VA STATE CAPITOL
Richmond, VA

Eric Fritz
Construction Management

Project Team
- *Owner: People of Virginia*
- *Owner Rep. – Department of General Services*
- *Arcithect – Hillier Architecture*
- *CM – Gilbane / Christman Assoc.*
- *Structural Engineer – Robert Silman & Assoc.*
- *Mech. & Elect. Engineer – Joseph Loring & Assoc.*
- *Civil Engineer – Draper Aden Associates*

Mechanical and Electrical System
- *Mechanical*
  - *Demolition of existing equipment*
  - *Forced air handler units combined with a hot / cold water system.*
  - *7 100% Make-Up AHU's*
  - *8 Constant Volume AHU's*
  - *1 Variable Air Volume Unit*
- *Electrical*
  - *Demolition of existing equipment*
  - *5 Switchboards with varying amperes*
  - *208Y/120V, 3 Phase, 4 Wire System*
  - *42 Panelboards*

Project Overview
- *27,000 SF Subterranean Extension and a 90,000 SF Renovation.*
- *Total Construction Cost: $64,800,000*
- *A CM at Risk project with a GMP contract being held with the owner.*
- *Construction Dates:*
  - *Extension: 7/19/04 to 12/1/05*
  - *Existing Capitol: 9/20/04 to 12/11/06*

Architecture
- *Existing Capitol:*
  - *Five story high structure*
  - *Jeffersonian Style Architecture*
  - *The facade is a three-ply stucco system*
- *Extension:*
  - *Two level subterranean structure*
  - *Exhibit space for artwork and historical items is the main feature.*
  - *High end materials will be used for the finishes.*

Structural System
- *Existing Capitol*
  - *Masonry Brick Foundation*
  - *Masonry Brick Structural Walls with stucco facade*
- *Extension*
  - *Structural concrete walls and slab on grade*
  - *Roof will be a concrete slab protected with waterproofing*
- *An elaborate soil retention system will used to protect the Existing Capitol.*
  - *Consists of a slurry wall, jet grout columns, and compensation grouting.*

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Eric Fritz
Penn State AE – CM
Virginia Capitol
Richmond, VA
April 8, 2005

Executive Summary:

The major proposal for the Virginia Capitol Building was to the structural wall and beam system on the Extension. A precast system was considered in lieu of a cast-in-place system. The precast system would save forty days on the schedule and 1568 labor hours, but the cost would rise by $8,000 and the design would be very complex. Due to these factors the CIP system is the best recommendation for this project.

Another construction change consideration was to the utility trench cover. The current trenches are covered with a precast plank and topped with a 2 inch concrete slab. This system would not easily support a future expansion of the utilities that exist in the trench. A RWC Series Access Panel was proposed for the system. This panel had a schedule and cost overrun of 2 days and $3,600, respectively, but the system would allow for easy access to the trenches and there would be 168 labor hours saved. Due to the accessibility of the access panels, they would be the best consideration on this project.

The results of the labor research in the Richmond area showed that the construction companies will have a problem finding reliable skilled workers. Therefore, one of the criteria points for the changes had to deal with how much labor was involved. With the accepted proposal, the labor would be reduced by 168 hours.

Research was also performed on how technology, such as 3D and 4D CAD, benefits the sequence of trades. This is relevant to this project due to the owner move out in mid May 2005 and the congested plenum spaces involved in the construction. The major drawback to using this technology is that the system is not fully adapted in the construction industry yet. Senior industry members do not like to change what they are currently doing, so they are reluctant to use this technology.

The overall accepted changes to the Virginia Capitol Extension and Renovation project is an increase in schedule by 2 days and an increase in cost by $3,600. However, the labor hours were decreased by 168 and the design is more beneficial to the overall needs of the owner.

To: The Dept. of General Services (DGS)
Virginia Capitol
Richmond, VA
April 8, 2005

From: Eric Fritz
The Pennsylvania State University
Architectural Engineering
Construction Management

Proposal Letter:

The overall goal of this document is to provide alternatives in order to obtain an enhanced construction project. The enclosed document contains solutions to requests for value engineering, schedule reduction, and constructability on the Virginia Capitol Extension and Renovation. This research will reduce the cost and schedule of your project as well as providing additional quality. Research was also performed on how technology can improve the sequencing of trades throughout a construction project. This project was not highlighted for this research due to certain security issues pertaining to the building, but a proposed plan was given for the Capitol.

Value engineering was an important focus of this document. The future expansion was considered for this project since the renovation will be a '100 year overhaul.' A particular system that was considered was the precast plank and topping slab that is designed to cover the utility trenches. A recessed flooring system would allow for expansion of the future utilities without as much hassle.

Schedule reduction and cost reduction was considered for all of the proposed systems. Constructability solutions were looked at for the cast in place concrete foundation walls. The slopes and subterranean condition will make any system difficult to construct, so a precast system was analyzed for this structure.

After these systems were analyzed, it was determined that the recessed flooring would be a good alternative, but the precast wall panels and beams for the extension may be too difficult to design and construct. Although, there were schedule and cost benefits with this system, it has much uncertainity.

	CIP to Precast Walls & Beams	Precast Planks and CIP Slab to Recessed Flooring	Labor Shortages	Technology Benefiting Sequence of Trades
Value Engineering		√		
Constructability Review	√	√		
Schedule/Cost Reduction	√	√	√	
Research Study			√	√

Project Description

The Virginia Capitol Building is a 216 year old structure originally designed by Thomas Jefferson. The original structure was much smaller than the current Capitol due to an extensive overhaul from 1904-06. In this time period, the east and west wings were added to the primary building. Theses wings now hold the Chamber of the Senate and the House of the Delegates. Construction of the recent Extension and Renovation began in July 2004 and will finish by January 2007. The construction needs to be finished by January 2007 due to the 400th Anniversary of the Jamestown Settlement being held in Richmond, in which the Queen of England is planning to attend. The goal of this project is to be a '100 year renovation.' DGS does not want to perform any more renovations to the structure in the next 100 years. Other important facts include:

Primary Project Team:

- Owner: Department of General Services (DGS)
- CM at Risk: Gilbane / Christman Association
- Architects: Hillier
- Mech./Elec. Engineer: Joseph Loring Associates
- Structural Engineer: Robert Silman Associates
- Civil Engineer: Draper Aden Associates

Project Costs:

- Construction Costs: $64,800,000
- Design Cost: $1,000,000
- Total Costs: $65,800,000

Project Schedule:

- Design Start: October 1, 2003
- Construction Start: July 12, 2004
- Substantial Completion: December 11, 2006

Delivery System:

- This project is a CM at Risk delivery system. Gilbane / Christman will hold a GMP contract with the Owner. This is one of the first CM at Risk jobs that the Commonwealth of Virginia is attempting. They switched from the traditional Lump Sum/Low Bid GC delivery system to CM at Risk, which they hope to have better success.

  One of the interesting relationships in this organization is the association between Gilbane Building Company and Christman. Gilbane is a large construction management firm which joined forces with Christman. Christman is a firm that specializes in historical renovations. This relationship is not considered a joint venture though. It is considered an association between the two.

Architecture:

- Existing Capitol:
  - Jeffersonian Style Architecture
  - Five Story Structure
  - Façade is a three-ply structure
- Extension:
  - Two level subterranean structure
  - Exhibit space for artwork and historical items
  - High end finishes

Building Systems Summary:

- Demolition
  - A large majority of this project is demolition due to the fact that it is a renovation project.
  - Types of materials:
    - Existing MEP equipment and materials.
    - Exterior stucco system.
    - Walls, flooring, and ceilings.
      - Walls and ceiling is a plaster material.
      - Majority of flooring is tile.
    - Brick Pavers
    - A few select doors and windows.
      - The rest are going to be restored and placed back in.
  - Asbestos was located on the ground level in the vault. GCA secured the area to remove the tile flooring.
    - There is continuing asbestos investigation occurring in the building.

- Structural Steel Frame
  - There is a small amount of structural steel frame used to support the existing roof. This consists of mainly diagonal bracing.
  - The only other structural steel will be used in the extension. This will also be used as a roof support.

- Cast in Place Concrete
  - The extension will be made from cast-in-place concrete.
  - Both horizontal and vertical formwork will be used.
    - The method of formwork will be up to the subcontractor. The bid has not been awarded yet.
    - The method that GCA is expecting is the standard wood formwork.
  - The concrete will be placed by a concrete pump for the majority of the work. Where possible, it will be placed directly form the truck.

- Mechanical System
  - Both structures will use a combined forced air and hot/cold water supply system.
    - Forced air system is using rectangular duct. Supplied by roof mechanical units.
    - Hot/Cold Water supply will use radiator system on the floors. Supplied by piping that comes from the east MEP tunnels.
  - Fire Suppression system is an overhead dry sprinkler system.
  - Existing Capitol Mech. Room Locations
    - There are two main rooms located on the roof.
    - Mechanical rooms are located on the ground floor – South End
  - Extension Mechanical Room Locations
    - They are located on the Northeast end of the extension. This is where the MEP tunnel comes into the Capitol Structure.

- Electrical System
  - Service: 12000 kV
  - 277/480V, 3 Phase System

- Masonry
  - Existing Capitol
    - The Capitol has an existing brick foundation system.
    - The Capitol has exterior brick walls that are covered by the stucco system.
    - Masonry scope of work primarily consists of touchpointing of brick.
    - They will use a scaffolding system to touchpoint the bricks.
    - Scaffolding is the basic metal frame with wood plank structure.
      - This will be erected in four different phases. One side of the Capitol at a time.
  - Extension
    - There is not any masonry used in the extension.
      - Extension exterior walls will be made of structural concrete surrounded by waterproofing for moisture protection.

- Curtain Wall
  - Existing Capitol
    - A 3-Layer stucco system will be applied to the Exterior of the Capitol using a scaffolding system.
      - This will be applied using brushes and trowels.
      - This system will keep the architectural feel of the Existing Capitol Exterior as well as act as a moisture barrier.
    - Extension
      - There are no curtain walls used for the Extension other than some of the wall partitions.
        - These walls are made of concrete.

- Support of Excavation
  - Existing Capitol
    - The only excavation around the north, west, and east ends of the Capitol is the trench drain system.
      - This will act as a permanent dewatering system for the Capitol.
  - Extension
    - The extension will use an elaborate soil retention system.
    - The sequence for building is as follows:
      - A 35 foot slurry wall will be placed on the south side of the Existing Capitol, where the existing South Portico Stairs exist.
      - Tie backs will be tied into this slurry wall.
      - Jet Grouting and Compensation Grouting will be integrated into this slurry wall.
    - All of these systems are needed due to the stringent deflection and lateral movement specifications for the Existing Capitol.
    - Soldier Pile and Lagging will be used around the east, west, and south side of the extension.
    - There is no need for dewatering at this time.

Local Conditions:

- The preferred method of construction that particularly shows up in Richmond is concrete work. Concrete is more typical than steel due to the historical nature of the projects. Many owners want concrete instead of steel.

  Parking is a problem in Richmond. The downtown area is a congested site with a large number of state or federal government structures. There is also a medical school, The Virginia Commonwealth Medical School, in other government buildings. This means that there are a lot of commuters that travel to downtown Richmond. The Virginia Capitol Police only allow vehicles that are required for construction onto the site. The rest of the vehicles, including the Construction Management firm's vehicles are required to be parked off site. The only place to park these vehicles are in the parking garages that are in downtown. There are two that are close to the Capitol, but they are overcrowded.

  Another problem with local conditions is the availability of subcontractors. Richmond is booming with construction projects at this time. There is already a shortage of qualified contractors for large construction projects and in the next six months there are a variety of large projects that will start. This includes a Performing Arts building located two blocks from the Virginia Capitol Building, which Gilbane / Christman was awarded as a CM at Risk. Virginia is also a 'Right to Work' state which means that the state does not require union workers.

  The majority of the soil in and around Richmond is made up of clay and sand. This layer of soil is approximately 20 feet deep and called the Pleistocene soils.

The water table fluctuates. On this project it is about 20 feet below grade. They are not sure if dewatering will have to occur or not.

Client Information

- The Owner of this project is the people of Virginia and they are being represented by The Department of General Services. DGS is a very hands when it comes to construction. They oversee all of the Virginia State projects and they are knowledgeable in the construction industry.

  There are a variety of reasons for renovating the existing Capitol and building the Extension. The main reason for the renovation is because the existing building has many problems at the present time. The existing Capitol has moisture penetration, locations of asbestos, and it has also flooded some areas at times. DGS wants to fix these problems and in doing so, they are calling for a "100 Year Building." This means that they want the current renovation to be able to withstand 100 years of time. The other main reason for the extension and renovation is the 400th year anniversary of Jamestown that is coming up in 2007. They are planning on a huge celebration in Richmond, which will be attended by the Queen of England.

  Expectations:
  - ✓ Cost: Cost should not exceed the projected total cost. They need to keep it below budget due to the fact that the people of Virginia are the ones paying for it.
  - ✓ Quality: Quality is a premium. DGS wants this building to last for 100 years. The architect also has many high end finishes and designs in the structure.
  - ✓ Schedule: Schedule is important. This project needs to be finished by 2007. There will be major late fees involved if this date is not reached.
  - ✓ Safety: Safety is important with the owner and the construction management team on this project as in most construction projects. This project is already in the public eye and an accident will be extremely detrimental to the project.

  Examples of these issues are evident in their Design and Construction Meetings that are held every week. Cost and Schedule is a major issue in these meetings. They are the main topics discussed. As for quality and safety, all of the workers on site are required to go through a training sessions. There are two sessions, one for quality and one for safety.

  The owner's main phasing issue deals with the Existing Capitol Building. They want to keep their government workers in the Capitol as long as possible. Therefore, the extension's construction will start first. The Capitol workers are going to move into the Old State Library, which is adjacent to the Capitol. This building is being renovated right now. This move will occur in the spring of 2005. At this time, renovation will begin inside the Existing Capitol.

MEP Coordination

- The mechanical subcontractor will take the lead in coordination with the other MEP subcontractors. This subcontractor will review the drawings and place his coordination and spacing plan onto a set of coordination drawings. The mechanical contractor will then send these drawings to the plumbing and fire protection subcontractors next. After they have added their systems and communicated concerns back to the mechanical contractor, they will give the drawings to the electrical, telecom, and security contractors.

  Throughout the entire project, there will be weekly coordination meetings that occur at Gilbane / Christman's site trailer. Either the foreman or project managers from the MEP trades will come to these meetings to coordinate their plans for the next two weeks. These plans will be placed into a two week look-ahead schedule or description. The concrete or structural subcontractor will also get involved in this process when needed. These contractors will become involved when the MEP trades have to interfere with their work.

- *Areas of Greatest MEP Coordination Concern*
  - There is a large challenge to fit a lot of the mechanical ducts, electrical conduit, security, and telecom systems into an old building that was never designed to accommodate these systems. The designers had to create new chases and/or utilize existing ones that run through the existing Capitol. This is a huge concern for the CM team and the MEP trade contractors that are bidding the project.

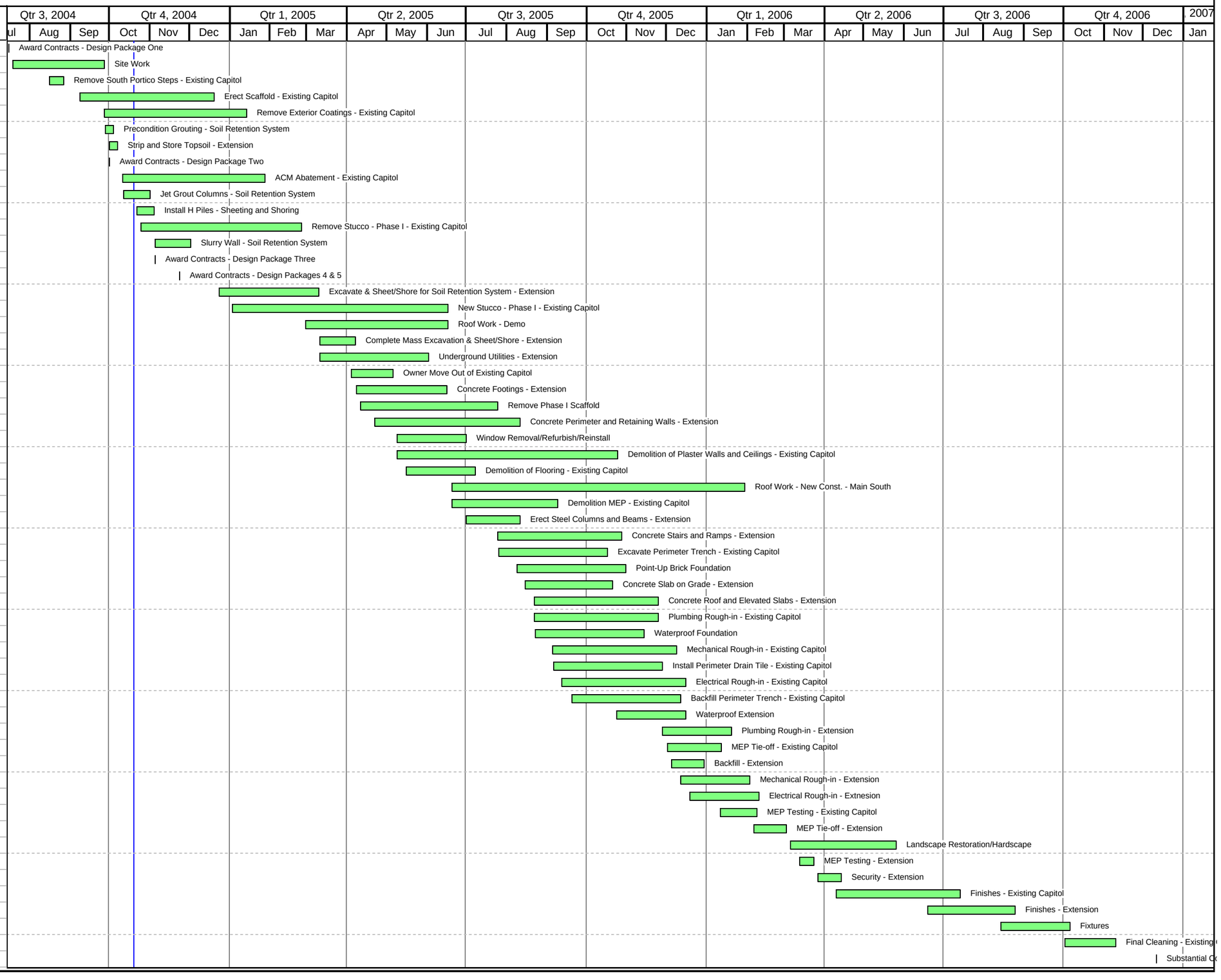
    One thing that they are doing is tearing up the entire ground floor corridors and creating small utility tunnels that will run under the floor. This will alleviate some of the space issues that are going to hinder the construction on this project, but they still have to deal with the vertical chases running through the building. As of this time there are no major MEP coordination concerns for the Extension that will be built off the south side of the Capitol.

    A coordinated MEP construction plan will be reached by the CM running weekly MEP coordination meetings. The superintendents will require the MEP subcontractors to discuss what they will be doing and come up with a plan that will make construction run smoothly.

    Since the majority of construction has not started yet, there have not been any field conflicts that have arisen with the structural and MEP systems. Most of the work that has been performed so far has included demolition of finishes and MEP equipment and site work.

VA Capitol Const. 05-Apr-05

Activity Name	Original Duration	Start	Finish
Award Contracts - Design Package One	0	16-Jul-04	16-Jul-04
Site Work	51	19-Jul-04	27-Sep-04
Remove South Portico Steps - Existing Capitol	10	16-Aug-04	27-Aug-04
Erect Scaffold - Existing Capitol	73	09-Sep-04	20-Dec-04
Remove Exterior Coatings - Existing Capitol	80	27-Sep-04*	14-Jan-05
Precondition Grouting - Soil Retention System	5	28-Sep-04	04-Oct-04
Strip and Store Topsoil - Extension	5	01-Oct-04	07-Oct-04
Award Contracts - Design Package Two	0	01-Oct-04	01-Oct-04
ACM Abatement - Existing Capitol	80	11-Oct-04	28-Jan-05
Jet Grout Columns - Soil Retention System	15	12-Oct-04	01-Nov-04
Install H Piles - Sheeting and Shoring	10	22-Oct-04	04-Nov-04
Remove Stucco - Phase I - Existing Capitol	90	25-Oct-04	25-Feb-05
Slurry Wall - Soil Retention System	20	05-Nov-04	02-Dec-04
Award Contracts - Design Package Three	0	05-Nov-04	05-Nov-04
Award Contracts - Design Packages 4 & 5	0	24-Nov-04	24-Nov-04
Excavate & Sheet/Shore for Soil Retention System...	55	24-Dec-04	10-Mar-05
New Stucco - Phase I - Existing Capitol	120	03-Jan-05	17-Jun-05
Roof Work - Demo	80	28-Feb-05	17-Jun-05
Complete Mass Excavation & Sheet/Shore - Exten...	20	11-Mar-05	07-Apr-05
Underground Utilities - Extension	60	11-Mar-05	02-Jun-05
Owner Move Out of Existing Capitol	25	04-Apr-05	06-May-05
Concrete Footings - Extension	50	08-Apr-05	16-Jun-05
Remove Phase I Scaffold	76	11-Apr-05	25-Jul-05
Concrete Perimeter and Retaining Walls - Extension	80	22-Apr-05	11-Aug-05
Window Removal/Refurbish/Reinstall	40	09-May-05	01-Jul-05
Demolition of Plaster Walls and Ceilings - Existing ...	122	09-May-05	25-Oct-05
Demolition of Flooring - Existing Capitol	40	16-May-05	08-Jul-05
Roof Work - New Const. - Main South	161	20-Jun-05	30-Jan-06
Demolition MEP - Existing Capitol	60	20-Jun-05	09-Sep-05
Erect Steel Columns and Beams - Extension	30	01-Jul-05	11-Aug-05
Concrete Stairs and Ramps - Extension	70	25-Jul-05	28-Oct-05
Excavate Perimeter Trench - Existing Capitol	60	26-Jul-05	17-Oct-05
Point-Up Brick Foundation	60	09-Aug-05	31-Oct-05
Concrete Slab on Grade - Extension	50	15-Aug-05	21-Oct-05
Concrete Roof and Elevated Slabs - Extension	70	22-Aug-05	25-Nov-05
Plumbing Rough-in - Existing Capitol	70	22-Aug-05	25-Nov-05
Waterproof Foundation	60	23-Aug-05	14-Nov-05
Mechanical Rough-in - Existing Capitol	70	05-Sep-05	09-Dec-05
Install Perimeter Drain Tile - Existing Capitol	60	06-Sep-05	28-Nov-05
Electrical Rough-in - Existing Capitol	70	12-Sep-05	16-Dec-05
Backfill Perimeter Trench - Existing Capitol	60	20-Sep-05	12-Dec-05
Waterproof Extension	40	24-Oct-05	16-Dec-05
Plumbing Rough-in - Extension	40	28-Nov-05	20-Jan-06
MEP Tie-off - Existing Capitol	30	02-Dec-05	12-Jan-06
Backfill - Extension	20	05-Dec-05	30-Dec-05
Mechanical Rough-in - Extension	40	12-Dec-05	03-Feb-06
Electrical Rough-in - Extnesion	40	19-Dec-05	10-Feb-06
MEP Testing - Existing Capitol	20	12-Jan-06	08-Feb-06
MEP Tie-off - Extension	20	06-Feb-06	03-Mar-06
Landscape Restoration/Hardscape	60	06-Mar-06	26-May-06
MEP Testing - Extension	10	13-Mar-06	24-Mar-06
Security - Extension	15	27-Mar-06	14-Apr-06
Finishes - Existing Capitol	70	10-Apr-06	14-Jul-06
Finishes - Extension	50	19-Jun-06	25-Aug-06
Fixtures	40	14-Aug-06	06-Oct-06
Final Cleaning - Existing Capitol	30	02-Oct-06	10-Nov-06
Substantial Completion	0	11-Dec-06	11-Dec-06

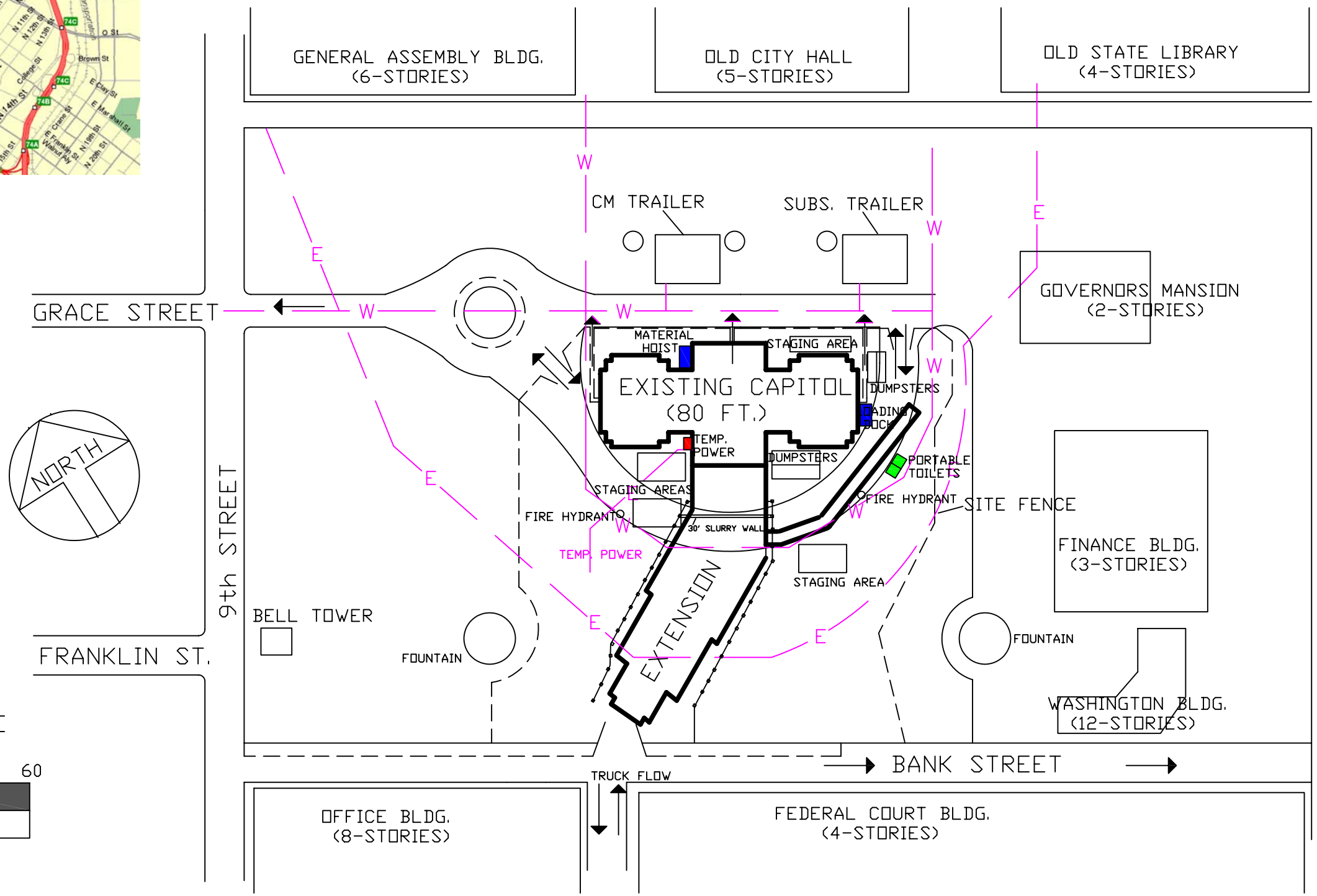


Estimate

The estimate will be presented in the presentation for this thesis, but do to the sensitivity of the material it can not be used in any handouts or paper copies of the report.

Code Number	Division	Estimate
1	General Requirements	
2	Site Construction	
3	Concrete	
4	Masonry	
5	Metals	
6	Wood and Plastics	
7	Thermal & Moisture Prot.	
8	Doors and Windows	
9	Finishes	
10	Specialties	
11	Equipment	
12	Furnishings	
13	Special Construction	
14	Conveying Systems	
15	Mechanical	
16	Electrical	
17	Security	
	Contingency & Other Costs	
	TOTAL COSTS	

VICINITY MAP



GRAPHIC SCALE

60 30 0 60

(in feet)

VA STATE CAPITOL
9TH AND GRACE STREET
RICHMOND, VA 23219

DRAWN BY:
ERIC FRITZ
11/03/04

SITE PLAN

Investigation Areas

- *Extension:*
  - CIP structural walls and beams
    - The cast-in-place walls and beams serve as a structural support system for the extension. Precast wall panels and beams will be investigated to determine which system would be the best for the project.
    - Another major issue that will be investigated with this system is the labor needed to build each method. At this current time, Richmond is seeing a shortage of skilled labor for their construction projects.

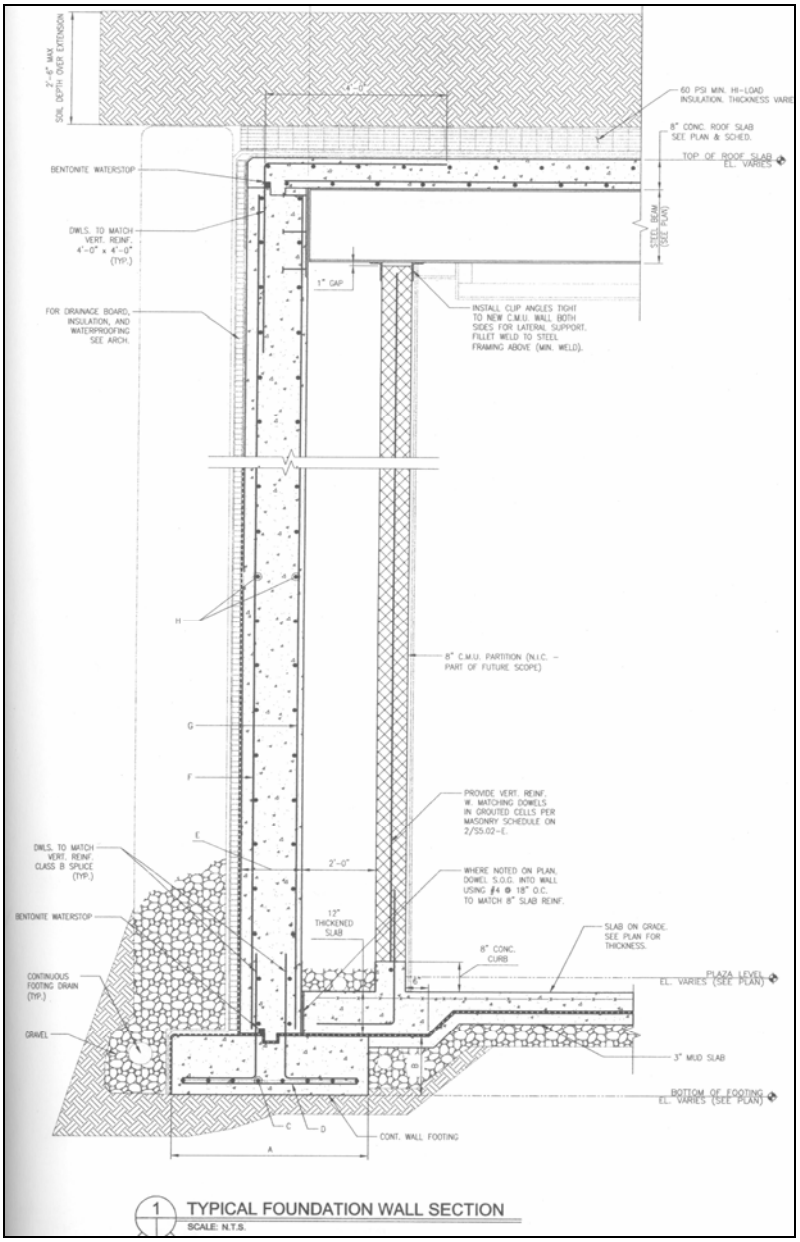
- *Existing Capitol:*
  - Utility Trench System
    - The existing trench is topped with a precast plank and a 2 inch topping slab. This serves as the access points over the utility tunnels. A RWC Series Access Panel will be investigated for this system.

- *Technology:*
  - The research topic will investigate how technology, such as 3D and 4D CAD, can supplement and benefit the sequencing of trades throughout a building. This is important on this project due to the fact that the utility spaces are confined and congested and the occupants will have to move out of the building before renovation and construction of the Existing Capitol can start.

Breadth: Change CIP Structural Walls and Beams to Precast

Issue: One of the biggest problems facing construction companies in Richmond, Virginia is the lack of skilled labor. Currently, there are approximately six large scaled projects in progress in the downtown area. Many of the project managers are worried that the labor will not be available when it is needed. Cast-in-place concrete requires a good deal of skilled labor, so an alternative system needs to be discussed.

Proposal: Therefore, the advantages and disadvantages of using precast walls and beams instead of a cast-in-place system were investigated.



Current Cast-in-Place Foundation Wall System

Results: Although the precast system would save a great deal on schedule and labor, the design and construction complexities outweigh these advantages. The cast-in-place system is the best method of construction on this site.

- **Time**
  The CIP concrete system takes a total of 80 days to complete, while the precast system takes a total of 40 days to complete. Some assumptions were made based upon the precast system and cast-in-place system, so there may be some variability between these numbers.

- **Cost**
  - CIP Concrete
    - ✓ Foundation Walls: $300,200
    - ✓ Beams: $121, 200
    - ✓ **Total Cost: $421,400**

  - Precast Concrete
    - ✓ Structural Wall Panels: $315,400
    - ✓ Beams: $113,900
    - ✓ **Total Cost: $429,300**

- **Labor**
  One of the main reasons why precast was analyzed in lieu of the cast-in-place concrete is that the labor force is extremely stretched in Richmond. According to several project managers from the Richmond area, this is a main concern among the management on construction projects. There are currently six major construction projects in progress within a five to six block area in downtown Richmond. Richmond does not have the construction labor to deal with this problem and the construction companies have been looking for possible solutions. Precast would help solve this issue on the Virginia Capitol project.

  ●***Projects currently under construction in Richmond***

  - ✓ Virginia Capitol Extension and Renovation
  - ✓ Performing Arts Center
  - ✓ City Hall Renovation
  - ✓ Finance Building – Extensive Renovation
  - ✓ MVC Medical Campus
  - ✓ VCU Educational Campus

  According to the Monthly Labor Review (November 2004 edition), the employment rate in Richmond, Virginia has increased by 2.4 percent since 2002 and the construction industry has increased by 2.1 percent in the northeast region. The following table shows the amount of labor that would be saved if precast was used on this project.

	Cast-in-Place		Precast	
	Walls	Beams	Wall Panels	Beams
Daily Labor Hours	48	200	72	72
# of days to complete	76	4	34	6
Total Labor Hours	4448		2880	

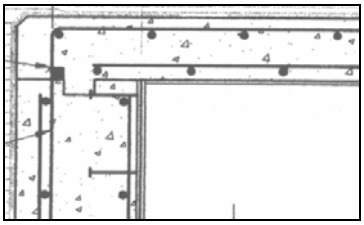
- **Design**
  According to Mark Taylor of Nitterhouse Concrete Products and Dr. Hanagan of the Pennsylvania State University Architectural Engineering Department, the design complexity is the biggest drawback with the precast system. Since the structure is subterranean and many slopes are involved in the building, the design will be difficult. Some of the concerns with the design include:

  - ✓ Dowels and key joints for the footing and roof slab connections
  - ✓ Embeds for pick points
  - ✓ Embeds for waterproofing attachment
  - ✓ Subterranean Conditions

  Due to the fact that there will be a horizontal soil load on the precast, the design needs to account for moment forces. To accommodate for this, the present key joint design will have to be used in the precast walls and dowels will need to be extruding the precast from the top face in order for the system to tie into the CIP roof slab. The embeds for the pick points will be present at the top of the precast walls and beams. This allows for easy picking from the trucks to the erection site. In order for the waterproofing to be attached to the precast, hangars will have to be placed on the outside of the wall panels. This would require major design coordination between fabricators, structural engineers, and the waterproofing subcontractor. The subterranean conditions are also not typical for the use of precast concrete.

  The average size of the precast panels would be a 12'x10' section. The width depends on where the section is placed. The width ranges from 1 to 2 feet. With these sizes, the maximum weight of a precast section is 36,000 pounds.

  All of these factors contribute to the complexities of using precast walls in lieu of cast-in-place concrete. Since the design is so difficult for the precast wall panels, it would not be economical to use the precast beams due to the small size of the project.



Example of the joint design that ties the precast to the roof slab

- **Constructability and Installation**
  Constructability is another main concern for using precast in lieu of cast-in-place concrete for this project. Since the project is an underground structure that has many slopes involved, waterproofing and joints will be very challenging. As described above, the precast concrete will have to have keys in the top and bottom of the panel to tie into the roof slab and the footing. This will help with the loading. Dowels will also have to extrude from the top of the panel. This is to help against a moment connection. These issues add to some safety concerns as well.

  Lay down areas exist in and around the structure. The walls will be placed prior to the columns, therefore the bottom of the structure's excavation could be used as a lay down area. A better option would be to have the wall panels and beams taken directly off the trucks. The trucks have access around the structure, so this would enable easy picking directly from the trucks.

  The bottom of the excavation is at street level on the south side of the site, therefore trucks would be able to enter from this direction for the pieces to be placed at the south end of the structure. The trucks can drive around the existing driveway at the top of the site for erection of the north end.

- **Crane**
  The crane currently on-site is a 100-ton Link Belt crane. It will have a 120 foot boom with a lifting capacity of 10,000 pounds and an 80 foot radius. This crane will not be large enough for the precast panels and beams. The heaviest pick for the panels and beams will be 36,000 pounds. A 140 ton Manitowoc 3900 T-Series 1 crane would have to be used instead of the Link Belt. This has a 110 foot boom with a lifting capacity of 41,300 pounds and a 60 foot radius. Page 33 of the appendix section shows the crane locations and turning radius.

- **Strength and Durability**
  According to an article by the National Precast Concrete Association, precast concrete will continue to gain strength over time, where as some other materials may lose strength due to the exterior environment. This is extremely important on the Virginia Capitol project due to the subterranean condition. The precast panels will be subject to moisture, but the precast should withstand this moisture better than cast-in-place concrete could.

  The panels can be designed to withstand heavy structural loads. The main loads needed to be withstood for this building will be the force from the soil and the roof slabs. There will be no wind forces and the building will be mainly under grassy areas, so the structure will not have to deal with much overhead weight other than the existing soil.

- **Weather**
  The concrete was scheduled to be placed during the winter months for the subterranean structure. Precast would have enabled the construction crew to work through some of the harsh weather in Richmond, Virginia. Richmond did not get much snow this past winter, but they needed heaters for the concrete to cure and they experienced a lot of wet weather that hampered their construction efforts.

- **Safety**
  The major safety issue involved with the precast concrete is crane safety. Other possible concerns are the fact that dowels will have to stick out of the precast until the roof slab was poured. Safety caps would have to be placed on the end of these dowels to reduce the possibility of puncture wounds.

- **Quality**
  Precast concrete enables the quality to be controlled for the panels and beams. Since the material is being manufactured in a secure environment, the design and fabricating specifications will be adhered to. With other construction methods, variable site conditions can create the possibility of adjustments or shortcomings during construction.

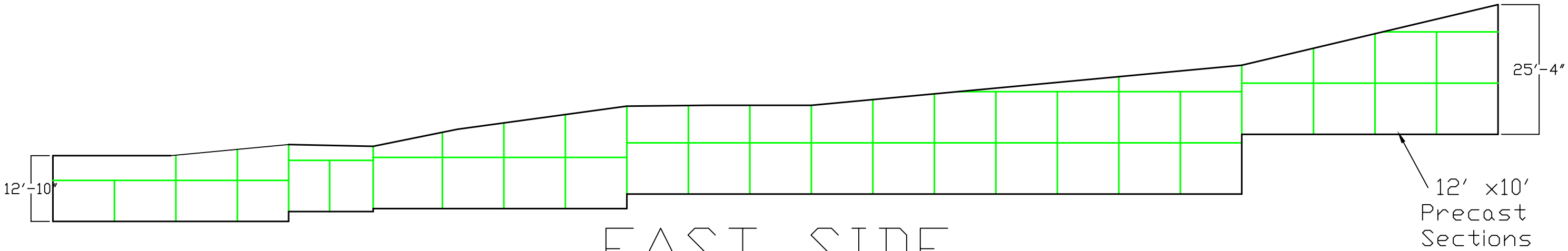
	PRECAST WALL SYSTEMS	MASONRY	METAL PANEL	TILT-UP
Design Flexibility	X	X		
Factory Controlled Production to Assure Quality	X		X	
Thermal Efficiency	X			
Water Leak Resistance	X			
Low Maintenance	X			X
Durability	X	X		X
Low Life Cycle Costs	X			
Year Round Fast Construction	X			

Figure 1: Comparison of different wall systems (MAPA Wall Panels)

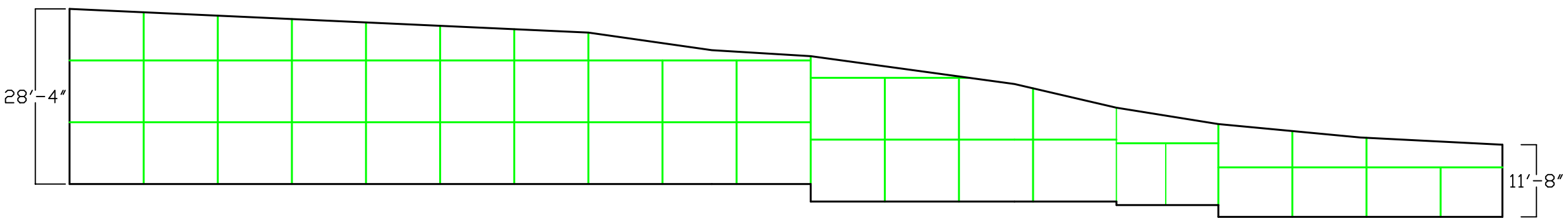
Table of Results: The following is a table of results for the walls and beams. After comparing these results, there are some advantages with precast when looking at cost, labor involved, and quality. The major disadvantages are the constructability, complexity of design, and the crane use. Although there are some major advantages with the precast system which includes a savings of 40 days on the construction schedule, talks with industry members showcased the design complexity as a deciding factor not to use the precast system in lieu of the CIP system.

	Cast-in-Place Concrete	**Precast Concrete**
Cost	$421,400	$429,300
Time	80 days	40 days
Labor Hours	4448	2880
Installation	Plenty of room available on site	Area for direct picks from trucks. Ease of installation.
Constructability	Difficult to build formwork for the slopes involved.	Challenging. Building is on a slope, so the joints and pieces will be difficult to design and erect
Quality	Corners could be cut. Quality depends upon the laborers on site.	Manufactured in controlled factory environment. High quality
Crane/Pump Use	Requires use of a concrete pump truck	Requires use of crane. A 100 ton link belt crane is on current site. Lifting capacity of 5 tons with an 80 foot radius. A Manitowoc 3900 crane is needed for the desired lifting capacity.
Weather	Weather needs to be in desired temperature range and it needs to be protected from moisture.	Can be constructed during most weather conditions.

Plan of Proposed Precast Wall System



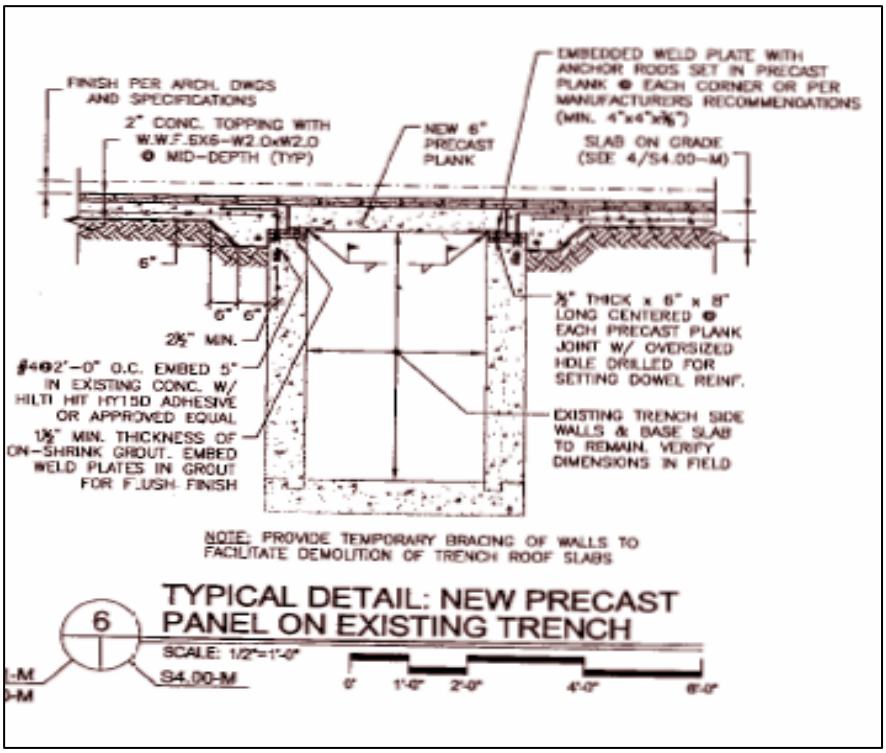
EAST SIDE



WEST SIDE

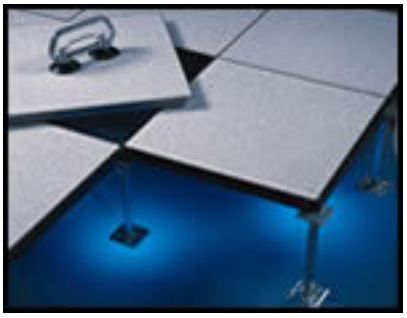
Change Plank and Slab System to Recessed Flooring

Issue: The Virginia Capitol project is being called a "100 year renovation." The project team is trying to achieve a building that will not need a major renovation overhaul for at least 100 years. The utility tunnels in the Capitol exist under the first floor slab on grade. The current tunnels are made out of concrete, sealed with a precast planks, and then a 2 inch topping slab is placed over the precast. The utilities that are being placed in the tunnels are going to be congested and due to ever-growing technology, this system does not allow ease of updating the structure. The figure, shown below, is a section cut of the current system.



Detail of current trench system. New system would have access flooring in lieu of precast and topping slab

Proposal: A value engineering idea would be to use a recessed computer flooring system that would allow for easier access to the utility tunnels as well as ease of installation. The type of flooring that was considered for this proposal was the RWC Series Access Panel, which is made by Maxcess Technologies. The RWC Access Panels are resistance-welded, concrete-filled steel panels that are designed to accommodate high loads. Each panel has an epoxy coated finish for a protective surface.



Example of RWC Access Flooring (Maxcess Website)

Results: The proposed system has similar time and cost results as the precast plank and topping slab system. Therefore; the recessed flooring system should be used due to the future expansion and constructability benefits that this flooring brings to the structure. The advantages and disadvantages of the proposal are described below.

- **Time**
  The precast and topping slab system would take three days to complete (1 for the precast planks and 2 for the topping slab). The recessed flooring would take 5 days to install.

- **Cost**
  - Precast Planks and Topping Slab
    - ✓ Excluding Trench System: $23,000
  - RWC Access Flooring
    - ✓ Excluding Trench System: $26,600

- **Labor - Number of crew members needed**

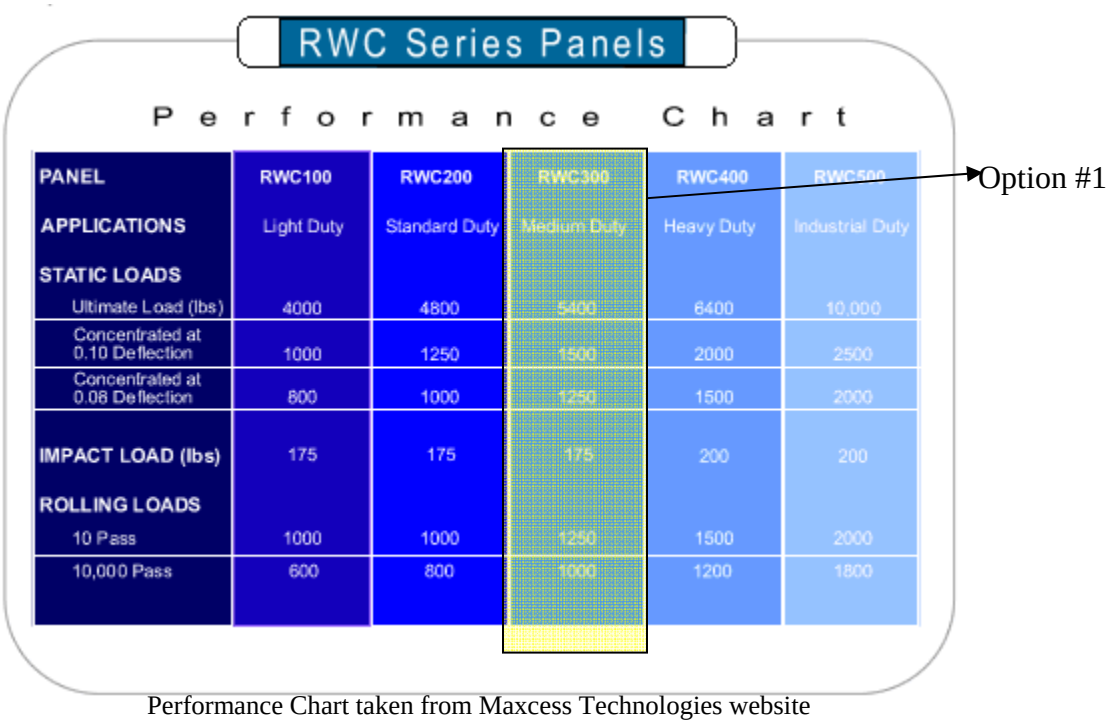
	Plank and Slab		**RWC Flooring**
	Planks	Slab	Access Flooring
Daily Labor Hours	72	88	16
# of days to complete	1	2	5
Total Labor Hours	248		80

  As described in the previous analysis, labor is a big issue for the Richmond area. The recessed flooring system would only require two carpenters to install, where as the plank and slab system requires a much larger concrete crew to erect.

- **Constructability and Installation**
  The recessed floor can easily be constructed in the large spaces that exist in the Capitol Building. The areas are large enough to install the flooring as well as having a material storage area nearby. The constructability may be easier then the precast planks because the precast planks would require more structural support then the recessed flooring and the planks would be larger than the 2’ x 2’ sections of access flooring.

Since this building is being called a 100 year renovation, it needs to adhere to future expansion. The technology and systems used in this building at the present time will most likely become outdated in the future and new wires and conduit will need to be placed in the tunnel system. The recessed computer flooring will allow for easy access to the utility tunnels and this will allow for easy future expansion.

- **Strength and Durability**
  The precast planks with the topping slab would be very durable. To try to match this durability, the RWC 300 was picked from the table below. This should help make this flooring's strength and durability stand up to the 100 year renovation that is trying to be reached.



PANEL	RWC100	RWC200	RWC300	RWC400	RWC500
APPLICATIONS	Light Duty	Standard Duty	Medium Duty	Heavy Duty	Industrial Duty
STATIC LOADS					
Ultimate Load (lbs)	4000	4800	5400	6400	10,000
Concentrated at 0.10 Deflection	1000	1250	1500	2000	2500
Concentrated at 0.08 Deflection	800	1000	1250	1500	2000
IMPACT LOAD (lbs)	175	175	175	200	200
ROLLING LOADS					
10 Pass	1000	1000	1250	1500	2000
10,000 Pass	600	800	1000	1200	1800

Performance Chart taken from Maxcess Technologies website

- **Quality**
  According to Maxcess Technologies website, the RWC Series panel is their premier product line. This system can accommodate very high loads and the protective epoxy finish should protect the flooring from wear and tear.

Example of concrete filled steel panels (Maxcess website)

Table of Results: The following table compares the advantages and disadvantages of the two proposed systems. The cost and time factors are relatively similar, but the labor hours and future expansion factors are to the access flooring's benefit. Therefore, the RWC access flooring system would be the best method of construction for this project.

	Recessed Computer Flooring	**Precast Planks and Topping Slab**
Cost	$26,600 plus trench cost	$23,000 plus trench cost
Time	5 days	3 days
Labor Hours	248	80
Future Expansion	Allows for easy access and extensive future expansion	Access would be difficult. Would involve the use of crane or lift system
Installation	Easy installation. Pieces can be stored in the building.	Planks are difficult. Topping slab requires time for curing and setting up.
Quality	High quality access floor with protective finish	Durable and strong

Research – Benefits of Technology to the Sequencing of Trades

Issue: The sequencing of trades in the construction industry is becoming more and more complex as the design of structures become more modern. New visualization technology has begun to enter the construction industry in the past ten years. Some of this technology includes 3D and 4D CAD, which can enhance the visualization of 2D CAD drawings. This technology can become a major asset to the industry if it is implemented and used to its fullest capability.

This is relevant to the Virginia Capitol project due to the fact that the current tenants of the building have to move out of the building before renovation starts and the utility tunnels and plenum spaces are going to be very congested because the building was not originally designed for the new systems. 3D and 4D CAD would be able to help alleviate the situations by showing the sequence of work, space issues, and storage and material flow.

Proposal: Due to the increasing complexity of construction projects and the move towards better productivity, research was performed in order to show how 3D and 4D CAD could be a benefit for the construction industry. This research will also introduce drawbacks and concerns that are hindering this technology from entering the industry. The main sources of information were literature review and questionnaires that were issued to industry members. Extensive research has been done in the field of 3D and 4D construction visualization, in an effort to explain the construction process. The benefit of this research may allow a visual approach to project planning, management, and construction and a reduction in the errors in planning projects (Issa, Danso-Amoako, and Fukai). Questionnaires were primarily sent to project managers and project engineers of large construction companies. The expected results of the information gathering are to find what the benefits and drawbacks are of this technology and how it is being received by the construction industry.

Results: The research used extensive literature review to compare 2D, 3D, and 4D CAD modeling. This comparison should help the reader gain a perspective of how each visual aid can assist them on their particular project. Industry members are able to see the benefits of 3D and 4D CAD, but the technology has not been fully received by the construction industry yet.

2D CAD

In spite of this growing technology, construction documentation largely remains in 2D format (Issa, Fukai, and Lauderdale). 2D visualization uses two location coordinates, which are the ‘x’ and ‘y’ variables. This means that the management team and the craftspeople in the field have to mentally visualize what the design intent is from the 2D documents. This process has mixed results to the differing levels of skill and experience among individuals. The bulky rolls of 2D documents do not support the decision making needs of the industry. Therefore, 3D or 4D modeling could be a benefit.

3D CAD

3D visualization introduces a third plane of visualization. This third plane is the 'z' variable. 3D drawings and virtual models are currently being used in the coordination of building systems, such as mechanical and plumbing trades (Issa, Danso-Amoako, and Fukai). But the use of this modeling has been slow to catch on in the construction industry. The reasons for this are shown below in Table 2.

Models allow everyone, be they lay people or highly skilled personnel, to understand and visualization starts the very second one's eyes see the model (Issa, Danso-Amoako, and Fukai). A major benefit of 3D is that construction problems can be addressed before they occur in the field. This will cut down on the amount of re-work needed as well as reduce the amount of change orders and RFIs. Other benefits would be better communication between the entire team and a better visualization of how a project would be constructed. According to Dr. Thomas of the Penn State's Civil Engineering Department, re-work accounts for average losses in the 40-50% range on a construction project. The losses in productivity are due to time spent to remove defective work, time spent in redoing work, schedule interruptions, and poor morale. The figure on page 34 of the appendix section shows an example in the visualization differences between a 2D and 3D model.

4D CAD

"4D modeling provides a mechanism to visualize elements of 3D CAD models based on associated schedule intervals. This technology allows project managers to evaluate construction plans for time and space conflicts between operations and building elements" (Riley 2000). 4D is produced by linking a 3D model to a schedule such as Primavera. Since 4D uses time intervals as an element, sequencing of trades would particularly benefit from the use of this technology. 4D would allow the user to see the work being performed, the storage spaces, and the material paths at a given time (Riley 2000). 4D models provide an added dimension to planning, allowing conflicts to be evaluated between building components (Riley 2000). Major visualization benefits of 4D modeling include:

- ✓ Work Space
  - o 4D allows you to easily visualize a work space and see who and what is being constructed at a given time.
- ✓ Storage Spaces
  - o Storage spaces are always important in construction. 4D allows you to see where the spaces will be located at a given time. This eases congestion on a work site.
- ✓ Work Flow
  - o 4D allows you to visualize the work flow as the construction schedule has it determined. This will make coordination and construction easier and allow for better productivity.

Dr. David Riley wrote that a major challenge to construction managers is the conceptualization of how work crews, equipment, and materials will compete for limited available space during a construction project. He went on to say that 4D requires five elements for an effective model. They are special information, balance project needs, increase in detail is needed, communicate the plans, and involve project participants in planning (Riley 2000). The Virginia Capitol could benefit from this technology by applying their work space, storage areas, material paths, and access points to the model. This would allow the team to visualize the sequencing of trades and communication would improve due to this feature.

There is a shortage of skills in the area of construction planning, with the number of experienced planners having the knowledge or ability to effectively plan construction projects decreasing (Heesom 2004). It was also found that experienced project managers have very little time to plan on most construction projects (Heesom 2004). 4D CAD would be a major benefit for planning, but there is very little use of this technology currently in progress in the construction industry. According to Riley, one main reason for this may be due to the fact that 3D modeling is not used often in the industry.

Feedback from industry members

1. *Have you used 3D CAD on a construction project before?*

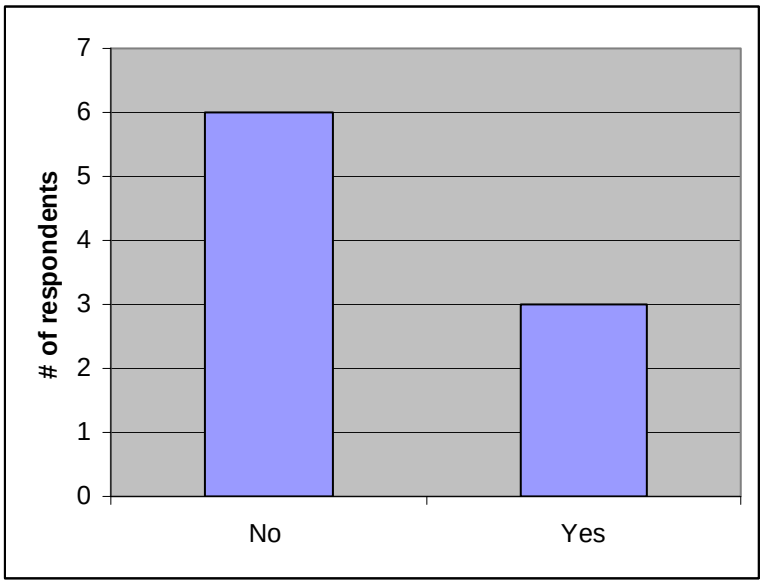


Figure 2: Respondents to using 3D CAD

2. *Have you used 4D CAD on a construction project before?*

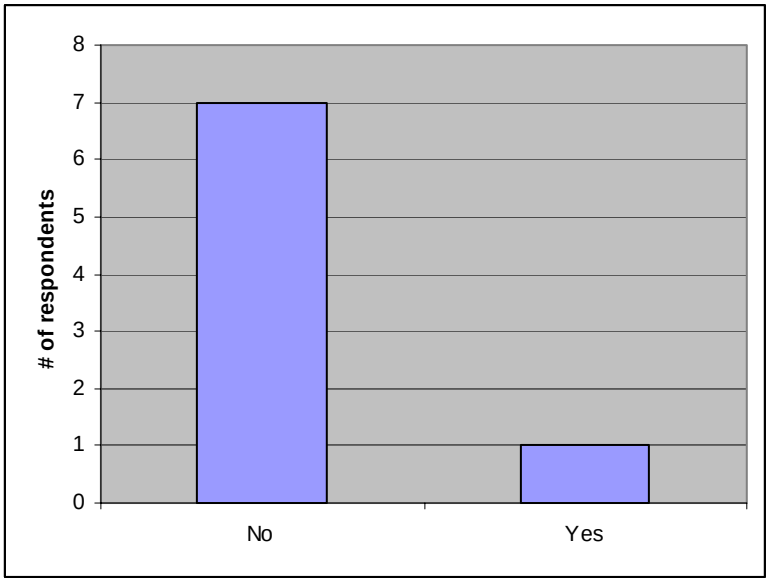


Figure 3: Respondents to using 4D CAD

3. *In your opinion, will CAD ever be widely used in the construction industry?*

   Everyone responded yes to this question, but the majority of respondents said that it will mainly be used on complex jobs like hospitals and labs.

4. *What are the advantages of 3D and 4D to 2D?*

Advantages of 3D	Advantages of 4D
Visualizations are better	Visualizations are enhanced
Forces trades to build the job and make it fit into a space	Shows work flow, work spaces, material flow, and storage at a given time
Materials can be shop fabricated more easily after using 3D CAD	Able to see schedule sequence better than the Gantt chart
Expedites the construction in the field	Personnel does not have to be skilled to visually see construction sequence
Reduces construction cost	Reduces construction cost
Increases clarity of the design	Increases clarity of the design
Allows project team to find interferences	Allows project team to find interferences
Good for MEP coordination	Good for MEP coordination
Able to create 2D drawings by slicing the 3D model	Better understanding of the structures and systems
Better understanding of the structures and systems	
Good for quantity take-offs	

Table 1: Advantages of 3D and 4D CAD

5. What are the major obstacles/drawbacks to 3D and 4D CAD?

	Obstacles / Drawbacks of 3D and 4D CAD
1.	Unwillingness of current industry members to learn the new technology (Old dos do not want to learn new tricks)
2.	Upfront time and cost of the new technology
3.	Finding someone with technical expertise to use the 3D or 4D model and cost associated with the person
4.	Time to produce the model and obtain the needed accuracy
5.	Changes in the design or sequencing of the construction requires the re-rendering of the images and updating the 4D project; therefore longer to make revisions
6.	Not efficient on simple projects
7.	Having the entire team buy into the usefulness
8.	More use of computers would equal less time a person is looking at the drawings themselves. This would cut down on their technical knowledge of the project

Table 2: Obstacles of 3D and 4D CAD

With this feedback from industry members, it is easy to see that the industry can see the possible benefits of using this technology, but 3D and 4D modeling is not very prevalent in the construction industry at this time. There are many reasons for this, but the main reason may be the unwillingness of current industry members to adapt to a new technology. The industry also needs to see the start to finish gains in project cost, schedule, and productivity instead of looking at the upfront cost and time.

Virginia Capitol

This research ultimately ties into the Virginia Capitol project because the building has tight spaces for the MEP work and the work may be sequenced in order for the tenants to move out. Due to security reasons, this research could not obtain the CAD files from the architect, but a proposed phase plan was introduced. This plan breaks the building into three large areas as seen in following figure. These areas could then be renovated in succession allowing the tenants to occupy certain spaces at certain times.

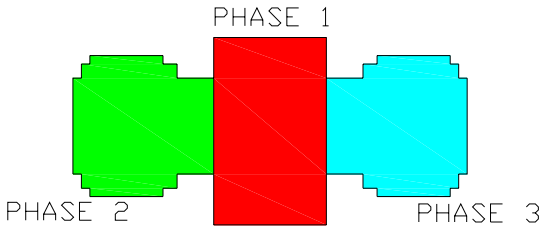


Figure 4: Proposed phased construction plan

There are a few concerns when a project is under construction while it is being occupied though. The main concern is safety. The areas would have to be separated by temporary partition walls to insure that a tenant cannot enter a construction area. A main concern on this project would be security. Security could be improved by implementing a card reader system for the construction workers entering the building. This would insure that only classified workers could enter the building at a given time. Other security measures would be the partition walls and added security guards on the premises. Another issue would be noise. The partition walls would have to have a certain amount of resistance to noise and some of the louder work would need to be performed during off hours. These are all concerns that would have to be addressed before implementing a phasing plan like this.

Conclusions

Project: The previous proposals provided solutions to requests for value engineering, schedule reduction, and constructability on the Virginia Capitol Extension and Renovation. Some of the considerations were more valuable and useful than others. These proposals not only took factors such as cost and schedule into mind, but they also considered the whole process and what added value to the owner. The approved quantifiable analyses cost the project $3,600 and 2 days in schedule, but it saved the project team 168 labor hours and improved the quality of the structure. The overall affect of the proposals were good as the building will be built with a more enhanced process and with better quality.

Personal: In my research and analysis efforts throughout my Senior Thesis work, I have gained a great deal of knowledge. I have learned to think with a broader view. Not only can you think about one particular system or idea, but you have to see how each system works together and who will all be affected. In the process of doing this, I have new knowledge about different construction systems and different views of what needs to be completed on a construction project. One finding throughout my research was that the majority of industry members are difficult to contact. The reason for this is probably due to the fact that these people do not have much extra time to talk to a college student.

All of my work during senior thesis has benefited me in many ways. I have learned a great deal about the construction process, the construction industry, and the people that are involved in the whole process. It has been a fulfilling part of my college career at the Pennsylvania State University.

References

Precast vs. CIP

Fiori, Christine. "What's Wrong with Working in Construction? How Image and Diversity Issues Are Affecting the Shortage of Skilled Labor." ASCE: Construction Research 2003.

Menard, Robert. "Why Precast Costs Less." Precast Solutions Magazine: Spring 2004.www.precast.org/publications/solutions/2004spring/whyprecastcostsless.htm#top

NPCA. Building, Housing, Landscape & Specialty Products: Precast Concrete Wall Panels. http://www.precast.org/specifiers/wall_s.pdf

Recessed Computer Access Flooring

Maxcess Technologies Inc. RWC Series Panel Access Flooring. http://www.maxcessfloors.com/rwc_main.cfm

R.S. Means 2005. Building Construction Volume.

Technology and Sequence of Trades

Akinci, B., Tantisevi, K. and Ergen, E. "Assessment of the Capabilities of a Commercial 4D CAD System to Visualize Equipment Space Requirements on the Construction Sites." Carnegie Mellon University.

Gott, Brian. Evolution from 2D to 3D - a product development manager's perspective: Part II. April 2004. http://cgweb.co.za/Article.ASP?pklArticleID=2977&pklIssueID=466

Heesom, D. and Mahdjoubi, L. "Trends of 4D CAD Applications for Construction Planning." Construction Management and Economics. February 2004.

Issa, R.R.A., Danso-Amoako, M. and Fukai, D. "Evaluation of Computer Anatomic Modeling for Analyzing Pre-Construction Problems." Rinker School of Building Construction.

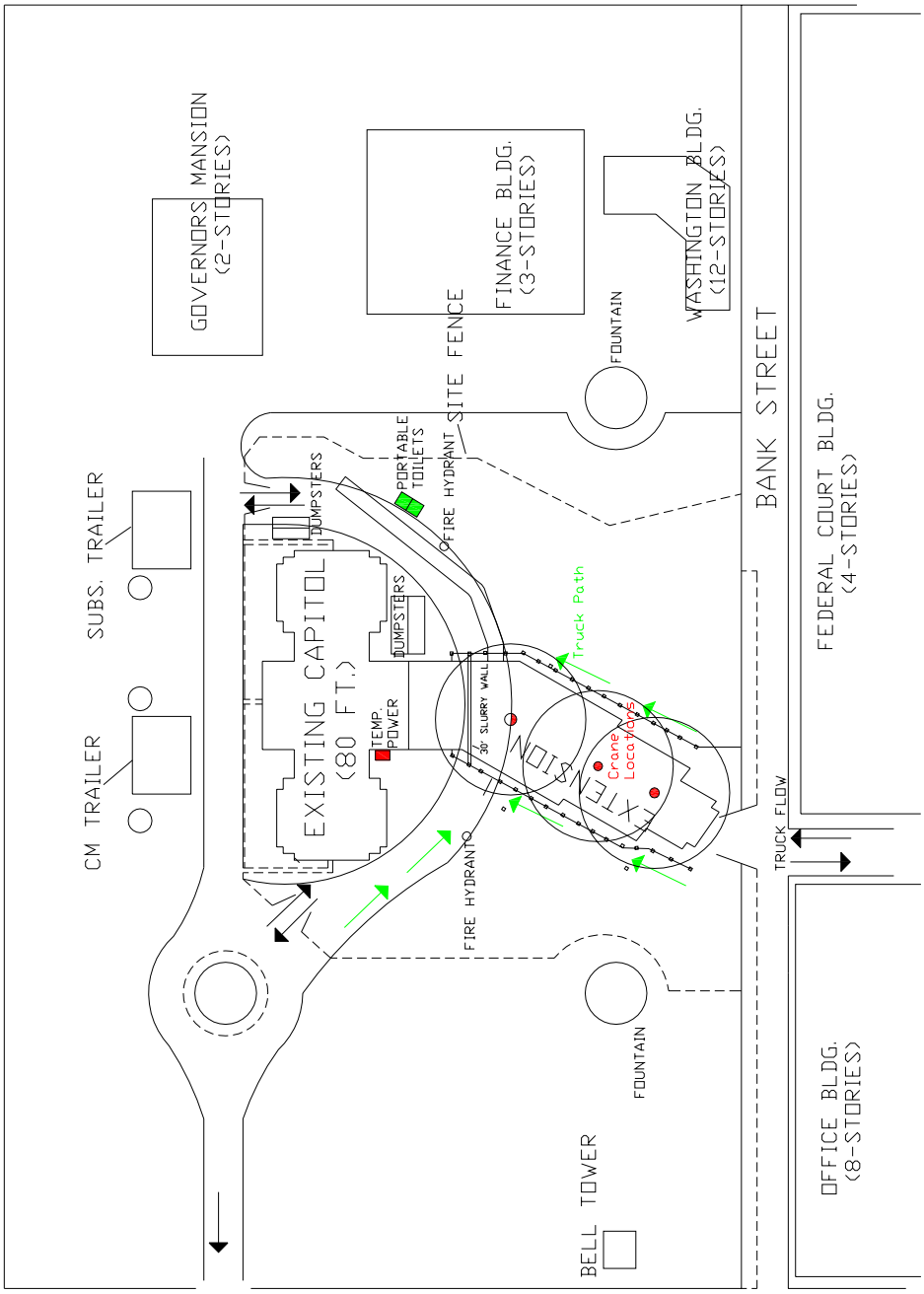
Issa, R.R.A., Fukai, D. and Lauderdale, G. "A Study of 3D and 2D Construction Drawings Acceptance in the Field." Rinker School of Building Construction.

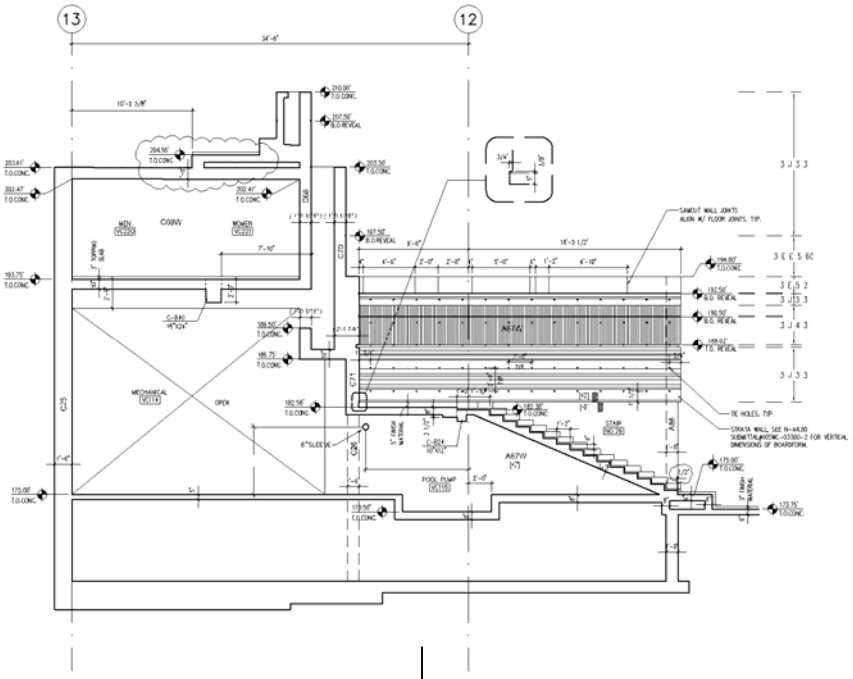
References (cont'd)

Riley, D. (2000). The role of 4D Modeling in the Trade Sequencing and Production Planning. Proceedings from 4D CAD and Visualization in Construction Workshops, Feb. 24-25, 2000.

Tan, Bo. "A Visual Process for Planning Trade Flow on Construction Projects." Pennsylvania State University Thesis. May 2005

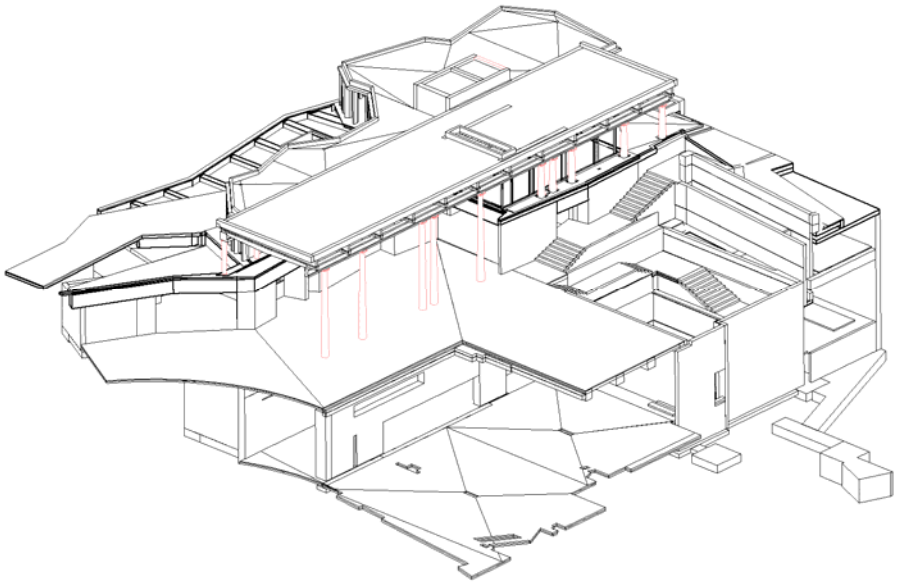
Crane Locations for Precast Walls and Beams (shown in red dots)





Building Section view (Image from Morley Builders)

The difference in visualization between a 2D and a 3D model.



3D Model of the Building Section (Image from Morley Builders)

Recessed Computer Flooring Takeoffs

Rooms	SF of tunnel space (precast planks & floor topping)	Perimeter
1st Floor Rooms	2246 SF	886 LF

	Recessed Floor	**Concrete Tunnels and Precast Planks**	Cost per sf/CY	Total Cost
Slab on Grade (1st Floor)	0 cy of concrete	14 cy of concrete	210	2,940
Access Flooring	2246 sf of flooring	0 sf of flooring	11.85	26,615
Precast Planks (6 " thick)	0	2246 sf of plank	7.7	17,300
Trench Concrete	85 cy	85 cy		
Total Cost (not including trench conc.)	**$26615.1**	**$23,000**		

Schedule	**Total Days**
Recessed Floor	5
Plank and Topping Slab	4

Precast and CIP Takeoffs

Concrete Beams	Qty.	L	W x D	CY	CIP App. Cost Each	CIP Cost	Precast App. Cost Each	Precast Total Cost
B1	1	20'	30x36	5.5	4950	4950	3000	3000
B2	1	20'	12x24	1.5	1350	1350	1300	1300
B3	1	32'	12x36	3.5	2993	2993	2325	2325
B4	1	18'	18x24	2	1850	1850	1000	1000
B5	28	26'	12x20	1.6	1376	38528	1375	38500
B6	8	36'	12x20	2.2	1826	14608	1650	13200
B7	22	30'	12x20	1.9	1624	35728	1425	31350
B8	1	46'	12x14	2	1700	1700	4000	4000
B9	1	10'	8x24	0.5	525	525	700	700
B10	1	10'	8x24	0.5	525	525	700	700
B11	1	10'	8x16	0.4	420	420	650	650
B12	1	10'	8x23	0.5	525	525	700	700
B13	1	10'	8x23	0.5	525	525	700	700
B14	1	10'	8x23	0.5	525	525	700	700
B15	1	10'	8x23	0.5	525	525	700	700
B16	1	10'	8x23	0.5	525	525	700	700
B17	1	10'	8x23	0.5	525	525	700	700
B18	1	20'	12x18	1.2	1080	1080	1200	1200
B19	1	20'	24x24	3	2700	2700	1425	1425
Total	**74**			**28.8**	**Total Cost**	**121118**	**Total Cost**	**113905**

Approximately 22 pieces per day = 6 days
Approximately 16.10 cy per day = 4 days

Foundation Wall

	Concrete Wall
CY of Concrete	820
SFCA	23824
Cost per SFCA	12.6
Total Cost	**300182.4**
Daily Output (SFCA)	315
# of days	76

	Precast
SF	11900
Cost per SF	26.5
Total Cost	**315350**
Daily Output (SF)	350
# of days	34

There would be a total of 97 precast panels.