Central Bed Tower Expansion

University of Virginia | Charlottesville, VA

Technical Assignment 3

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Construction Management

Executive Summary

For Technical Report 3, the UVA Project Manager, Mr. Christopher Hoy, participated in a telephone interview to discuss the progress of HBE and any issues that were encountered over the course of construction. Others topics that were discussed in this interview include the Constructability Challenges that the construction team were faced with, any schedule delays and possible scenarios to accelerate the project schedule, and items that went through the value engineering process. Along with the interview, this report also includes a summary of the PACE Roundtable event that took place on November 9, 2011 at the Penn Stater in State College, PA. The Roundtable was helped in providing insightful ideas for analysis topics of the Hospital Bed Expansion which will be discussed at the end of this report.

As with any hospital renovation project, Interim Life Safety and Infection Controls become serious concerns. Questions are raised as to how these systems/safety measured will be maintained without disruption from construction. Mr. Hoy gave details regarding the measures that were taken to mitigate these risks. By mandating stringent Infection Control requirements, the management team was able to successfully protect the hospital patients and visitors from any outside interference during their stay at the hospital. Other constructability concerns related to structural issues regarding the addition of two new elevators and preparations for the existing hospital to accept new loads and connections. To avoid structural instability, these issues were addressed with column reinforcement and proper steel framing being placed in the future elevator shafts.

Schedule delays have become a serious concern on the Hospital Bed Expansion. The UVA facilities management team planned accordingly by initiating the column reinforcement process before HBE was even sent out for bid. Despite UVA's efforts, the project still struggled with a schedule delay as the designated renovation areas were still occupied eight months after the project start date. If the project management team had known there would have been such a delay with owner occupancy, a bigger push would have been made for priority areas to be vacated so construction could begin.

There are some items on this project that have been included for value engineering purposes. The existing Ballasted Ethylene Propylene Diene Monomer (EPDM) is being replaced with a Thermoplastic Polyolefin (TPO) roof which will add a significant long term cost benefit in the form of easier maintenance and possible contributions to a lower mechanical load. Mr. Hoy expressed that all items considered for value engineering that did not make the final cut to be included in the project had no bearing on operational procedures.

The PACE Roundtable provided insightful ideas for analysis topics on this project. Analysis topics to be researched include an alternative layout of the glass façade to provide more privacy to the patient room occupant and possibly contribute to easing the mechanical and/or electrical loads of the facility. Due to the need of phasing on this project, potential BIM modeling has been emphasized throughout the report to be included as a research topic. Prefabricated acoustical walls are also being researched further to potentially help accelerate the project schedule by creating longer work areas for designated renovation areas.

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Constructability Challenges

Infection Control Risk Assessment (ICRA)

The UVA Health System recognizes that facility patrons are the number one priority, and the hospital administration has dedicated time and funds to ensure the safety of everyone visiting or staying at the hospital. In essence, the construction team has tried to maintain an "unseen" presence throughout the project to ensure the comfort and safety of all hospital occupants.

Because this work is being done to an occupied hospital, it is critical that the safety of patients, visitors, and staff take priority amongst all concerns of the construction management team. The largest risks take shape in the form of Infection Control and Interim Life Safety Systems. In order to reduce the risk of disrupting these systems and/or creating dangerous situations involving dust or heat, the management team used stringent requirements that mandated the use of Directive No. 723A/902A which outlines the health safety requirements for construction in occupied hospital facilities.

Directive No. 723A/902A categorizes activities of construction into Class I and Class II:

Class I address less invasive work such as minor plumbing, electrical, carpentry and duct work, aesthetic improvements and installation of phones, computers, medical gases, TV cable, etc. This class would pertain to the individual renovations of multiple lobby areas outside of the major construction zone. Some of the required procedures for this category include:

a. Water misting of surfaces to control dust while cutting.
b. Seal around doors for projects that produce large quantities of dust.
c. Block off and seal air vents and diffusers
d. Noise and vapor containment shall comply with Occupational Safety Hazard Association (OSHA) regulations
e. Construction waste shall be contained in sealed plastic bags
f. We mop and/or vacuum with HEPA filtered vacuum before leaving the work area
g. Place dust mat at entrance and exit of work area
h. Remove blockage and seal from air vents and diffusers.

Class II addresses major construction that will require barrier precautions and include asbestos removal, demolition of walls and ceilings, removal of windows, doors, casework, tiles, construction of wall, ceiling, new rooms, major utility changes, major equipment installation, etc. This class pertains to all construction areas within the hospital, which are Steel Strengthening, HBE expansion, and Lobby Renovations. Some of the required procedures for this category include:

a. All temporary construction barriers shall be completed of noncombustible materials before construction begins

b. Hospital Epidemiology may inspect the work site before construction beings.
c. All air vents shall be blocked off and sealed to prevent contamination of duct system before construction begins
d. Dust mats shall be used at entrances to the work area
e. All holes, pipes, conduits, punctures and exposures shall be sealed appropriately
f. Wet mop area with disinfectant
g. Work area shall be vacuumed with a HEP filtered vacuum
h. Construction waste shall be bagged or transported in covered carts

In addition to this directive, routine and random inspections will be required throughout the project to ensure compliance of all necessary procedures. Hospital Epidemiology may also visit the work site to ensure compliance with this directive and reserves the right to add requirements to a project on an individual basis.

The temporary construction walls have been denoted by the construction team as ICRA walls. These walls have strict requirements on how they are installed so as to reduce noise and dust penetration. The ICRA walls are also built as a 1-hour fire rated barrier to provide occupants on either side adequate time to evacuate the building.

Because these ICRA walls are temporary, much effort was taken by the construction management team to blend the walls with the existing facility to create the illusion of purposeful placement to direct hospital traffic. This also became a constructability concern for the management team.

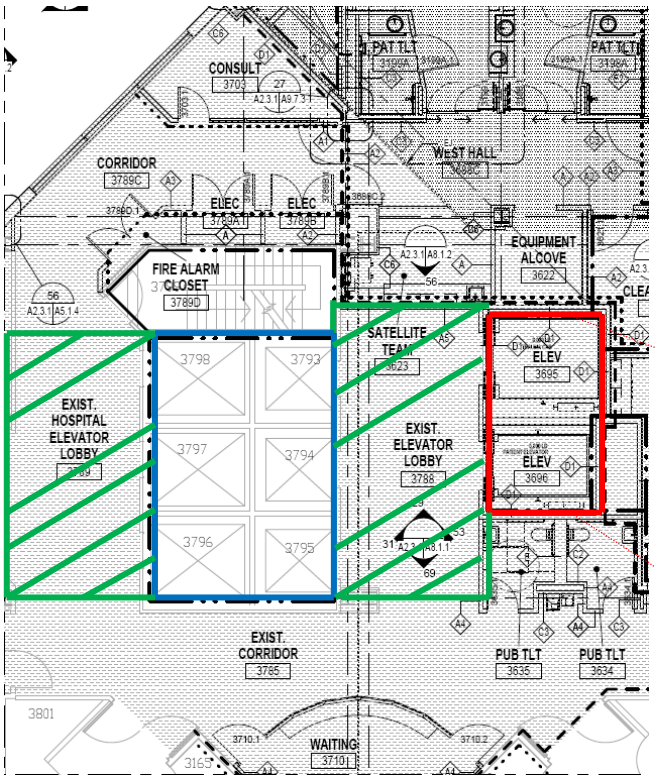
Additional Elevators, Traffic Flow, and Communication

As mentioned above, the temporary walls became an integral part of the hospital by serving as information centers for the hospital. Construction updates were posted on the walls to benefit the hospital patrons with information about the renovations and additions. The walls also aided in the realm of marketing; by promoting future events and activities at the hospital, the hospital patrons were able to be more easily informed about upcoming events. Maintaining control between patrons and construction workers also became a main issue with the addition of two new elevators that face an existing elevator bank.

The two visitor elevators extend through the heart of the facility from the basement to penthouse level. As seen in Figure 1, these additional elevators are located directly across from an existing elevator bank which must remain active at all times. Due to the proximity of the new elevators, several challenges arose during construction that forced new thought processes for the method of demolition, construction, and installation of the new elevators.

Because 10’x20’ sections of concrete were being cut out of each floor, concerns arose in reference to maintaining the structural stability of each floor and the means of demolishing the concrete floor. As seen in Figure 2, the structural stability issue was mitigated with permanent steel framing placed around each future elevator shaft on each floor which improved the structural stability by creating a

more rigid frame. Because the elevator shaft framing needed to coincide with the steel erection, temporary construction walls were required to be built around the construction areas on every floor prior to the work commencing. After steel framing was in place for the shafts, the floor slab could then be penetrated. The hole was cut out in small pieces as to elude any hassle in removing the materials from the building, and to avoid any massive pieces falling to the floor below



Red – New Elevators

Blue – Existing 6 Elevator Bank

Green – Circulation Area

Figure 1 shows the additional elevators and circulation area between new and existing elevator banks.

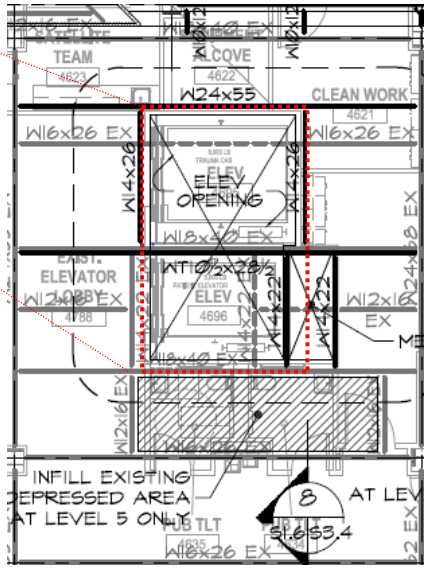


Figure 2 shows the new elevator framing.

Preparation of Existing Structure

A major concern for the management team was preparing the existing structure to accept a new load. In lieu of the future load, the existing structure needed to be reinforced to maintain structural soundness. In order to maintain the hospital's structural stability, fifty-eight (58) columns need to be reinforced with additional steel plates and angles. Before HBE was even sent out for bid, the UVA facilities management team planned accordingly by hiring a subcontractor to begin the reinforcing process on around twelve (12) of the fifty-eight (58) columns; the column reinforcing continues before structural steel can be erected for the new expansion.

Along with the column reinforcing, issues arose with the connection details of connecting the new steel into the existing hospital. After construction began, an unforeseen condition was discovered concerning the existing floor elevations. The existing floors were found to be uneven and the concrete topping ranged as much as a couple of inches in some spots. This problem added a

significant cost of a half million dollars as a separate subcontractor was hired out to fix every floor level in the existing hospital. Every floor was chipped down to a reasonable level, and then a topping coat was poured to level out each floor slab.

The Hospital Bed Expansion is being built atop of the existing Hospital lobby, Heart Center, Short Stay Unit, and Discharge Center which forces some of the occupants to temporarily relocate during the construction (See Figure 3). The Discharge Center was temporarily relocated due the expected construction traffic that will be traveling through the area with materials. Not only was occupant relocation an issue was done, but it was also vital to coordinate the new building footprint with the renovation footprint so they would coincide with construction.

Figure 3 shows the existing lobby and discharge center which will serve as the new building footprint

Schedule Acceleration Scenarios

Owner Move Out

The Hospital Bed Expansion has undertaken an additional 60,000 square foot renovation of the adjacent structure. As this is an occupied structure, the owner must temporarily move out of the designated spaces before construction can even begin. Although this is not construction related, if the owner does not move out by the agreed time period then the schedule will be affected by severe delays.

The owner was, in fact, eight (8) months late in moving out of the designated areas. This has severely affected the construction schedule, where the project was originally set for a November 2011 final completion date, the final completion date has now been pushed back to April 2012. If the time frame of this delay had been known, the project management team could have prioritized

the areas needed to maintain a prompt schedule. Looking back on this phase of the project, the management team would have encouraged the owner to move out of the 8th floor first so preparations could be made for the new penthouse that was to be built on top of the new expansion/renovation.

Although the owner recognized their contribution to the schedule delay, there was still disappointment when the schedule slipped into 2012. Even though the schedule slipped, the hospital still needed certain spaces by specific dates which then changed the delivery plan for the construction team. Because of certain spaces were needed, phased delivery was implemented, where originally the entire project was to be turned over all at once.

This has the potential to utilize BIM modeling on the project to create phases and visualizations for the benefit of Owner, staff, and the construction management team.

Column Reinforcing

Because the structural steel could not begin until the column reinforcing had a significant portion done, it became crucial for the project management team to push in getting this done. As mentioned in the Constructability Challenges section, fifty-eight (58) columns needed reinforcing to ensure a structurally stable building. If these columns were not completely reinforced by the dedicated date, then there was the potential of extending the project schedule more than it had already been delayed. The UVA management team lessoned the stress of finishing the steel reinforcement on time by planning ahead. A contractor was to begin the steel strengthening process before HBE was even sent out for bid. Around twelve (12) columns were reinforced before the Hospital Bed Expansion went underway. It is unclear if the original contractor remained on site to finish the remaining column reinforcement.

Schedule Risks

As mentioned earlier, the owner recognized the impact they have had on the schedule delay throughout the process. This combined with the unforeseen condition of uneven floor slabs, column reinforcement, and the natural schedule issues that accompany a hospital renovation, provides much room for improvement concerning the project completion date. However, there may also be potential for improvement on the project management side.

Throughout the project, several team members have come and go. This causes a potential delay as staff must take time to bring the new team members up to speed on the project. There is also a question if the project was staffed well enough with the proper number of team members with the proper qualifications. For a $55 million expansion/renovation project, a six member team hardly sounds as though it could effectively bring the job to completion within the given time frame. Perhaps a designated safety manager could be added to the project team which would create a beneficial relief for the current team members.

The Regulating Agency of Healthcare Facilities performs regular and random facility inspections. A major component of this inspection is that of the Interim Life Safety System and Infection Control. If the strict procedures set forth by the hospital, by Directive No. 723A/902A , are not being upheld, then the inspection agency could fail to pass the project which would result in potential loss of 65% of project funding. Therefore, it is absolutely critical that these safety measures be upheld and enforced; it would be advantageous for the project team and owner to add a safety manager to accompany the project so as to ensure proper safety measures. The safety manager could then also monitor the other safety hazards prevalent on the jobsite, such as the steel erection over an occupied facility, pedestrian traffic patterns, and tight project site.

Techniques

In lieu of the significant time delay due to a late owner move out, it may be valuable to consider implementing BIM models to use for phasing throughout the project. A proper phasing model linked to a schedule will aid the hospital occupants and construction team in visualizing the timeline for construction along with the consequences of any delays that may be incurred. Along with the phasing model, an existing conditions model should be created to avoid unforeseen conditions such as was experienced with the floor slabs.

It may be advantageous to also look into an alternate staffing plan that adds resources to the construction team. With only one project engineer and one general superintendent on the project team, it is unfair to expect the growing mountain of paperwork to always be maintained. I would recommend adding an Office Engineer, at least one other Area Superintendent, and a Safety Coordinator to manage site hazards and maintain a daily routine of project inspections.

Due to the flexibility of working offsite during other trade construction, prefabricated systems have gained popularity amongst construction management. Whether it is modular rooms, walls, or ductwork, prefabrication can turn a construction project into a simple puzzle where the onsite construction workers simply need to place the pieces. Because this building is constructed out of a complex steel frame, prefabricating individual rooms would be impractical. However, it would be plausible to prefabricate a corridor of ductwork, electrical conduit, and telecommunications for each floor. If these systems could be pieced together offsite, coordination and schedule could be accelerated by reducing the time each trade needs to be on each floor.

Value Engineering Topics

Because a large portion of this project is funded by the government, the Formal State mandated the Value Engineering (VE) process at the Design Development stage. During Design Development, a list of possible VE items from each trade package was compiled for the owner to choose from. Other than the two elevators which were added, the Project Manager did not specify which items were considered or implemented for Value Engineering; however he did note that none of the VE items had any bearing on the building operations. Because of the complications accompanying the installation of two new elevators, it was considered by the owner to forego the addition, but the

long term benefit of the additional two elevators outweighed the complications and inconvenience of construction.

Some areas can still be highlighted as VE items despite not being highlighted by the Project Manager. Included in the HBE package was a roof replacement of the high and low roofs. The 8th floor was topped with an existing Ballasted Ethylene Propylene Diene Monomer (Ballasted EPDM) roof (See Figure 4) and is being replaced with a Thermoplastic Polyolefin (TPO) roof (See Figure 5). The Ballasted EPDM roof is not favored by facilities management because of the maintenance issues that accompanies it. While the existing roof was being replaced, several leaks were found underneath the stones that would otherwise not have been found without removing the entire ballasted system. With this system, roof leaks tend to never be fixed as it is difficult to find the true source of the leak under the stones. When the roof does need to be repaired, it is time consuming and laborious to strip stone before finding the area which needs repair. A TPO roof is much more popular amongst the facilities management as it is much easier to maintain due to good accessibility of the membrane. The white membrane is also considered to provide a mechanical benefit to the building. Because of the white surface, sun rays will reflect off the membrane, causing the roof to remain cooler which will lessen the necessary mechanical load in the building.

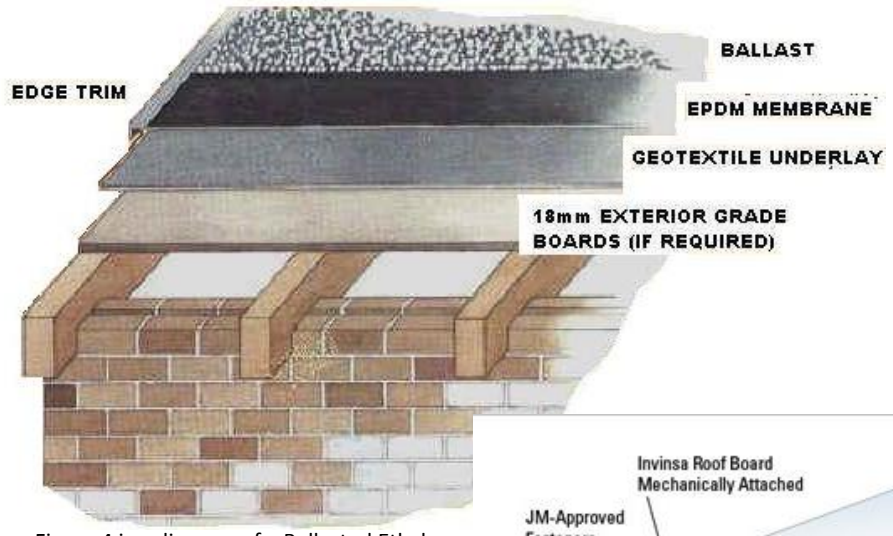


Figure 4 is a diagram of a Ballasted Ethylene Propylene Diene Monomer (EPDM) roof.

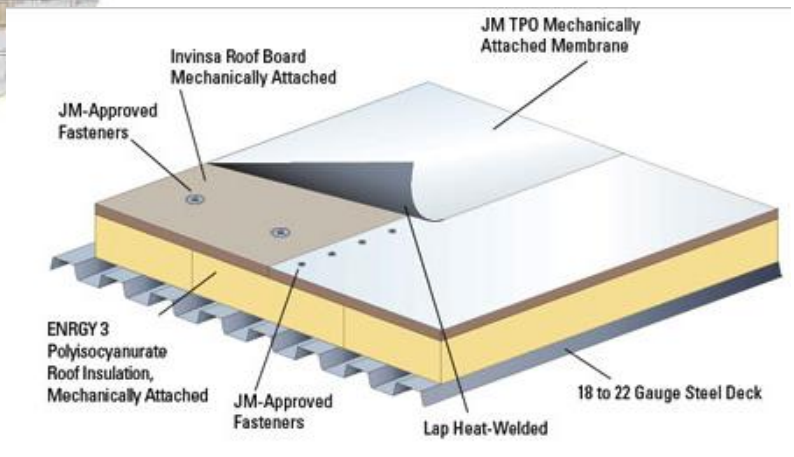


Figure 5 is a diagram of a Thermoplastic Polyolefin (TPO) roof

The existing lobby is also topped with a Ballasted EPDM roof. However, this lower level roof is to be replaced with an intensive green roof. This roof should still be replaced, although an extensive green roof may want to be considered rather than the intensive option, simply because the maintenance of an intensive roof will be much more involved than that of an extensive roof. It would not be recommended to place a TPO roof on this level as it is in the direct line of sight for new patient rooms and the white membrane may be bothersome to the patients.

The glass façade may also be considered for Value Engineering. Because the façade faces North, the glass glare will not be a major issue. This is an aesthetically pleasing alternate that will help to soften the appearance of the old metal wall panels of the original structure. Although it is aesthetically pleasing, a full glass façade might be impractical. Varying window placement could be considered in order to save on direct and indirect costs while giving the end user desired privacy in the patient rooms and still maintaining an attractive exterior. Perhaps different glazing options could be researched to provide a uniform look across the façade.

As mentioned earlier, BIM modeling would be a practical and useful tool in phasing this project. Although there is an upfront cost in order to implement this process, the long term benefits could potentially be astronomical in consideration of saving the project schedule, maintaining a satisfied hospital staff and patron base, and avoiding any serious unforeseen conditions. A 4D phasing model would be developed along with an existing conditions model to best serve the project management team and hospital staff. If a 4D phasing model was developed, a construction kiosk could be placed in the hospital lobby where the construction updates would continuously be monitored by health system patrons.

Critical Industry Issues

Several industry members met at the Penn Stater in State College, PA for the Pace Roundtable on November 9, 2011. While at the roundtable, several industry topics were discussed concerning sustainability, process innovation, technology, and the economy's affect on construction. Tim Jones of Massaro CM Services and Chris Hoy of UVA have served as well informed contacts for the Hospital Bed Expansion and the Penn State Thesis.

Energy Management Services

The first session addressed the new trend of Green Building and how sustainable construction has affected the long term use of buildings. Green Building Construction is now at the point where a long term analysis can be made on LEED certified buildings to determine the effectiveness of sustainable design/construction; and with the analyses will come alterations to building construction to improve the sustainable designs even more to create the most efficient facility possible.

The conclusion was made amongst industry members that the most successful projects/buildings are those where energy goals are dictated to the architect/engineer. It was surprising to hear the

industry members suggest a different direction for user controls to become less 'flexible' as in the end users will have less control over the individual systems. This would make sense though, since everyone's body has a different temperature or climate control, it would be impractical to design for everyone's ideal environment; which then brings the designer to the mindset of unbiased climate control. In other words, the design criteria should be based on reasonable temperature ranges for each season and remember that the end user has control over the clothes worn to work. Individual controls are something that could be considered for the Hospital Bed Expansion. Since each room is a single patient Intensive Care Unit, it will probably be feasible to maintain the flexibility of individual units.

Integrated Decisions for High Performance Retrofit Projects

The second session addressed the effectiveness of a properly fitted team working on a renovation project. This concept could be expanded to new construction as well as renovation projects to improve the quality of the project. Unfortunately, a team is often times thrown together for convenience, but your project team can truly make or break a project. It is important to have a well bonded team who will work together to overcome issues on a site and reach the end goal together. A poorly placed team can end up working with tension amongst each other placing the project at risk of mistakes, time delays, and cost increases.

Every person has their niche. In construction, it is important to group people according to the project they are on and the different niches that each team member possesses so as to improve the quality of the project by bringing multiple expertise and ideas to the table. This is something to mull over with the HBE staffing plan, as the owner expressed concerns of inadequate/insufficient staffing.

Problem Identification and Technical Analysis Options

Analysis Method 1: Acoustical Walls

Seeing as work will be done on an occupied hospital, there are noise restrictions that dictate work schedules for construction. The type or work being done (welding, demolition, painting, etc.) will determine what hours are allowed to be worked in the hospital. This work hour restriction is reasonable for the large renovation seeing as there is much more of a variety of work to do. However, this will limit the efficiency of work for Steel Strengthening and Lobby Renovations. Local regulations also give guidelines for high-level noise operations for occupied buildings.

These regulations could significantly reduce the productivity of construction teams working on certain areas. It might be advantageous to use prefabricated acoustical ICRA walls around the designated work areas inside the hospital. By creating prefabricated ICRA walls, the preparation and demolition of these work areas should be much less laborious and time consuming. Materials would also be saved, as the walls could simply be transported to the next work area to be used thus saving on time, energy, and cost. If these walls prevent sound from being transmitted to either

side, then there is also the potential that air circulation will be prevented as well. It will be important to not only analyze the acoustical benefit of these walls, but the air quality and circulation across these walls will also need to be investigated.

The Project Manager also expressed concern over vibrations stemming from the equipment being used (pneumatic tightening, hammer drilling, concrete demo, etc.) in the renovation areas. In the analysis of acoustical walls, it would worthwhile to also investigate the effect of vibrations throughout the hospital and attempt to mitigate this issue.

Before moving onward with this analysis, the local regulator will need to be contacted to confirm the work restrictions outlined in the project specifications. The local regulator may also be able to provide solutions to the problem associated with noise and vibrations. Upon confirmation of this issue and possible solutions, research will go into the composition of an acoustical and non-acoustical wall, calculations of noise volume and air circulation, vibration control, and cost associated with the walls. A productivity check will then be done to determine if this could be a solution to restricted work schedules.

Analysis Method 2: BIM Modeling

BIM modeling seems to be a common theme throughout this project. Although BIM was not utilized on this project, the technology could have greatly bettered the construction schedule, reduced unforeseen issues, and created less frustrated staff. As mentioned earlier, the owner created a significant time delay due to their failure of moving out of designated spaces eight (8) months past the original timeframe. If this issue would have been foreseen by the project management team, priority would have been given to certain floors, specifically the 8th floor, which would have created a work sequence that could keep the schedule on track. In order to mitigate this issue, a 4D Phasing model could have been developed by the project management team and designer.

By using the 4D Phasing model, a timeline is not only shown for the owner move-out, but phasing is then created for the entire project. Rather than having a straight schedule, phases would be introduced such as:

- Phase 1: Steel Strengthening
- Phase 2: Owner Move-Out/Site-Mobilization
- Phase 3: ICRA Walls and Safety Systems Installed
- Phase 4: Demolition of Renovation Area
- Phase 5: Building Footprint/Shell Construction
- Phase 6: Interior Construction
- Phase 7: Commissioning/Turn-Over

Of course the model would portray the ideal phased schedule, but this can also represent various scenarios of time delays and how the project would be affected allowing the management team to act quickly with alternate sequencing. If BIM modeling is used, the entire project could then be

phased which could help the owner and hospital staff to better understand what exactly is going on in their workplace.

Along with the 4D modeling being used for the owner move-out, a 4D phased model would be beneficial for the staff. The UVA Project Manager has articulated that the hospital staff has been somewhat frustrated with the lack of knowing what exactly is being done in their workplace and when they can expect the hospital to go back to normal. It is important to always remember employees and patrons of the facility you are invading and try to keep them happy because if they are happy, then the owner is happier. With this 4D model could come an information center in the hospital that would feature this model and any updates made to it. This 'kiosk' would be beneficial to all staff and patrons who want to know what is going on.

BIM modeling would also be advantageous when determining existing conditions of the facility. As mentioned earlier, the unforeseen condition of uneven floor slabs was costly in money and time. There is technology being used elsewhere that helps determine the existing conditions of a facility by scanning areas with a floor laser. This potential of this technology is too great not to research for this analysis.

Because the room mock-up has had so many changes made to it, a virtual model might be valuable in determining the layout of the mockup before spending money on an inadequate mockup. Once the virtual model is approved, a mockup can then be made which will then hopefully eliminate many of the changes that were made.

In this analysis, a 4D phasing model would be created to link with the schedule and presented to a few staff members at the hospital to determine if this is an avenue they would prefer to walk down next time major construction is being done to their building. Research will also be done concerning the existing conditions model, and how exactly it works.

Analysis Method 3: Façade Change

An understandable transition has been made from the '90s style of white metal panels to the new popular style of glass walls. With more window space on 100% glass panel façade, the patients can enjoy the warm sunshine and views from their 8th floor rooms. Although the glass wall is aesthetically pleasing, there may be more practical layouts for the façade.

Having the entire wall composed of glass isn't entirely feasible. True, a patient probably does enjoy the added view space, but the average person has a view spectrum between 3'-7' off of the ground, making the window space below and above that unnecessary. Uneasiness also surfaces regarding the privacy of a patient; yes, blinds will be used in the rooms, but when the curtains are up in the daytime, who wants a pedestrian looking into their room? There is a solution to this problem.

Transparent solar glazing (See Figure 7,8,&9) is a system of window glazing that essentially has a solar panel built into the glass panel. These systems can come in varying colors and styles so there

is still flexibility that comes with the panels. This is the potential to maintain the aesthetic look to the façade but gives the user a little more privacy (See panel layout in Figure 6). This system may also affect the electrical and mechanical loads of the facility. Calculations can be made to determine if these panels will be an electrical or mechanical benefit to the facility. The constructability of this system will also need to be researched along with the long term performance of this system.

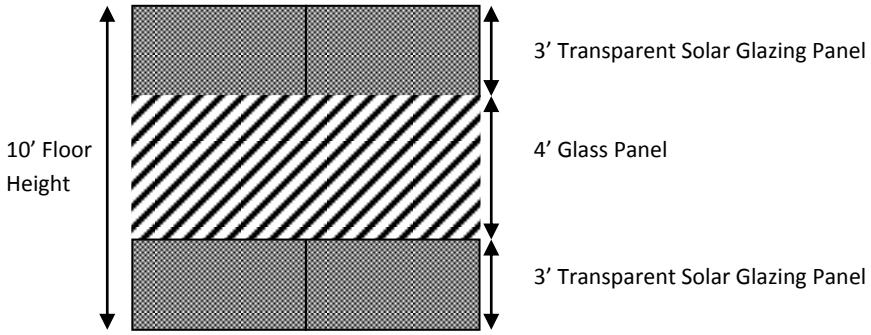


Figure 6 shows a possible layout of the altered glass façade.

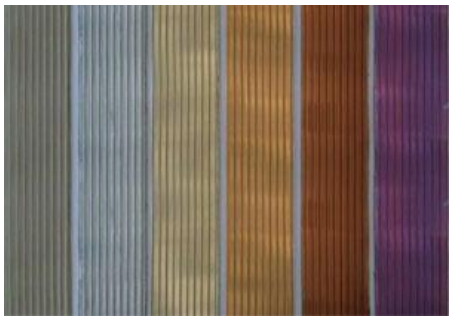


Figure 7 & 9 (Upper & Lower Right) show samples of façade layout incorporating Transparent Solar Glazing. Figure 8 (Upper Right) shows colors that can be used with the Solar Glazing.

Analysis Method 4: Prefab Systems

A popular means of accelerating the schedule is prefabricated systems. As mentioned in the Analysis 1 topic, prefabricated acoustical walls have the potential to save much needed time. This concept can be applied to other systems in the building as well. Modular rooms would not be realistic as the structure is a complex steel frame. However, prefabricated corridor runs of mechanical, electrical, and telecommunications could be an effective way to save time for the tradesman on site. However, something to consider for this is whether or not unions play a part in the construction of this facility. If unions are playing a part in building these systems offsite, then many times they are required to install their own work. Research will be done to investigate the union requirements in Charlottesville, VA.

Works Cited

Figure 4: Ballasted EPDM

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Figure 5: TPO

John Manvilles. *TPO Single Ply Roof*. 2011. Graphic. John Manvilles, Inc, Denver. Web. 16 Nov 2011. <http://www.specjm.com/contactus_general.asp>.

Figure 7: Sample Glass Façade

Transparent Photvolaic Glass. 2009. Photograph. Solar Glazing Magazine, Pasadena, CA. Web. 16 Nov 2011. <http://www.solarglazingmag.com/?attachment_id=261>.

Figure 8: Colored Glazing

Multiwall Polycarbonate. 2010. Photograph. Eco Products LLC, Royal Oak, MI. Web. 16 Nov 2011. <http://www.ecoproductsllc.com/products.html>.

Figure 9: Sample Glass Façade

Transparent BIPV Glass Facade. 2011. Photograph. Building Integrated PhotovoltaicsWeb. 16 Nov 2011. <http://www.buildingintegratedphotovoltaics.co.uk/bipv-glass-facades.html>.

Project manager

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Faculty Advisor

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