 64-74. ASCE.

Figure 5.19: Structural Analysis information

Sustainability (LEED) Evaluation

Description:

A process in which a BIM project is evaluated based on LEED or other sustainable criteria. This process should occur during all stages of a facilities life including planning, design, construction, and operation. Applying sustainable features to a project in the planning and early design phases is more effective (ability to impact design) and efficient (cost and schedule of decisions). This comprehensive process requires more disciplines to interact earlier by providing valuable insights. This integration may require contractual integration in planning phase. In addition to achieving sustainable goals, having LEED approval process adds certain calculations, documentations, and verifications. Energy simulations, calculations, and documentations can be performed within an integrative environment when responsibilities are well defined and clearly shared.

Potential Value:

- Facilitates interaction, collaboration, and coordination of team members early in the project process are considered to be favorable to sustainable projects.
- Enables early and reliable evaluation of design alternatives.
- Availability of critical information early helps problem resolution efficiently in terms of cost premium and schedule conflicts.
- Shortens the actual design process by the help of early facilitated design decisions. Shorter design process is cost effective and provides more time for other projects.
- Leads to delivery better project quality.
- Reduces documentation load after design and accelerates certification because concurrently prepared calculations can be used for verification.
- Reduces operational costs of the facility due to the energy performance of the project. It optimized building performance via improved energy management.
- Increases the emphasis on environmentally friendly and sustainable design.
- Assists project team with potential future revisions throughout the life cycle.

Resources Required:

- Design authoring software

Team Competencies Required:

- Ability to create and review 3D Model
- Knowledge of up-to-date LEED Credit Information
- Ability to organize and manage the database

Selected Resources:

- Krygiel, E., and Brad, N. , 2008, "Green BIM: Successful Sustainable Design with Building Information Modeling," San Francisco.
- McGraw Hill Construction, 2010, "Green BIM-How Building Information Modeling Is Contributing to Green Design and Construction," Smart Market Report, McGraw Hill Construction.
- The Computer Integrated Construction Research Program, 2010, "BIM Project Execution Planning Version 2.0," Penn State University.
- Balfour Beatty Construction, 2010, "Sustainability and Engineering Guide Version 2.0," Balfour Beatty Construction.

Figure 5.20: Sustainability (LEED) evaluation information

Code Validation

Description:

A process in which code validation software is utilized to check the model parameters against project specific codes. Code validation is currently in its infant stage of development within the U.S. and is not in widespread use. However, as model checking tools continue to develop, code compliance software with more codes, code validation should become more prevalent within the design industry.

Potential Value:

- Validate that building design is in compliance with specific codes, e.g. IBC International Building Code, ADA Americans with Disabilities Act guidelines and other project related codes using the 3D BIM model.
- Code validation done early in design reduces the chance of code design errors, omissions or oversights that would be time consuming and more expensive to correct later in design or construction.
- Code validation done automatically while design progresses gives continuous feedback on code compliance.
- Reduced turnaround time for 3D BIM model review by local code officials or reduced time that needs to be spent meeting with code commissioners, visiting the site, etc. or fixing code violations during punch list or closeout phase.
- Saves time on multiple checking for code compliance and allows for a more efficient design process since mistakes cost time and money.

Resources Required:

- Local code knowledge
- Model checking software
- 3D Model manipulation

Team Competencies Required:

- Ability to use BIM authoring tool for design and model checking tool for design review
- Ability to use code validation software and previous knowledge and experience with checking codes is needed.

Selected Resources:

- Automated Circulation Validation using BIM. GSA. 1-22.
- Eastman, C., Liston, K., Sacks, R. and Teicholz, P. BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors. New York, NY: Wiley, 2008.

Figure 5.21: Code validation information

Design Reviews

Description:

A process in which stakeholders view a 3D model and provide their feedbacks to validate multiple design aspects. These aspects include evaluating meeting the program, previewing space aesthetics and layout in a virtual environment, and setting criteria such as layout, sightlines, lighting, security, ergonomics, acoustics, textures and colors, etc. This BIM use can be done by using computer software only or with special virtual mock-up facilities, such as CAVE (Computer Assisted Virtual Environment) and immersive lab. Virtual mock-ups can be performed at various levels of detail depending on project needs. An example of this is to create a highly detailed model of a small portion of the building, such as a facade to quickly analyze design alternatives and solve design and constructability issues.

Potential Value:

- Eliminate costly and timely traditional construction mock-ups
- Different design options and alternatives may be easily modeled and changed in real-time during design review base on end users and/or owner feedbacks
- Create shorter and more efficient design and design review process
- Evaluate effectiveness of design in meeting building program criteria and owner's needs
- Enhance the health, safety and welfare performance of their projects (For instance, BIM can be used to analyze and compare fire-rated egress enclosures, automatic sprinkler system designs, and alternate stair layouts)
- Easily communicate the design to the owner, construction team and end users
- Get instant feedbacks on meeting program requirements, owner's needs and building or space aesthetics
- Greatly increase coordination and communication between different parties. More likely to generate better decisions for design

Resources Required:

- Design Review Software
- Interactive review space
- Hardware which is capable of processing potential large model files

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D model
- Ability to model photo realistically including textures, colors and finishes and easily navigable by using different software or plug-ins
- Strong sense of coordination. Understanding roles and responsibilities of team members
- Strong understanding of how building/facility systems integrate with one another

Selected Resources:

- Bassanino, May Wu, Kuo-Cheng Yao, Jialiang Khosrowshahi, Farzad Fernando, Terrence Skjaerbaek, Jens. (2010). "The Impact of Immersive Virtual Reality on Visualisation for a Design Review in Construction," 14th International Conference Information Visualisation.
- Dunston, Phillip S., Arns, Laura L., and McGlothin, James D. (2007). "An Immersive Virtual Reality Mock-Up for Design Review of Hospital Patient Rooms," 7th International Conference on Construction Applications of Virtual Reality, University Park, Pennsylvania, October 22-23.
- Majumdar, Tulika, Fischer, Martin A., and Schwegler, Benedict R. (2006). "Conceptual Design Review with a Virtual Reality Mock-Up Model," Building on IT: Joint International Conference on Computing and Decision Making in Civil and Building Engineering, Hugues Rivard, Edmond Miresco, and Hani Melham, editors, Montreal, Canada, June 14-16, 2902-2911.
- Maldovan, Kurt D., Messner, John I., and Faddoul, Mera (2006). "Framework for Reviewing Mockups in an Immersive Environment," CONVR 2006:6th International Conference on Construction Applications of Virtual Reality, R. Raymond issa, editor, Orlando, Florida, August 3-4, on CD.
- NavisWorks (2007), "Integrated BIM and Design Review for Safer, Better Buildings," (http://www.eua.com/pdf/resources/integrated_project/Integrated_BIM-safer_better_buildings.pdf).
- Shiratuddin, M.F and Thabet, WalidA. (2003). "Framework for a Collaborative Design Review System Utilizing the Unreal Tournament (UT) Game Development Tool," CIB REPORT.
- Xiangyu Wang and Phillip S. Dunston. (2005). "System Evaluation of a Mixed Reality-Based Collaborative Prototype for Mechanical Design Review Collaboration," Computing in Civil Engineering, Volume 21, issue 6, page: 393-401.

Figure 5.222: Design reviews information

Programming
Description:
A process in which a spatial program is used to efficiently and accurately assess design performance in regard to spatial requirements. The developed BIM model allows the project team to analyze space and understand the complexity of space standards and regulations. Critical decisions are made in this phase of design and bring the most value to the project when needs and options are discussed with the client and the best approach is analyzed.
Potential Value:
▪ Efficient and accurate assessment of design performance in regard to spatial requirements by the owner.
Resources Required:
▪ Design Authoring Software
Team Competencies Required:
▪ Ability to manipulate, navigate, and review a 3D model
Selected Resources:
▪ GSA BIM Guide

Figure 5.23: Programming information

Site Analysis
Description:
A process in which BIM/GIS tools are used to evaluate properties in a given area to determine the most optimal site location for a future project. The site data collected is used to first select the site and then position the building based on other criteria.
Potential Value:
▪ Use calculated decision making to determine if potential sites meet the required criteria according to project requirements, technical factors, and financial factors ▪ Decrease costs of utility demand and demolition ▪ Increase energy efficiency ▪ Minimize risk of hazardous material ▪ Maximize return on investment
Resources Required:
GIS software Design Authoring Software
Team Competencies Required:
▪ Ability to manipulate, navigate, and review a 3D model ▪ Knowledge and understanding of local authority's system (GIS, database information)
Selected Resources:
▪ **The Site Selection Guide**. US General Services Administration (GSA) Public Building Service. ▪ Optimal Site Selection for Military Land Management, R.M. Wallace, ASCE Conf. Proc. 138, 159 (2004). DOI: 10. 1061/40737(2004)159. ▪ Farnsworth, Stephen J. "Site Selection Perspective." Prospecting Sites. June 1995, 29-31. ▪ WPBG Sustainable Committee. **Optimizing Site Potential.** ▪ Suermann P.C. Leveraging GIS Tools in Defense and Response at the U.S. Air Force Academy. ASCE Conf. Proc. 179, 82 (2005) DOI: 10. 1061/40794(179)82. ▪ GIS – Based Engineering Management Service Functions: Taking GIS Beyond Mapping for Municipal Governments.

Figure 5.24: Site analysis information

Phase Planning (4D Modeling)

Description:

A process in which a 4D model (3D models with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit, addition, or to show the construction sequence and space requirements on a building site. 4D modeling is a powerful visualization and communication tool that can give a project team, including the owner, a better understanding of project milestones and construction plans.

Potential Value:

- Better understanding of the phasing schedule by the owner and project participants and showing the critical path of the project
- Dynamic phasing plans of occupancy offering multiple options and solutions to space conflicts
- Integrate planning of human, equipment and material resources with the BIM model to better schedule and cost estimate the project
- Space and workspace conflicts identified and resolved ahead of the construction process
- Marketing purposes and publicity
- Identification of schedule, sequencing or phasing issues
- More readily constructible, operable and maintainable project
- Monitor procurement status of project materials
- Increased productivity and decreased waste on job sites
- Conveying the spatial complexities of the project, planning information, and support conducting additional analyses

Resources Required:

- Design Authoring Software
- Scheduling Software
- 4D Modeling Software

Team Competencies Required:

- Knowledge of construction scheduling and general construction process. A 4D model is connected to a schedule, and is therefore only as good as the schedule to which it is linked.
- Ability to manipulate, navigate, and review a 3D model.
- Knowledge of 4D software: import geometry, manage links to schedules, produce and control animations, etc.

Selected Resources:

- Dawood, N., and Mallasi, Z. (2006). Construction Workplace Planning: Assignment and Analysis Utilizing 4D Visualization Technologies. ***Computer-aided Civil and Infrastructure Engineering***, Pgs. 498-513.
- Jongeling, R., Kim, J., Fischer, M., Morgeous, C., and Olofsson, T. (2008). Quantitative analysis of workflow, temporary structure usage, and productivity using 4D models. ***Automation in Construction***, Pgs. 780-791.
- Kang, J. H., Anderson, S. D., and Clayton, M. J. (2007). Empirical Study on the Merit of Web-based 4D Visualization in Collaborative Construction Planning and Scheduling. ***Journal of Construction Engineering and Management***, Pgs. 447-461.

Figure 5.25: Phase analysis information

Cost Estimation (Quantity Take-Off)

Description:

A process in which BIM can be used to assist in the generation of accurate quantity take-offs and cost estimates throughout the lifecycle of a project. This process allows the project team to see the cost effects of their changes, during all phases of the project, which can help curb excessive budget overruns due to project modifications. Specifically, BIM can provide cost effects of additions and modifications, with potential to save time and money and is most beneficial in the early design stages of a project.

Potential Value:

- Precisely quantify modeled materials
- Quickly generate quantities to assist in the decision making process
- Generate more cost estimates at a faster rate
- Better visual representation of project and construction elements that must be estimated
- Provide cost information to the owner during the early decision making phase of design and throughout the lifecycle, including changes during construction
- Saves estimator's time by reducing quantity take-off time
- Allows estimator's to focus on more value adding activities in estimating such as: identifying construction assemblies, generating pricing and factoring risks, which are essential for high quality estimates
- Added to a construction schedule (such as a 4D Model), a BIM developed cost estimate can help track budgets throughout construction
- Easier exploration of different design options and concepts within the owner's budget
- Quickly determine costs of specific objects
- Easier to strain new estimators through this highly visual process

Resources Required:

- Model-based estimating software
- Design authoring software
- Accurately built design model
- Cost data (Including Masterformat and Uniformat data)

Team Competencies Required:

- Ability to define specific design modeling procedures which yield accurate quantity take-off information
- Ability to identify quantities for the appropriate estimating level (e.g. ROM, SF, etc.) upfront
- Ability to manipulate models to acquire quantities usable for estimation

Selected Resources:

- Lee, H., Lee, Kim, J. (2008). A cost-based interior design decision support system for large-scale housing projects, ITcon Vol. 13, Pg. 20-38, http://www.itcon.org/2008/2
- Autodesk Revit. (2007) "BIM and Cost Estimating." Press release. Autodesk. 11 Sept. 2008. http://images.autodesk.com/adsk/files/bim_cost_estimating_jan07_1_.pdf
- Dean, R. P., and McClendon, S. (2007). "Specifying and Cost Estimating with BIM." ARCHI TECH. Apr. 2007. ARCHI TECH. 13 Sept. 2008. http://www.architechmag.com/articles/detail.aspx?contentid=3624.
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- Manning, R.; Messner, J. (2008). Case studies in BIM implementation for programming of healthcare facilities, ITcon Vol. 13, Special Issue Case studies of BIM use, Pg. 246-257, http://www.itcon.org/2008/18
- Shen Z, Issa R R A (2010) Quantitative evaluation of the BIM-assisted construction detailed cost estimates, Journal of Information Technology in Construction (ITcon), Vol. 15, pg. 234-257, http://www.itcon.org/2010/18
- McCuen, T. (2009, November 18). Cost Estimating in BIM: The Fifth Dimension. Retrieved September 21, 2010, from Construction Advisor Today: http://constructionadvisortoday.com/2009/11/cost-estimating-in-bim-the-fifth-dimension.html

Figure 5.26: Cost estimation (quantity takeoff) information

Existing Conditions Modeling

Description:

A process in which a project team develops a 3D model of the existing conditions for a site, facilities on a site, or a specific area within a facility. This model can be developed in multiple ways: including laser scanning and conventional surveying techniques, depending on what is desired and what is most efficient. Once the model is constructed, it can be queried for information, whether it is for new construction or a modernization project.

Potential Value:

- Enhances the efficiency and accuracy of existing conditions documentation
- Provides documentation of environment for future uses
- Aids in future modeling and 3D design coordination
- Provides an accurate representation of work that has been put into place
- Real-time quantity verification for accounting purposes
- Provides detailed layout information
- Pre-Disaster planning
- Post-Disaster record
- Use for visualization purposes

Resources Required:

- Building Information Model modeling software
- Laser scanning point cloud manipulation software
- 3D Laser scanning
- Conventional surveying equipment

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D model
- Knowledge of Building Information Model authoring tools
- Knowledge of 3D laser scanning tools
- Knowledge of conventional surveying tools and equipment
- Ability to sift through mass quantities of data that is generated by a 3D laser scan
- Ability to determine what level of detail will be required to add "value" to the project
- Ability to generate Building Information Model from 3D laser scan and/or conventional survey data

Selected Resources:

- United States General Services Administration (2009). "GSA Building Information Modeling Guide Series: 03 - GSA BIM Guide of 3D Imaging."
- Arayici, Y. (2008). "Towards building information modeling for existing structures." Structural Survey 26.3: 210. ABI/INFORM Global.
- Murphy, M., McGovern, E., and Pavia, S. (2009)."Historic Building Information Modelling (HBIM)." Structural Survey 27.4: 311. ABI/INFORM Global.
- Adan, A., Akinci, B., Huber, D., Pingbo, Okorn, B., Tang, P. and Xiong, X. (2010)."Using Laser Scanners for Modeling and Analysis in Architecture, Engineering, and Construction."

Figure 5.27: Existing conditions modeling information

Note: Images from Figures 5.5-5.27 are originally from the Computer Integrated Construction Research Group at the Pennsylvania State University.

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Feng, Lingjie, Ph.D., and Raymond Issa, Ph.D., P.E. Implementation of Building Information Modeling on K-12 Educational Facility Projects in Florida. Rep. Associated Schools of Construction, 2014. Web. 8 Apr. 2016.

Messner, John, and Chimay Anumba. BIM Project Execution Planning Guide Version 2.1. Rep. N.p.: Computer Integrated Construction Research Group, The Pennsylvania State University, 2010. Print.

Scheer, David, AIA, AIA TAP, Jeffrey Outlette, Assoc. AIA, AIA TAP, Travis Young, AIA, Francois Levy, AIA, and Bradley Khouri, AIA. BIM for Small Projects: Case Studies InInnovative BIM Use by Small Firms. N.p.: American Institute of Architects, 14 Oct. 2011. PDF.

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Appendix E: Foundation Redesign

Figures & Tables

Table 6.1: LFRD loading calculations

Type	Live Load (psf)	Dead Load (psf)	Snow Load (psf)	Load Combination Equation	Total Load (psf)
Floor 1 (Typ)	65	40	0	$1.2D + 1.6L_r$	152
Floor 1 (B.8-20 through B.8-15)	100	40	0	$1.2D + 1.6L_r$	168
(A.8-20 through A.8-15)	65	40	0		
Floor 1 (B.8-14, A.9-20)	100	40	0	$1.2D + 1.6L_r$	176
	65	40	0		
Floor 2 (Typ)	65	40	0	$1.2D + 1.6L_r$	152
Floor 2 (B.8-20 through B.8-15)	80	40	0	$1.2D + 1.6L_r$	159
(A.8-20 through A.8-15)	65	40	0		
Floor 2 (B.8-14, A.9-20)	80	40	0	$1.2D + 1.6L_r$	162
	65	40	0		
Floor 3 (Typ)	65	40	0	$1.2D + 1.6L_r$	152
Floor 3 (B.8-20 through B.8-15)	80	40	0	$1.2D + 1.6L_r$	159
(A.8-20 through A.8-15)	65	40	0		
Floor 3 (B.8-14, A.9-20)	80	40	0	$1.2D + 1.6L_r$	162
	65	40	0		
Roof Load	20	40	30	$1.2D + 1.6S$	128

Table 6.2: Pile cap loading condition calculations

	Tributary Area Calculations			Loads on Column by Floor								Column Sizing					Footing Sizing	
Column	Tributary Width (ft)	Tributary Length (ft)	Tributary Area (ft^2)	Floor 1 Load (psf)	Floor 1 Load (kip)	Floor 2 Load (psf)	Floor 2 Load (kip)	Floor 3 Load (psf)	Floor 3 Load (kip)	Roof Load (psf)	Roof Load (kip)	Load on Column (kip)	Existing Column Size	Floor 2-3 Column Size	Column Length (ft)	Column Self Weight	Column Total Load (kip)	Total Load on Pile Caps (kip)
D.5-20	7	12	84	152	12.77	152	12.77	152	12.77	128	10.75	36.3	W10x45	W8x31	42	1526	37.8	50.6
D.5-19	23	12	276	152	41.95	152	41.95	152	41.95	128	35.33	119.2	W10x45	W8x31	42	1526	120.8	162.7
D.5-18	23	12	276	152	41.95	152	41.95	152	41.95	128	35.33	119.2	W10x45	W8x31	42	1526	120.8	162.7
D.5-17	23	12	276	152	41.95	152	41.95	152	41.95	128	35.33	119.2	W10x45	W8x31	42	1526	120.8	162.7
D.5-16	23	12	276	152	41.95	152	41.95	152	41.95	128	35.33	119.2	W10x45	W8x31	42	1526	120.8	162.7
D.5-15	23	12	276	152	41.95	152	41.95	152	41.95	128	35.33	119.2	W10x45	W8x31	42	1526	120.8	162.7
D.5-14	24.33	12	292	152	44.38	152	44.38	152	44.38	128	37.38	126.1	W10x45	W8x31	42	1526	127.7	172.1
B.8-20	7	17	119	168	20.05	159	18.93	159	18.93	128	15.23	53.1	W10x49	W8x31	42	1526	54.6	74.7
B.8-19	23	17	391	168	65.87	159	62.19	159	62.19	128	50.05	174.4	W10x49	W8x31	42	1526	176.0	241.8
B.8-18	23	17	391	168	65.87	159	62.19	159	62.19	128	50.05	174.4	W10x49	W8x31	42	1526	176.0	241.8
B.8-17	23	17	391	168	65.87	159	62.19	159	62.19	128	50.05	174.4	W10x49	W8x31	42	1526	176.0	241.8
B.8-16	23	17	391	168	65.87	159	62.19	159	62.19	128	50.05	174.4	W10x49	W8x31	42	1526	176.0	241.8
B.8-15	23	17	391	168	65.87	159	62.19	159	62.19	128	50.05	174.4	W10x49	W8x31	42	1526	176.0	241.8
B.8-14	24.33	17	413.67	176	72.96	162	67.20	162	67.20	128	52.95	187.3	W10x49	W8x31	42	1526	188.9	261.8
A.9-20	7	17	119	168	20.05	159	18.93	159	18.93	128	15.23	53.1	W10x49	W8x31	42	1526	54.6	74.7
A.9-19	23	17	391	168	65.87	159	62.19	159	62.19	128	50.05	174.4	W10x49	W8x31	42	1526	176.0	241.8
A.9-18	23	17	391	168	65.87	159	62.19	159	62.19	128	50.05	174.4	W10x49	W8x31	42	1526	176.0	241.8
A.9-17	23	17	391	168	65.87	159	62.19	159	62.19	128	50.05	174.4	W10x49	W8x31	42	1526	176.0	241.8
A.9-16	23	17	391	168	65.87	159	62.19	159	62.19	128	50.05	174.4	W10x49	W8x31	42	1526	176.0	241.8
A.9-15	23	17	391	168	65.87	159	62.19	159	62.19	128	50.05	174.4	W10x49	W8x31	42	1526	176.0	241.8
A.9-14	24.33	17	413.67	176	72.96	162	67.20	162	67.20	128	52.95	187.3	W10x49	W8x31	42	1526	188.9	261.8
Aa.1-20	7	12	84	152	12.77	152	12.77	152	12.77	128	10.75	36.3	W10x45	W8x31	42	1526	37.8	50.6
Aa.1-19	23	12	276	152	41.95	152	41.95	152	41.95	128	35.33	119.2	W10x45	W8x31	42	1526	120.8	162.7
Aa.1-18	23	12	276	152	41.95	152	41.95	152	41.95	128	35.33	119.2	W10x45	W8x31	42	1526	120.8	162.7
Aa.1-17	23	12	276	152	41.95	152	41.95	152	41.95	128	35.33	119.2	W10x45	W8x31	42	1526	120.8	162.7
Aa.1-16	23	12	276	152	41.95	152	41.95	152	41.95	128	35.33	119.2	W10x45	W8x31	42	1526	120.8	162.7
Aa.1-15	23	12	276	152	41.95	152	41.95	152	41.95	128	35.33	119.2	W10x45	W8x31	42	1526	120.8	162.7
Aa.1-14	24.33	12	292	152	44.38	152	44.38	152	44.38	128	37.38	126.1	W10x45	W8x31	42	1526	127.7	172.1

Table 6.6a: Foundation estimate concrete takeoffs for existing design

Pile Caps Concrete								
Pile Cap		Qty	Sqft Area	Depth (in)	Volume per cap (cu. Ft.)	Volume - Rebar Volume	Total Volume (cu. Ft)	Total Volume (Cu. Yd)
P3		4	20.95	26	45.39	44.90	179.60	6.65
P5		12	45.56	26	98.71	97.90	1174.74	43.51
P6		2	38.25	28	89.25	88.03	176.06	6.52
P7		10	51.65	28	120.52	119.16	1191.64	44.13
Total								100.82

Table 6.6b: Foundation estimate formwork takeoffs for existing design

Formwork								
Pile Cap		Qty		Perimeter (ft)	Height (ft)	Sqft Area		Total sqft Area
P3		4		18.25	2.17	39.54		158
P5		12		27.00	2.17	58.50		702
P6		2		26.00	2.33	60.67		121
P7		10		26.67	2.33	62.22		622
Total								1604

Table 6.6c: Foundation estimate rebar takeoffs for existing design

Pile Cap Rebar								
Pile Cap	# Bar	Qty per cap	T&B?	LF	Total LF Per Cap	Volume Per cap (cu ft)	Total LF	Total Tons
P3	8	9	2	5	90	0.49	360	0.48
P5	8	12	2	6.25	150	0.82	1800.00	2.40
P6	8	14	2	8	224	1.22	448.00	0.60
P7	8	16	2	7.75	248	1.35	2480.00	3.31
Totals						3.88		6.79

Table 6.6d: Foundation estimate helical piles takeoffs for existing design

Helical Piles								
Pile Cap					Qty	Piles Per Cap		Total sqft Area
P3					4	3		12
P5					12	5		60
P6					2	6		12
P7					10	7		70
Total								154

Table 6.7a: Foundation estimate concrete takeoffs for proposed redesign

Pile Caps Concrete								
Pile Cap		Qty	Sqft Area	Depth (in)	Volume per cap (cu. Ft.)	Volume - Rebar Volume	Total Volume (cu. Ft)	Total Volume (Cu. Yd)
P3		4	20.95	26	45.39	44.90	179.60	6.65
P5		12	45.56	26	98.71	97.90	1174.74	43.51
P7		12	51.65	28	120.52	119.16	1429.97	52.96
Total								103.12

Table 6.7b: foundation estimate formwork takeoffs for proposed redesign

Formwork								
Pile Cap		Qty		Perimeter (ft)	Height (ft)	Sqft Area		Total sqft Area
P3		4		18.25	2.17	39.54		158
P5		12		27.00	2.17	58.50		702
P7		12		26.67	2.33	62.22		747
Total								1607

Table 6.7c: Foundation estimate rebar takeoffs for proposed redesign

Pile Cap Rebar								
Pile Cap	# Bar	Qty per cap	T&B?	LF	Total LF Per Cap	Volume Per cap (cu ft)	Total LF	Total Tons
P3	8	9	2	5	90	0.49	360	0.48
P5	8	12	2	6.25	150	0.82	1800.00	2.40
P7	8	16	2	7.75	248	1.35	2976.00	3.97
Totals						2.66		6.86

Table 6.7d: Foundation estimate helical piles takeoffs for proposed redesign

Helical Piles								
Pile Cap					Qty	Piles Per Cap		Total sqft Area
P3					4	3		12
P5					12	5		60
P7					12	7		84
Total								156

Appendix F: Acoustical Analysis

Figures & Tables

Table 7.2a: Room 108 acoustical analysis summary table

Room:	108 (Prekindergarten Classroom)							
Location:	Phase 1, Floor 1							
Partition	**Wall/Material Type (Actual)**	**Wall Type Assumption**	**Description**	**Adjacent Rooms**	**Recommended STC**	**Actual STC**	**Meets RQMT?**	**Notes/Assumptions**
WALL A								
Wall 1	A42A	Partition Type A (A42A)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Hallway	45	56	**YES**	
WALL B								
Wall 6	A40F	Partition Type A (A40F)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Closet	45	49	**YES**	
WALL C								
Wall 5	A40F	Partition Type A (A40F)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Personal Toilet Rm	53	49	**NO**	
WALL D								
Wall 4	A40F	Partition Type A (A40F)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Records/ Mailroom	45	49	**YES**	
WALL E (COMPOSITE)								
Composite STC Rating			25% Brick Façade w/ Metal Studs + 75% Glazing		40	36		
Wall 3	F30E	Partition Type F (STC not Provided)	Exterior Encolosure, Metal Studs 24" OC 4-1/2" thick, 5/8" GWB	Naylor Rd	N/A	45	**NO**	Assume 2 x 4 studs, 3/4" sheathing, 5/8" GB, 4" brick veneer, 3" FG (From Book Appendix)
Window 1	W6	Assume STC-35	Window		N/A	35		
WALL F								
Wall 2	A42A	Partition Type A (A42A)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Naylor Rd	40	56	**YES**	
CEILING/FLOORING ASSEMBLY								
Ceiling	N/A	N/A	Acoustical Tile, Composite Deck, Carpet	Visual Arts, Storage, Kiln	60	53	**NO**	Kiln can be 90dB; Assume this is similar to mechanical room (requires STC-60 rating)
Flooring	N/A	N/A	Carpet, Composite Deck, Acoustical Tile	Storage Rm	45	53	**YES**	**Assume 6" Conc Flooring http://www.kineticsnoise.com/arch/tests/concrete_below_deck.html

Table 7.2b: Room 215 acoustical analysis summary table

Partition	Wall/Material Type (Actual)	Wall Type Assumption	Description	Adjacent Rooms	Recommended STC	Actual STC	Meets RQMT?	Notes/Assumptions
Room:	215 (Library/Media Room)							
Location:	Phase 1, Floor 2							
WALL A (COMPOSITE)								
Wall 3	A40F	Partition Type A (A40F)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Hallway	N/A	49	NO	
Window 5	W19	Assume STC-35	Window		N/A	35		Part of composite Calc.
Window 3	W20	Assume STC-35	Window		N/A	35		Part of composite Calc.
Composite STC Rating			61% gyspum w/ Metal Studs + 31% Glazing		45	39		
WALL B								
Wall 1	A40F	Partition Type A (A40F)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	2nd Grade Classroom	50	49	NO	
WALL C(COMPOSITE)								
Composite STC Rating			32% Brick Façade w/ Metal Studs + 68% Glazing	Naylor Rd	40	36	NO	
Wall 3	Brick Façade/ Metal Studs	Partition Type F (STC not Provided)	Exterior Encolosure, Metal Studs 24" OC 4-1/2" thick, 5/8" GWB		N/A	45		
Window 1	W6	Assume STC-35	Window		N/A	35		
Window 2	W8	Assume STC-35	Window		N/A	35		
WALL D								
Wall 4	A40F	Partition Type A (A40F)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	IDF Rm, Speech Rm	50	49	NO	
CEILING/FLOORING ASSEMBLY								
Ceiling	N/A	N/A	Acoustical Tile, Composite Deck, Carpet	5th Grade, Staff Lounge, Staff R Room	50	53	YES	**Assume 6" Conc Flooring http://www.kineticsnoise.com/arch/tests/concrete_below_deck.html
Flooring	N/A	N/A	Carpet, Composite Deck, Acoustical Tile	Foyer, Toilet Rm Classroom	53	53	YES	**Assume 6" Conc Flooring http://www.kineticsnoise.com/arch/tests/concrete_below_deck.html

Table 7.2c: Room 205 acoustical analysis summary table

Partition	Wall/Material Type (Actual)	Wall Type Assumption	Description	Adjacent Rooms	Recommended STC	Actual STC	Meets RQMT?	Notes/Assumptions
Room:	205 (2nd Grade)							
Location:	Phase 1, Floor 2							
WALL A								
Wall 1	A42A	Partition Type A (A42A)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Hallway	45	56	YES	
WALL B								
Wall 2	A42A	Partition Type A (A42A)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Stariwell 206	45	56	YES	
WALL C (COMPOSITE)								
Composite STC Rating			29% Brick Façade w/ Metal Studs + 71% Glazing	Athletic Fields	35	36	YES	
Wall 3	A42A	Partition Type A (A42A)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB			56		
Window 1	W9	Assume STC-35	Window			35		35 OITC is suitable vs noise up to 61 dB
Window 2	W6	Assume STC-35	Window			35		36 OITC is suitable vs noise up to 61 dB
WALL D								
Wall 4	A42A	Partition Type A (A42A)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	2nd Grade (Rm 202)	50	56	YES	
WALL E								
Wall 5	A42A	Partition Type A (A42A)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Dean's Office	45	56	YES	
CEILING/FLOORING ASSEMBLY								
Ceiling	N/A	N/A	Acoustical Tile, Composite Deck, Carpet	Classroom	50	53	YES	**Assume 6" Conc Flooring http://www.kineticsnoise.com/arch/tests/concrete_below_deck.html
Flooring	N/A	N/A	Carpet, Composite Deck, Acoustical Tile	Classroom, Coaches Rm, Toilet Rm	53	53	YES	**Assume 6" Conc Flooring http://www.kineticsnoise.com/arch/tests/concrete_below_deck.html

Table 7.2d: Room 319 acoustical analysis summary table

Room:	319 (Music)							
Location:	Phase 1, Floor 3							
Partition	Wall/Material Type (Actual)	Wall Type Assumption	Description	Adjacent Rooms	Recommended STC	Actual STC	Meets RQMT?	Notes/Assumptions
WALL A								
Wall 1	A30G	Partition Type A (Assume A30F)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Hallway/ Closet	45	51	YES	*A30G not shown on drawings, assume A30F
WALL B								
Wall 2	S32	Partition Type S: 2-HR Shaft Wall	3/4" GWB on Interior Side, "CH Type Studs - Metal Studs 24" OC, 1" GWB on Shaft Side	Elevator to classroom	60	38	NO	
Wall 3	S32	Partition Type S: 2-HR Shaft Wall	3/4" GWB on Interior Side, "CH Type Studs - Metal Studs 24" OC, 1" GWB on Shaft Side	Elevator to classroom	60	38	NO	
WALL C								
Wall 4	A30G	Partition Type A (Assume A30F)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Hallway	45	51	YES	*A30G not shown on drawings, assume A30F
WALL D								
Wall 5	A30G	Partition Type A (Assume A30F)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Resource Rm (317)	45	51	YES	*A30G not shown on drawings, assume A30F
WALL E (COMPOSITE)								
Window 1	W6	Assume STC-35	Window	Exterior over Gym Roof	35	35	YES	
CEILING/FLOORING ASSEMBLY								
Ceiling	Tile	Roof	Acoustical Tile, Composite Deck, Roof	Roof	35	53	YES	
Flooring	PT-2	PT-2 Whole Floor	Carpet, Composite Deck, Acoustical Tile	2nd Grade Classroom	60	53	NO	

Table 7.2e: Room 1017 acoustical analysis summary table

Room:	1017 (Prekindergarten Classroom)							
Location:	Phase 2, Floor 1							
Partition	Wall/Material Type (Actual)	Wall Type Assumption	Description	Adjacent Rooms	Recommended STC	Actual STC	Meets RQMT?	Notes/Assumptions
WALL A (COMPOSITE)								
Composite Wall 1 (Interior)			96% wall 2, 4% window 3	Hallway	45	46	YES	
Wall 1	F30	Partition Type F (STC not Provided)	Exterior Encolosure, Metal Studs 24" OC - " thick, 5/8" GWB	Hallway		49		F30E STC not provided in Drawings, assume 5/8 Gyp, 3.5" met. stud 24' OC, 1.5" fiberglass, 5/8 Gyp
Window 3	W20	Assume STC-35	Window	Hallway		35		Part of composite interior wall
WALL B								
Wall 2	H41F	Partition Type F (STC not Provided)	Exterior Encolosure, Metal Studs 24" OC - " thick, 5/8" GWB	Hallway	45	45	YES	F30E STC not provided in Drawings, assume 5/8 Gyp, 3.5" met. stud 24' OC, 1.5" fiberglass, 5/8 Gyp
WALL C (COMPOSITE)								
Composite Wall 3 (Exterior Wall)			Approx 50% Wall 3, 50% Windows	Athletic Fields	40	36	NO	
Wall 3	G40F	Partition Type G (STC not Provided)	Exterior Enclosure, Metal Studs 24" OC - " thick, 5/8" GWB	Athletic Fields		44		G40F STC not provided in Drawings
Window 1	W1	Assume STC-35	Window	Athletic Fields		35		Part of composite exterior wall
Window 2	W4	Assume STC-35	Window	Athletic Fields		35		Part of composite exterior wall
WALL D								
Wall 4	F30	Partition Type F (STC not Provided)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Pre-K Rm (Rm 1011)	50	45	NO	F30E STC not provided in Drawings, assume 5/8 Gyp, 3.5" met. stud 24' OC, 1.5" fiberglass, 5/8 Gyp
WALL E								
Wall 5	A40F	Partition Type A (A40F)	5/8" GWB, Sound Attenuation Batts between Metal Studs 24" OC - " thick, 5/8" GWB	Personal Toilet Rm	53	49	NO	
CEILING/FLOORING ASSEMBLY								
Ceiling	N/A	Roof	Green Roof	Green Roof	N/A	N/A	N/A	Nothing above First Floor
Flooring	N/A	SOG	Ground	Ground	N/A	N/A	N/A	Nothing below Flooring, just ground

Table 7.3: Room 108 composite wall calculations using transmission loss data for each partition

Partition	Assumption	Area	% of wall	125	160	200	250	300	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	STC
F30 Wall TL	2 x 4 studs, 3/4" sheathing, 5/8" GB, 4" brick veneer, 3" FG	133	25%	32	33	39	44	45	48	51	55	57	58	58	57	55	45	46	53	49
Brick Exteiror Wall τ		-	-	0.000631	0.0005	0.00013	4E-05	3.2E-05	1.6E-05	7.9E-06	3.2E-06	2E-06	1.6E-06	1.6E-06	2E-06	3.2E-06	3.2E-05	2.5E-05	5E-06	-
Window TL	Laminated glass - two 1/8" glass with 0.03" interlayer	400	75%	26	27	27	28	29	30	32	34	35	36	36	36	35	35	39	43	35
Window τ		-	-	0.002512	0.002	0.002	0.00158	0.00126	0.001	0.00063	0.0004	0.00032	0.00025	0.00025	0.00025	0.00032	0.00032	0.00013	5E-05	-
Composite TL		533	100%	27	28	28	29	30	31	33	35	36	37	37	37	36	36	40	44	***36***

Sound Transmission Class (STC) Calculator

STC 36

1/3 Octave-Band Frequency (Hz)	Contour Level (dB)	TL (dB)	Deficiency (dB)	Max Deficiency ≤ 8 dB?
125	20	27	0	OK
160	23	28	0	OK
200	26	28	0	OK
250	29	29	0.0	OK
315	32	30	1.8	OK
400	35	31	3.8	OK
500	36	33	2.8	OK
630	37	35	1.8	OK
800	38	36	1.8	OK
1000	39	37	1.8	OK
1250	40	37	2.8	OK
1600	40	37	2.8	OK
2000	40	36	3.8	OK
2500	40	36	3.9	OK
3150	40	40	0.0	OK
4000	40	44	0	OK
		TOTAL	27	0

Wall is STC: 36

Figure 7.6a: Room 108 STC calculator

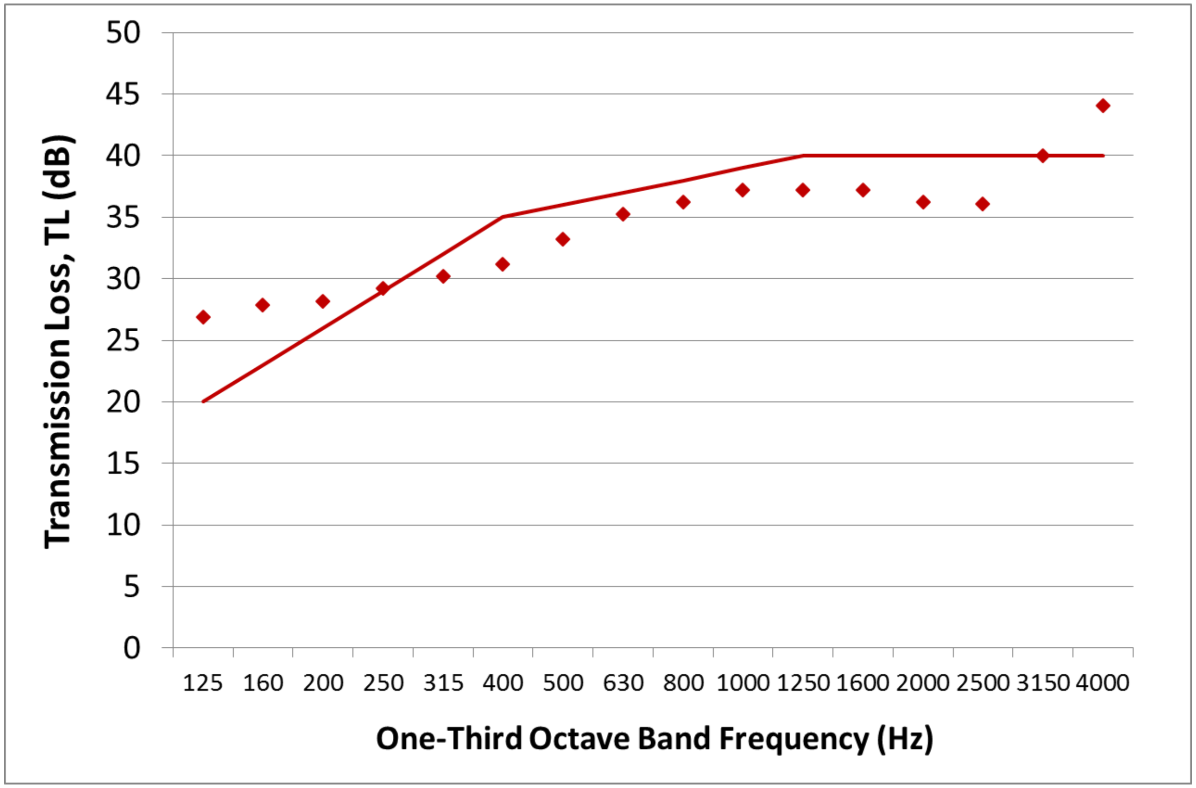

Figure 7.6b: Room 108 STC graphical representation from *Figure 7.6a*

Table 7.4: Room 205 composite wall calculations using transmission loss data for each partition

Partition	Assumption	Area	% of wall	125	160	200	250	300	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	STC
Brick Exterior Wall TL	2 x 4 studs, 3/4" sheathing, 5/8" GB, 4" brick veneer, 3" FG	105	29%	33	34	41	41	47	50	52	55	59	61	65	66	68	68	69	72	56
Brick Exteiror Wall τ		-	-	0.000501	0.0004	7.9E-05	7.9E-05	2E-05	0.00001	6.3E-06	3.2E-06	1.3E-06	7.9E-07	3.2E-07	2.5E-07	1.6E-07	1.6E-07	1.3E-07	6.3E-08	-
Window	Laminated glass - two 1/8" glass with 0.03" interlayer	255	71%	26	27	27	28	29	30	32	34	35	36	36	36	35	35	39	43	35
Window τ		-	-	0.002512	0.002	0.002	0.00158	0.00126	0.001	0.00063	0.0004	0.00032	0.00025	0.00025	0.00025	0.00032	0.00032	0.00013	5E-05	-
Composite TL		360	100%	27	28	28	29	30	31	33	35	36	37	37	37	36	36	40	44	***36***

Sound Transmission Class (STC) Calculator

STC	36

1/3 Octave-Band Frequency (Hz)	Contour Level (dB)	TL (dB)	Deficiency (dB)	Max Deficiency ≤ 8 dB?
125	20	27	0	OK
160	23	28	0	OK
200	26	28	0	OK
250	29	29	0.0	OK
315	32	30	1.5	OK
400	35	31	3.5	OK
500	36	33	2.5	OK
630	37	35	1.5	OK
800	38	36	1.5	OK
1000	39	37	1.5	OK
1250	40	37	2.5	OK
1600	40	37	2.5	OK
2000	40	36	3.5	OK
2500	40	36	3.5	OK
3150	40	40	0.0	OK
4000	40	44	0	OK
		TOTAL	24	0

Wall is STC: 36

Figure 7.7a: Room 205 STC calculator

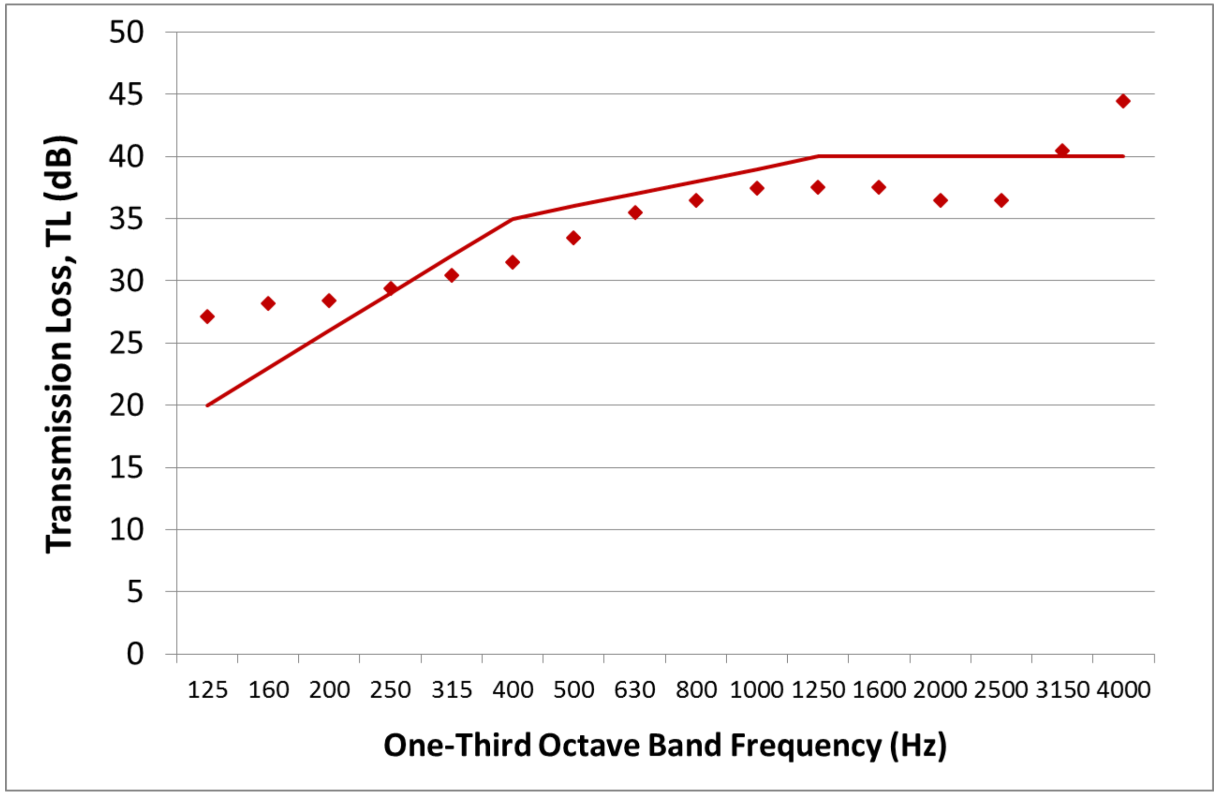

Figure 7.7b: Room 205 STC graphical representation from *Figure 7.7a*

Table 7.5: Room 215 **exterior** composite wall calculations using transmission loss data for each partition

Partition	Assumption	Area	% of wall	125	160	200	250	300	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	STC
Brick Exterior Wall TL	2 x 4 studs, 3/4" sheathing, 5/8" GB, 4" brick veneer, 3" FG	171	32%	33	34	41	41	47	50	52	55	59	61	65	66	68	68	69	72	56
Brick Exteiror Wall τ		-	-	0.000501	0.0004	7.9E-05	7.9E-05	2E-05	0.00001	6.3E-06	3.2E-06	1.3E-06	7.9E-07	3.2E-07	2.5E-07	1.6E-07	1.6E-07	1.3E-07	6.3E-08	-
Window	Laminated glass - two 1/8" glass with 0.03" interlayer	371	68%	26	27	27	28	29	30	32	34	35	36	36	36	35	35	39	43	35
Window τ		-	-	0.002512	0.002	0.002	0.00158	0.00126	0.001	0.00063	0.0004	0.00032	0.00025	0.00025	0.00025	0.00032	0.00032	0.00013	5E-05	-
Composite TL		542	100%	27	28	29	30	31	32	34	36	37	38	38	38	37	37	41	45	***36***

Sound Transmission Class (STC) Calculator

STC	36

1/3 Octave-Band Frequency (Hz)	Contour Level (dB)	TL (dB)	Deficiency (dB)	Max Deficiency ≤ 8 dB?
125	20	27	0	OK
160	23	28	0	OK
200	26	29	0	OK
250	29	30	0.0	OK
315	32	31	1.4	OK
400	35	32	3.4	OK
500	36	34	2.4	OK
630	37	36	1.4	OK
800	38	37	1.4	OK
1000	39	38	1.4	OK
1250	40	38	2.4	OK
1600	40	38	2.4	OK
2000	40	37	3.4	OK
2500	40	37	3.4	OK
3150	40	41	0.0	OK
4000	40	45	0	OK
		TOTAL	23	0

Wall is STC: 36

Figure 7.8a: Room 215 **exterior** STC Calculator

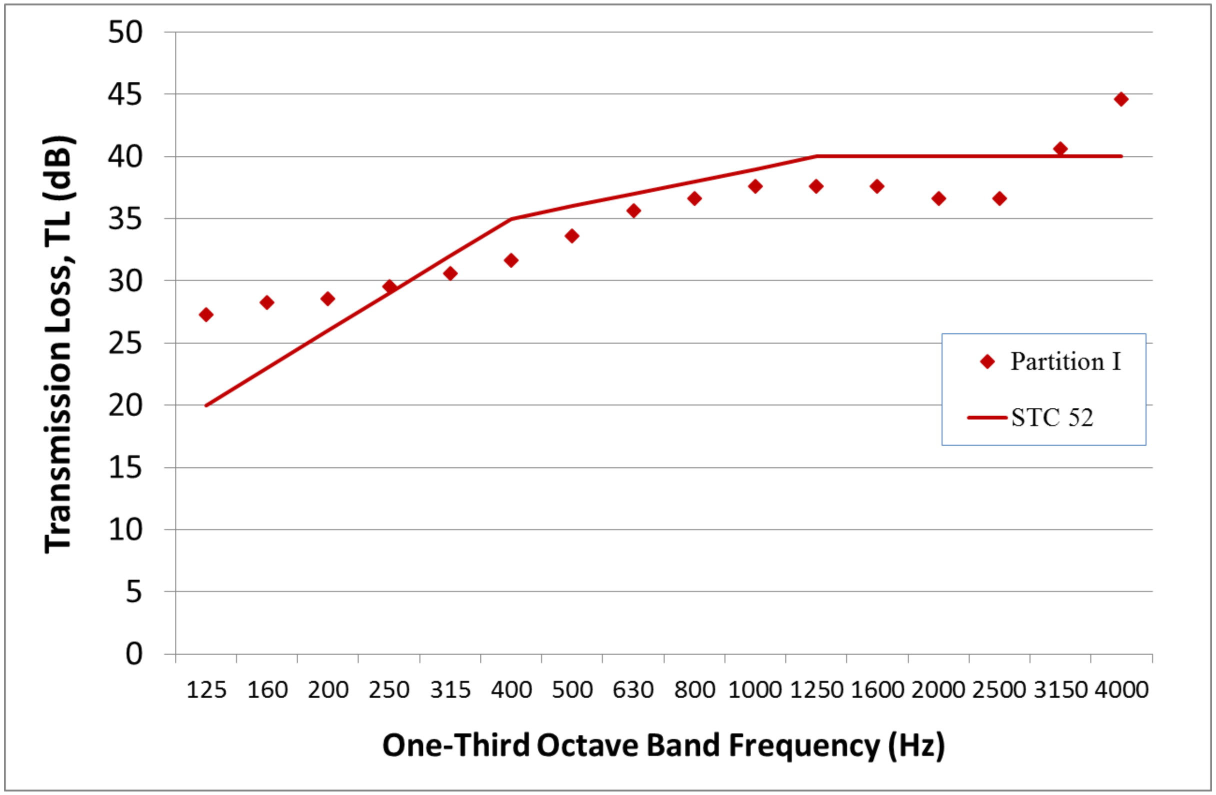

Figure 7.8b: Room 215 **exterior** STC graphical representation from *Figure 7.8a*

Table 7.6: Room 215 **interior** composite wall calculations using transmission loss data for each partition

Partition	Assumption	Area	% of wall	125	160	200	250	300	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	STC
A40F TL	2 x 4 studs, 3/4" sheathing, 5/8" GB, 4" brick veneer, 3" FG	314	61%	32	33	39	44	45	48	51	55	57	58	58	57	55	45	46	53	49
A40F τ		-	-	0.000631	0.0005	0.00013	4E-05	3.2E-05	1.6E-05	7.9E-06	3.2E-06	2E-06	1.6E-06	1.6E-06	2E-06	3.2E-06	3.2E-05	2.5E-05	5E-06	-
Window TL	Laminated glass - two 1/8" glass with 0.03" interlayer	202	39%	26	27	27	28	29	30	32	34	35	36	36	36	35	35	39	43	35
Window τ		-	-	0.002512	0.002	0.002	0.00158	0.00126	0.001	0.00063	0.0004	0.00032	0.00025	0.00025	0.00025	0.00032	0.00032	0.00013	5E-05	-
Composite TL		515	100%	29	30	31	32	33	34	36	38	39	40	40	40	39	38	42	46	*39*

Sound Transmission Class (STC) Calculator

STC	39

1/3 Octave-Band Frequency (Hz)	Contour Level (dB)	TL (dB)	Deficiency (dB)	Max Deficiency ≤ 8 dB?
125	23	29	0	OK
160	26	30	0	OK
200	29	31	0	OK
250	32	32	0.1	OK
315	35	33	2.1	OK
400	38	34	4.0	OK
500	39	36	3.0	OK
630	40	38	2.0	OK
800	41	39	2.0	OK
1000	42	40	2.0	OK
1250	43	40	3.0	OK
1600	43	40	3.0	OK
2000	43	39	4.0	OK
2500	43	38	4.6	OK
3150	43	42	1.1	OK
4000	43	46	0	OK
		TOTAL	31	0

Wall is STC: 39

Figure7.9a: Room 215 **interior** STC calculator

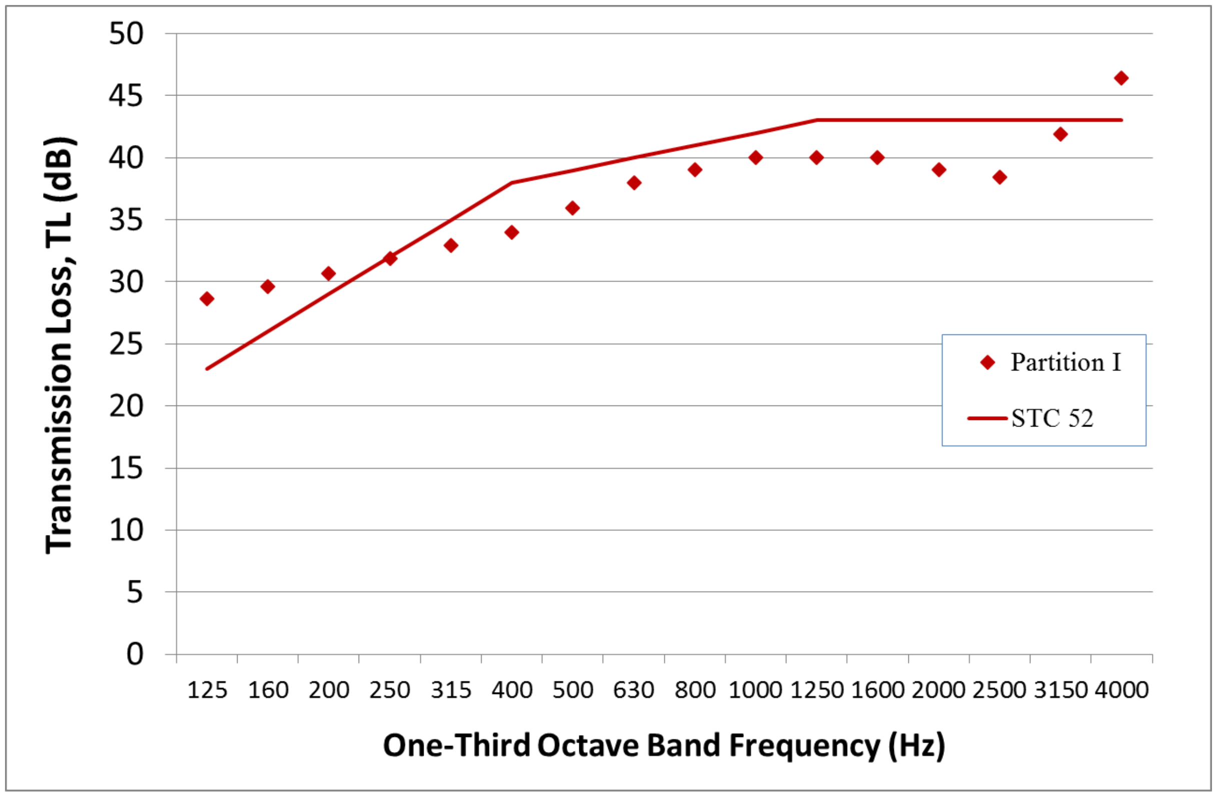

Figure 7.9b: Room 215 **interior** STC graphical representation from *Figure 7.9a*

Table 7.7: Room 1017 **exterior** composite wall calculations using transmission loss data for each partition

Partition	Assumption	Area	% of wall	125	160	200	250	300	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	STC
G40F Wall Type TL	24 g studs, 5/8" GB, 3-5/8" studs 24" studs 24" oc and 2" FG	171	32%	29	31	39	41	43	49	51	53	55	56	57	55	43	41	46	48	45
Brick Exteiror Wall τ		-	-	0.001259	0.00079	0.00013	7.9E-05	5E-05	1.3E-05	7.9E-06	5E-06	3.2E-06	2.5E-06	2E-06	3.2E-06	5E-05	7.9E-05	2.5E-05	1.6E-05	-
Window	Laminated glass - two 1/8" glass with 0.03" interlayer	371	68%	26	27	27	28	29	30	32	34	35	36	36	36	35	35	39	43	35
Window τ		-	-	0.002512	0.002	0.002	0.00158	0.00126	0.001	0.00063	0.0004	0.00032	0.00025	0.00025	0.00025	0.00032	0.00032	0.00013	5E-05	-
Composite TL		542	100%	27	28	29	30	31	32	34	36	37	38	38	38	36	36	40	44	***36***

Sound Transmission Class (STC) Calculator

STC	36

1/3 Octave-Band Frequency (Hz)	Contour Level (dB)	TL (dB)	Deficiency (dB)	Max Deficiency ≤ 8 dB?
125	20	27	0	OK
160	23	28	0	OK
200	26	29	0	OK
250	29	30	0.0	OK
315	32	31	1.4	OK
400	35	32	3.4	OK
500	36	34	2.4	OK
630	37	36	1.4	OK
800	38	37	1.4	OK
1000	39	38	1.4	OK
1250	40	38	2.4	OK
1600	40	38	2.4	OK
2000	40	36	3.7	OK
2500	40	36	3.8	OK
3150	40	40	0.0	OK
4000	40	44	0	OK
		TOTAL	24	0

Wall is STC: 36

Figure7.10a: Room 1017 **exterior** STC calculator

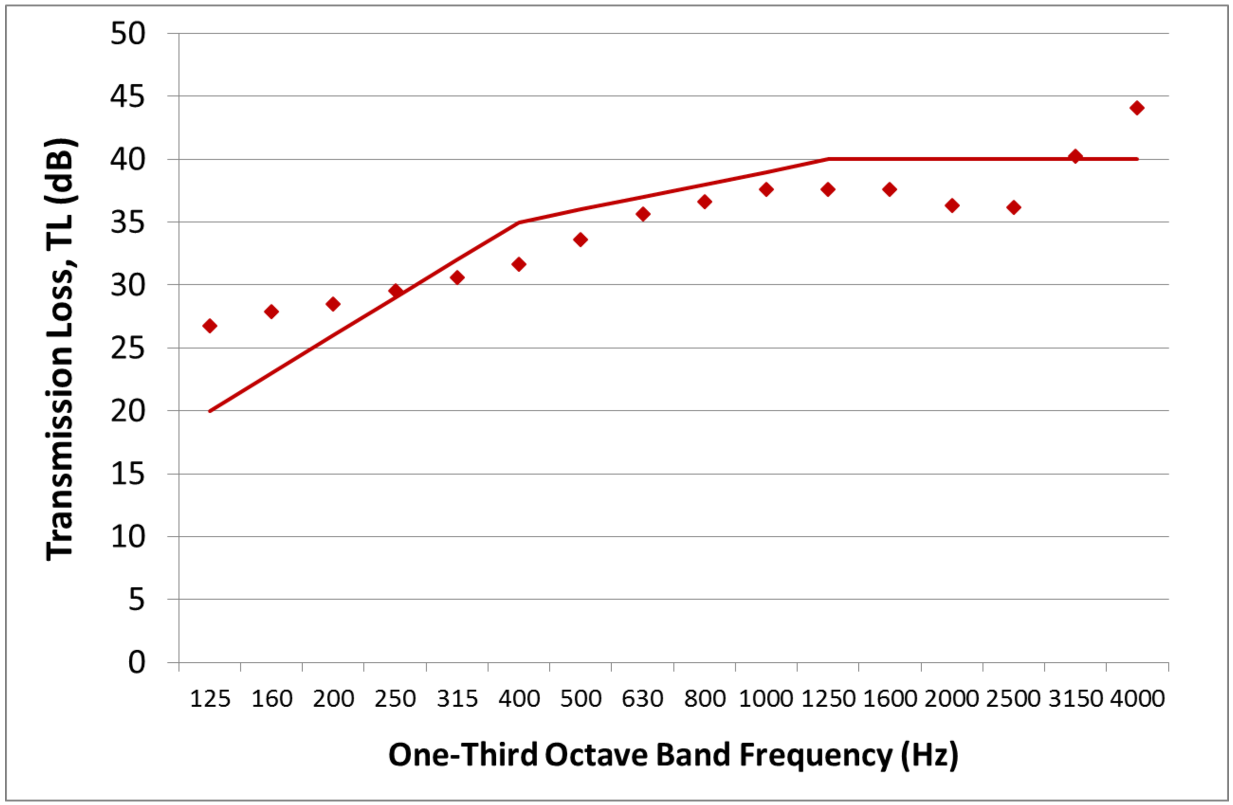

Figure 7.10b: Room 1017 **exterior** STC graphical representation from *Figure 7.10a*

Table 7.8: Room 1017 **interior** composite wall calculations using transmission loss data for each partition

Partition	Assumption	Area	% of wall	125	160	200	250	300	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	STC
F30 TL	2 x 4 studs, 3/4" sheathing, 5/8" GB, 4" brick veneer, 3" FG	258	96%	32	33	39	44	45	48	51	55	57	58	58	57	55	45	46	53	49
A40F τ		-	-	0.000631	0.0005	0.00013	4E-05	3.2E-05	1.6E-05	7.9E-06	3.2E-06	2E-06	1.6E-06	1.6E-06	2E-06	3.2E-06	3.2E-05	2.5E-05	5E-06	-
Window TL	Laminated glass - two 1/8" glass with 0.03" interlayer	12	4%	26	27	27	28	29	30	32	34	35	36	36	36	35	35	39	43	35
Window τ		-	-	0.002512	0.002	0.002	0.00158	0.00126	0.001	0.00063	0.0004	0.00032	0.00025	0.00025	0.00025	0.00032	0.00032	0.00013	5E-05	-
Composite TL		270	100%	31	32	37	40	41	42	44	47	48	49	49	49	48	44	45	52	***46***

Sound Transmission Class (STC) Calculator

STC 46

1/3 Octave-Band Frequency (Hz)	Contour Level (dB)	TL (dB)	Deficiency (dB)	Max Deficiency ≤ 8 dB?
125	30	31	0	OK
160	33	32	0.5403517	OK
200	36	37	0	OK
250	39	40	0.0	OK
315	42	41	1.4	OK
400	45	42	2.8	OK
500	46	44	1.5	OK
630	47	47	0.2	OK
800	48	48	0.0	OK
1000	49	49	0.0	OK
1250	50	49	1.0	OK
1600	50	49	1.2	OK
2000	50	48	2.3	OK
2500	50	44	6.5	OK
3150	50	45	4.7	OK
4000	50	52	0	OK
		TOTAL	22	0

Wall is STC: 46

Figure7.11a: Room 1017 **interior** STC calculator

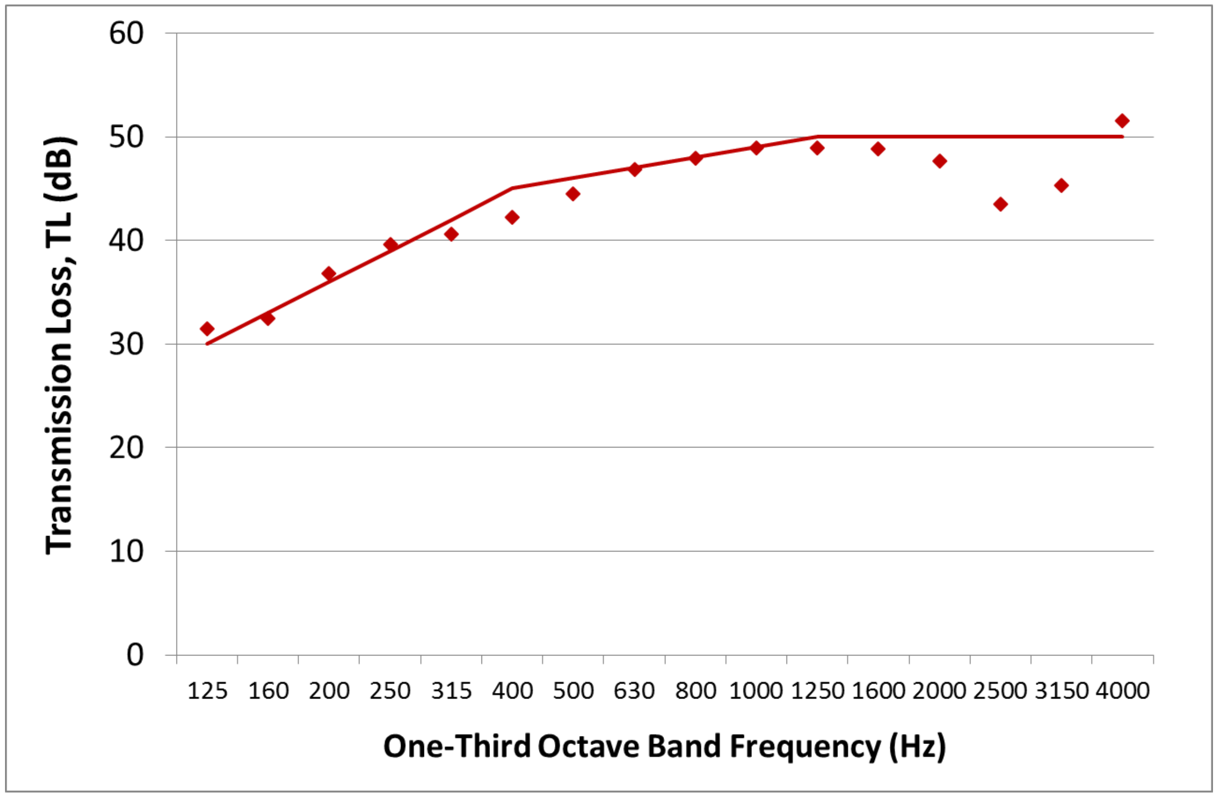

Figure 7.11b: Room 1017 **interior** STC graphical representation from *Figure 7.11a*

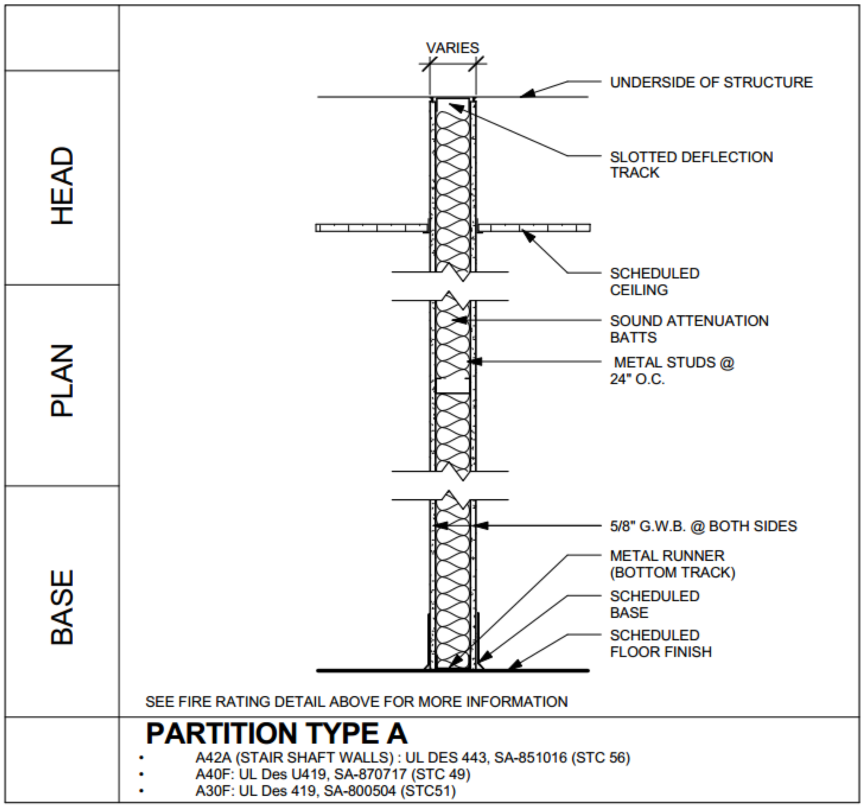

Figure 7.12: Type A partition from phase 1 architectural drawings

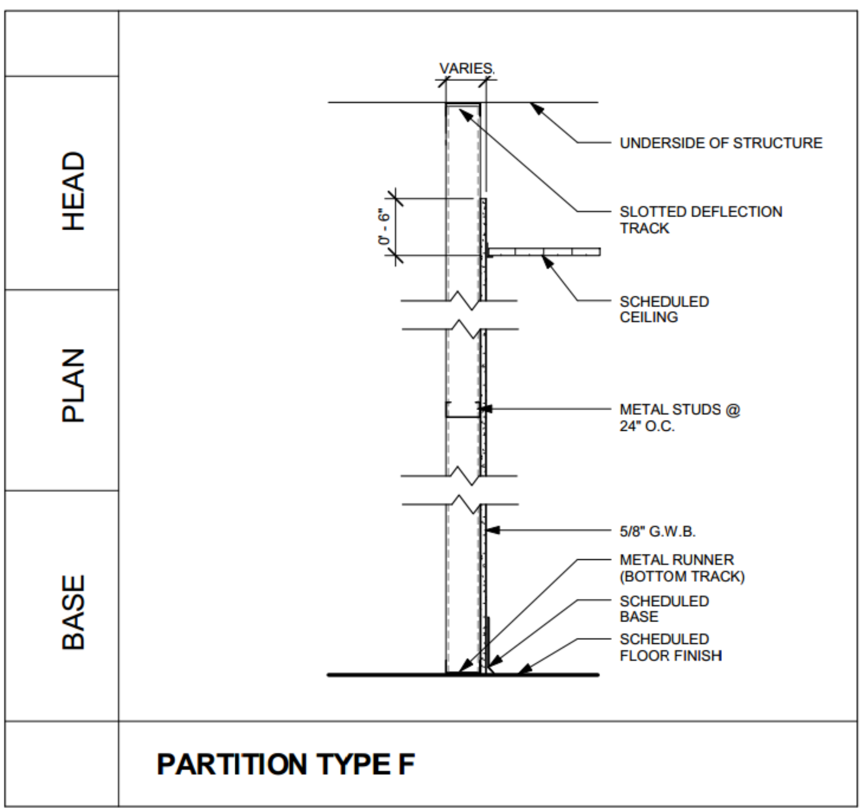

Figure 7.13: Type F partition from phase 1 architectural drawings

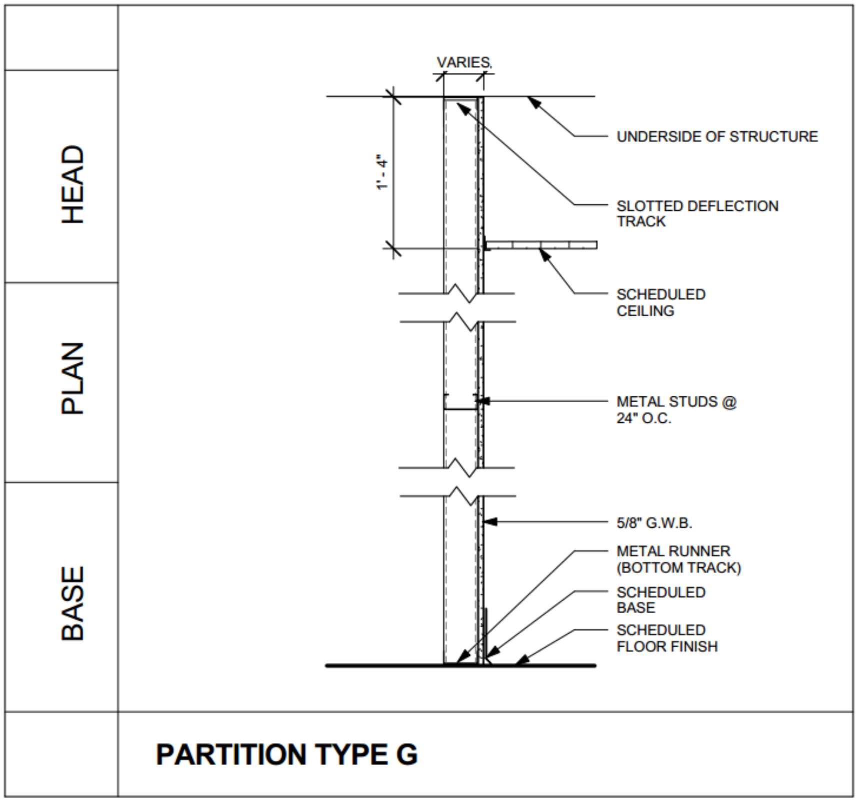

Figure 7.14: Type G partition

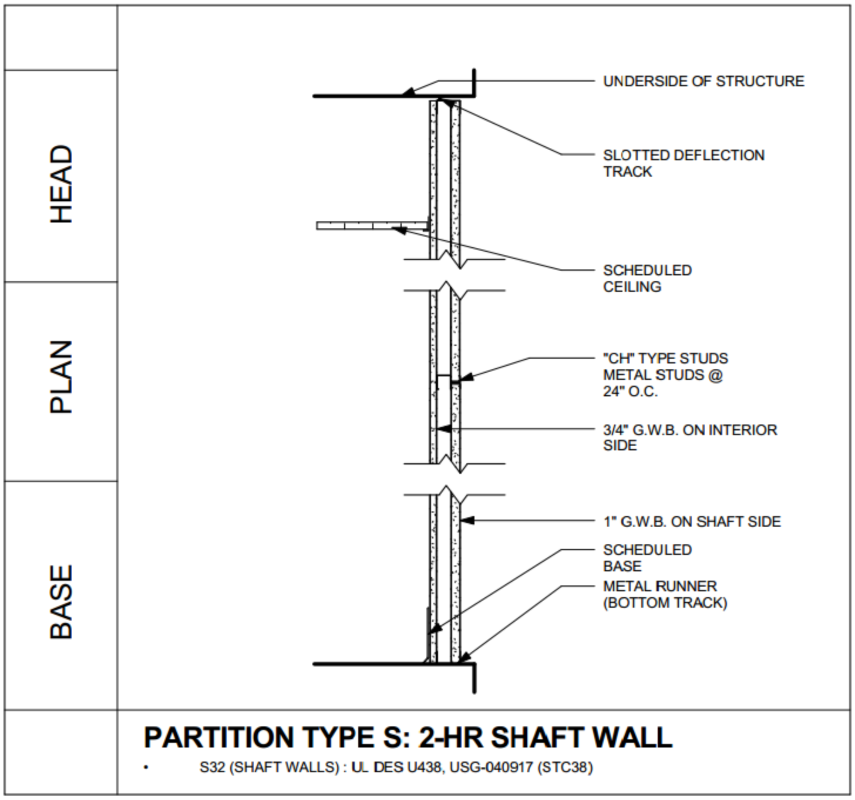

Figure 7.15: Type S partition

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