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.

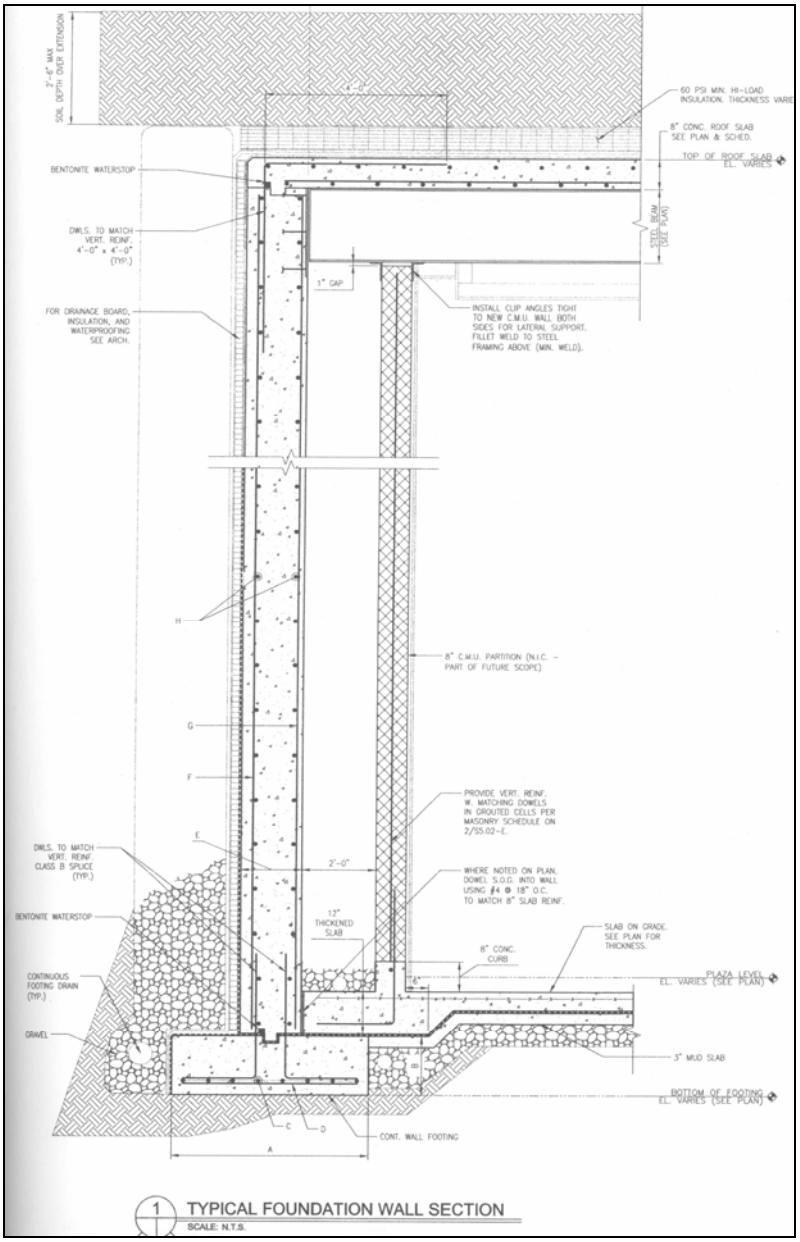
- *Existing Capitol:*
  - Utility Trench System
    - The existing trench is topped with a precast plank and a 2 inch topping slab. This serves as the access points over the utility tunnels. A RWC Series Access Panel will be investigated for this system.

- *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	

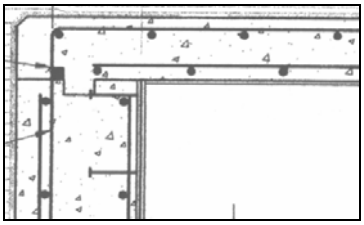
- **Design**
  According to Mark Taylor of Nitterhouse Concrete Products and Dr. Hanagan of the Pennsylvania State University Architectural Engineering Department, the design complexity is the biggest drawback with the precast system. Since the structure is subterranean and many slopes are involved in 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 32 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			

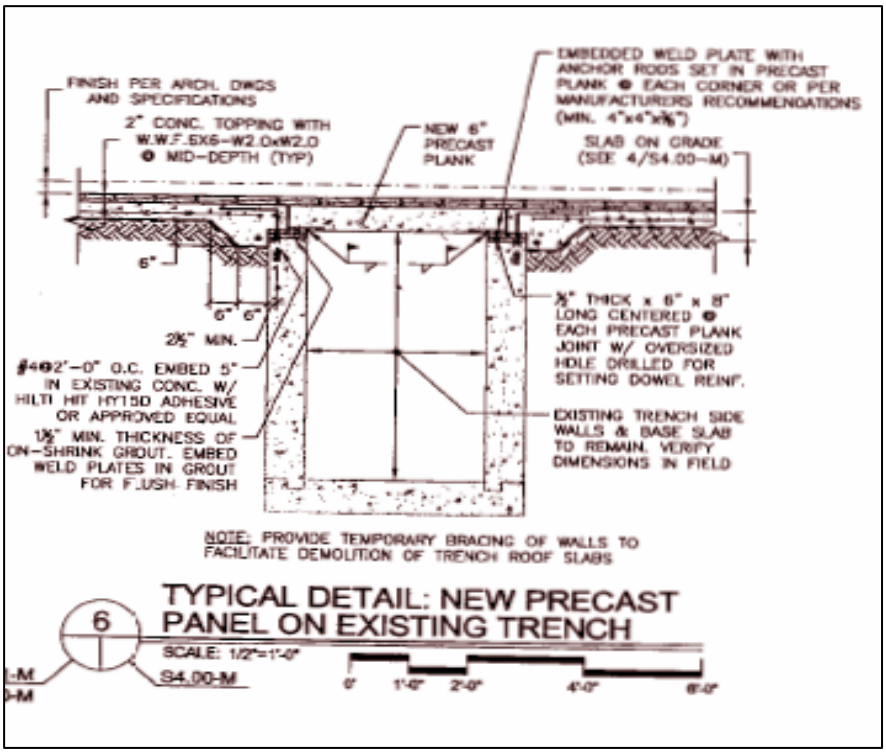
Figure 1: Comparison of different systems (MAPA Wall Panels)

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.

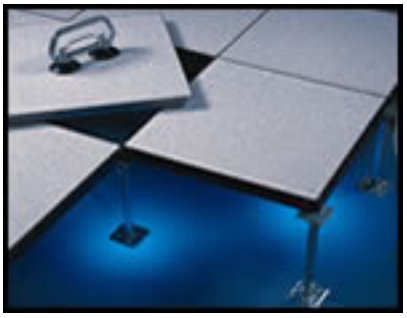
Change Plank and Slab System to Recessed Flooring

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**

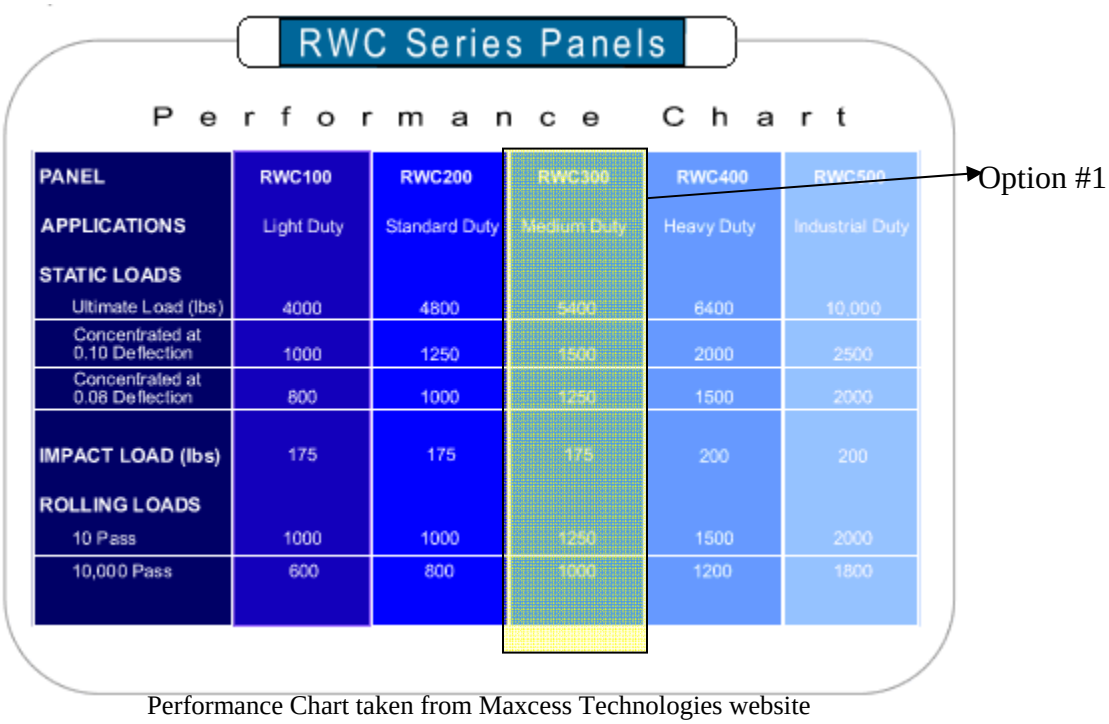
	Plank and Slab		**RWC Flooring**
	Planks	Slab	Access Flooring
Daily Labor Hours	72	88	16
# of days to complete	1	2	5
Total Labor Hours	248		80

  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 4.

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 33 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?*

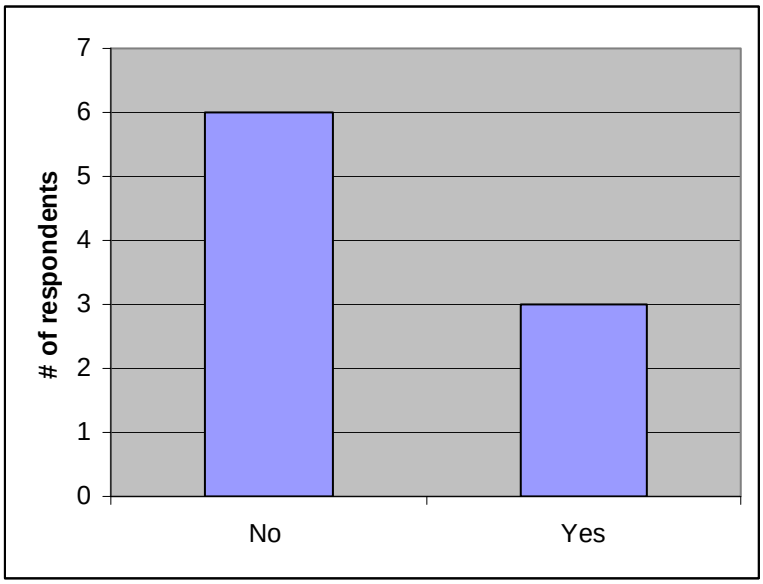


Figure 1: Respondents to using 3D CAD

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

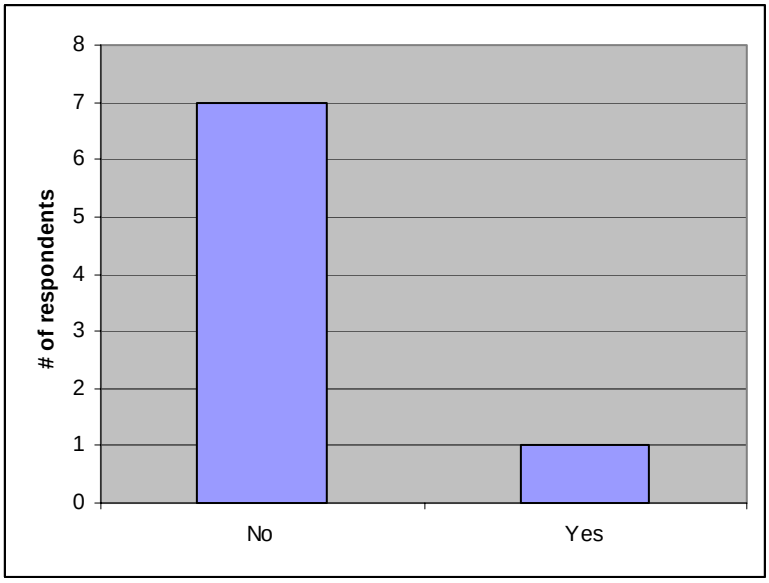


Figure 2: Respondents to using 4D CAD

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	

Figure 3: 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

Figure 4: 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.

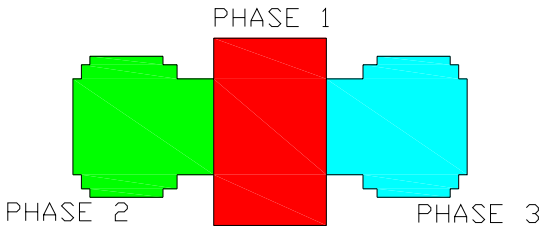


Figure 5: Proposed phased construction plan

The following is a revised schedule for the MEP and finishing trades.

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.