Technical Analysis:

4-Dimensional Visual Study of Building Envelope Construction

Introduction

The Center for Health Research and Rural Advocacy employs an expansive aluminum curtain wall system wrapping around the façade facing Centre Street. Numerous times in urban construction the curtain wall requires extra coordination to keep everyone safe and the workers productive. This curtain wall will be one of the signature aspects of the project and what most pedestrians, hospital employees, and researchers will notice everyday. Since the façade is in such close proximity to Centre Street, which is to remain fully operational during construction, workers and equipment have barely ample space to operate. Close coordination of erection, delivery sequencing, and even safety issues must be monitored by the management team and disclosed to other contractors on-site.

As a result of this curved design and proximity to the thoroughfare, a great deal of time and effort needs to be utilized in order to maintain proper construction sequencing and hazard control. Shop drawings provided by the curtain wall subcontractor coupled with the CPM schedule produced by Geisinger facilities accounts for the main management plan for the curtain wall construction. The development of the schedule and management plan most likely was developed by an engineer and took many aspects into consideration from the construction documents for the project. While the information contained in safety plans, schedules, and sequencing is extremely useful for on-site workers and superintendents who have experience reading them, often times the information is hard to comprehend by other parties.

Since buy-in by all project participants is extremely important to the project's success, utilizing a virtual reality application to display all the construction issues will be beneficial. The 4-dimensional analysis of the building envelope can be used as a tool to help convey construction and safety issues easily to other contractors. This analysis will take a look at the benefits a 4-D CAD model would display for building envelope construction of the Center for Health Research and Rural Advocacy.

Construction Sequencing

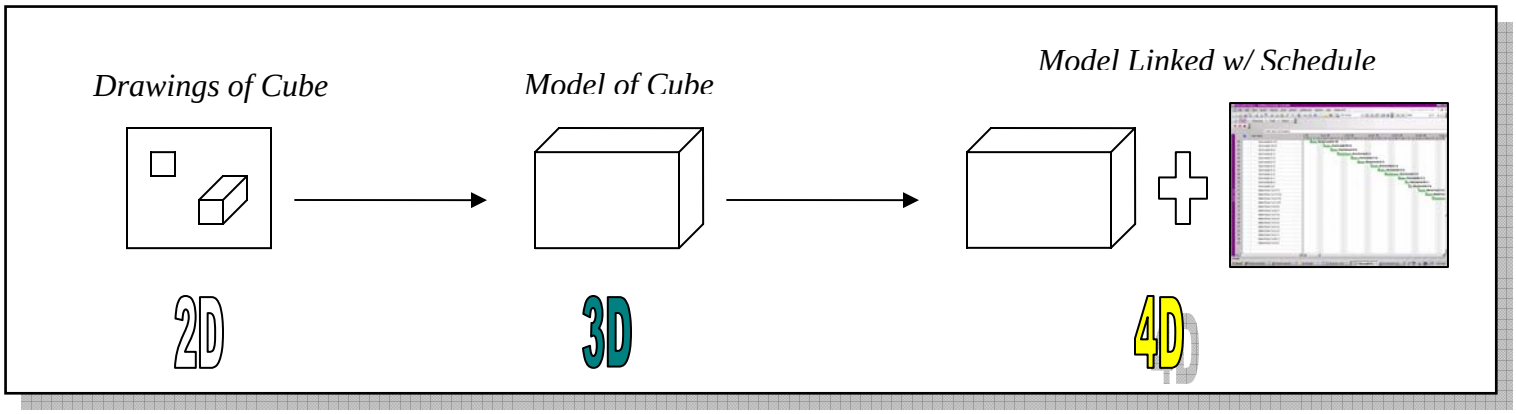
Developing an adequate management plan to properly coordinate all construction, safety, and even material delivery issues can be time consuming and difficult to display to other project participants. The pre-cast panel contractor may not understand the curtain wall contractors shop drawings and scheduling details. If these contractors are working in adjacent areas, it will be beneficial to visually show hazardous safety areas, crane locations, staging areas, and even sequencing.

The sequence developed contains pertinent information provided by the subcontractor, as well as the overall project knowledge possessed by the construction manager. Curtain wall construction will be done by column lines with the aluminum framing materials erected first, followed by the glass and glazing. Pre-cast architectural concrete is sequenced by elevation since the activity has the smallest duration of the envelope system. The relationships of the different envelope trades are difficult to picture visually as the sequence proceeds around the facility. Issues such as safety hazards and staging areas, which are not seen on a CPM schedule, can be visually identified easily through the use of a 4D site logistics study. Please reference the project schedule for the exterior skin located in Appendix C.1.

Development of 3D/4D Virtual Simulation of Building Envelope Construction

For help analyzing the building envelope construction sequence, a 3D model of the project has been developed as well as a 4-dimensional model for the façade construction. The 3D and 4D models will be used to justify changes in sequencing, site logistics, safety areas, and other concerns which may arise while viewing the model. To develop an accurate 4D model, the user must start with the 2-dimensional drawings of the project. From the drawings and specifications, a model of the building can be erected in a drafting program. To link this 3D model with time, building components are attached to their activities and durations in the project schedule. The facility can now be viewed and displayed for all relevant parties so they can comprehend the sequencing issues. This is a very effective way to help owners visualize the construction sequence without showing them a two-thousand activity schedule. Figure 2.1 graphically shows how to develop a 4-D model.

Figure 2.1 Development of a 4D Model



The 3-dimensional model for the Center for Health Research and Rural Advocacy was developed through the use of AutoCAD 2006 software. Aspects of the model are representations of the construction documents with emphasis on the envelope systems. The different façade types are displayed differently in order to conceptualize the interaction between trades. Interior modeling was used to identify proper elevations, connection locations, and accurate geometry. The model was developed in order to portray the following attributes:

- Temporary facilities, i.e. jobsite trailer, temporary fences
- Crane locations during envelope construction
- Access roads and site restrictions of adjacent buildings
- Staging areas
- Facility façade representations
- Trade interaction

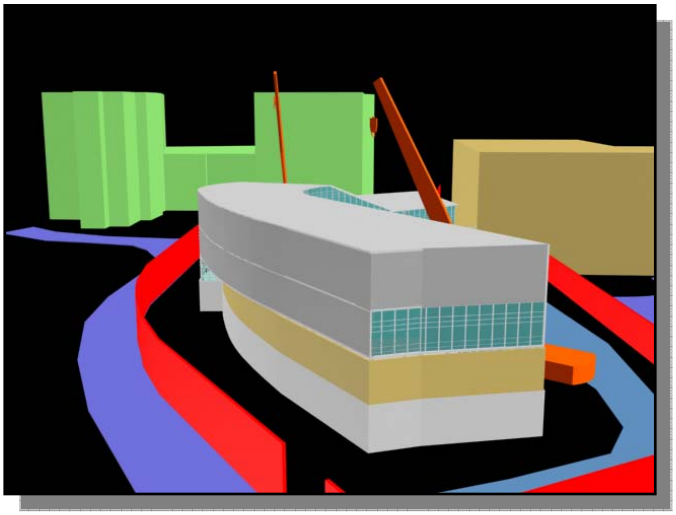


Figure 2.2 Perspective of West Elevation

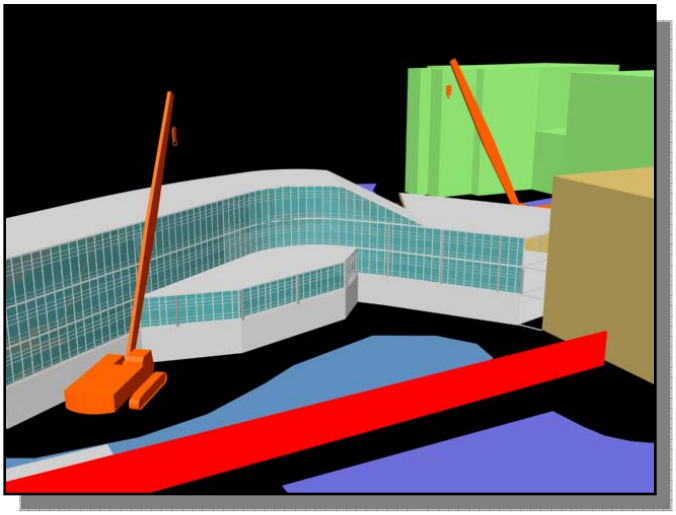


Figure 2.3 Perspective of South Elevation

Viewing the model may be completed within AutoCAD or by using virtual reality software. Exporting into a VRML file type allows users to interactively view and navigate the model easily over the internet or perhaps across a project website. Project websites can have these models of different construction activities available for all contractors to view and understand prior to starting their sequence of work on-site. Updates or changes in sequencing issues can be displayed and available for all subcontractors. This has potential benefits as revisions to CPM schedules require attention and time to determine changes. The model can simply be re-linked to the updated schedule and viewed instantly.

As seen in the figure below, the modeler can locate all site logistical issues such as adjacent facilities and staging areas. Shake-out areas for mullions and glazing will be virtually placed on the CHRRA project site to view possible challenges and sequencing issues. This is very beneficial for the management team since the site is extremely tight and space is not a luxury. Different logistic ideas can be modeled and discussed by project team members to determine the best location for all the temporary needs, thus eliminating the need to re-organize the site during construction due to discrepancies. Even through viewing the rendering of the project site some logistical issues can be derived. Deliveries will need to maneuver around the rear of the crane which will need to be monitored to ensure safety for all on-site personnel.

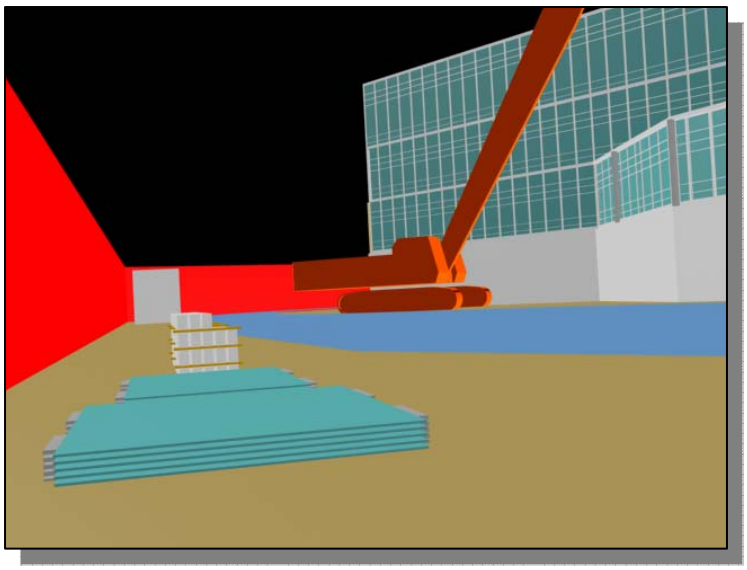


Figure 2.4 Crane and Staging Areas

The façade construction is grouped into manageable sections based on column lines, identical to the construction schedule developed for the project. These clusters will be employed by the 4D model to link portions of the construction process with the schedule. Each trade will have a

different color representing their construction activity so the management team can easily see where the crew should be working on any given day.

Upon completion of the 3D model of the CHRRA, the linking of the schedule with the façade parts became the next priority. Development of the 4D model was completed in the Navisworks Jetstream application, to create a representation of the envelope erection sequence. This application allows the modeler to create separate visual representations for each trade. For the Center for Health Research and Rural Advocacy project, the aluminum framing and glazing is shown as a transparent red when under construction, pre-cast is a transparent green, and metal stud and paneling is a transparent purple. Viewers can easily identify which crews are working in the designated area at any moment in time during the project schedule.

Implementing and using the 4D model can be done in a variety of ways. Project managers can print snapshots of the virtual project for a specific date and tape it to the trailer wall. Superintendents for the subcontractors can quickly and easily see what the project should look like on that date, and can quickly assess if they are on schedule or behind. This type of visual feedback is beneficial, not only for the management teams, but also for the laborers who can see their progress without the difficulties of navigating through a project schedule. Depending on the extent and detail of the 4D model created, mangers can simply take a laptop during their daily walk-through and quickly see if the sequence is being followed or deviated from. The model can also help alleviate complications with an owner who is worried the project is not on schedule. By showing the 4D model coupled with pictures of actual construction the owner can easily comprehend how the schedule is derived and implemented. This will eliminate some major issues with percent complete arguments during payment application.

The following section depicts the 4D model developed for the Center for Health Research and Rural Advocacy with brief descriptions of the process under virtual construction.

4D Virtual Simulation for Building Envelope Construction

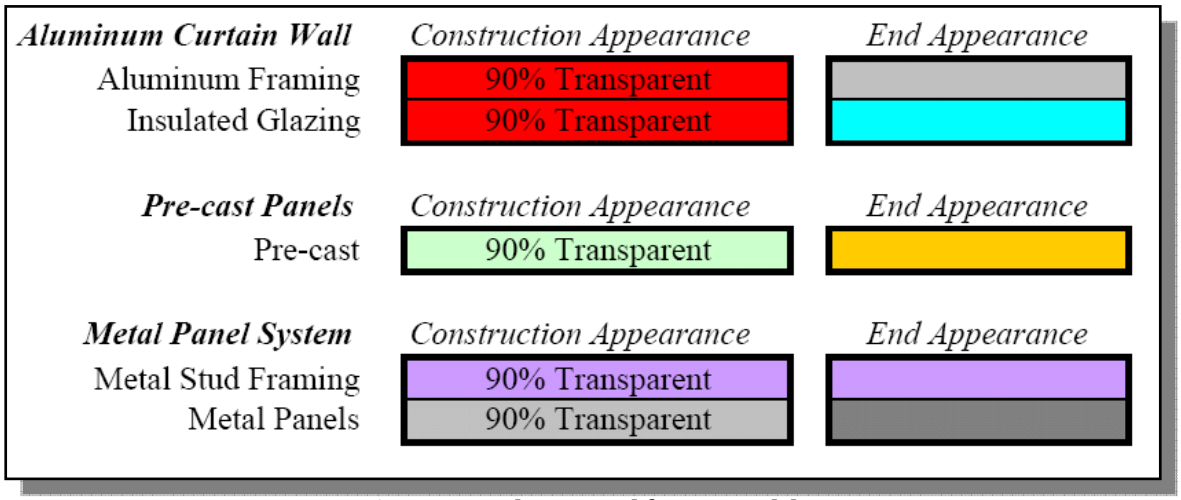
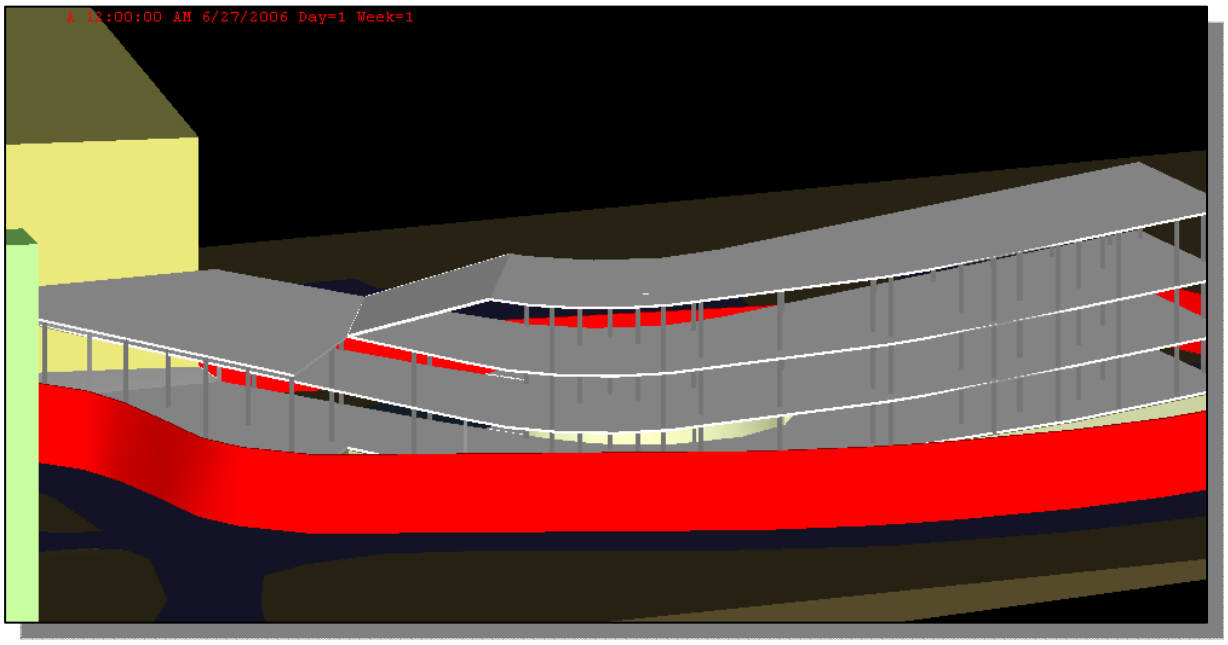
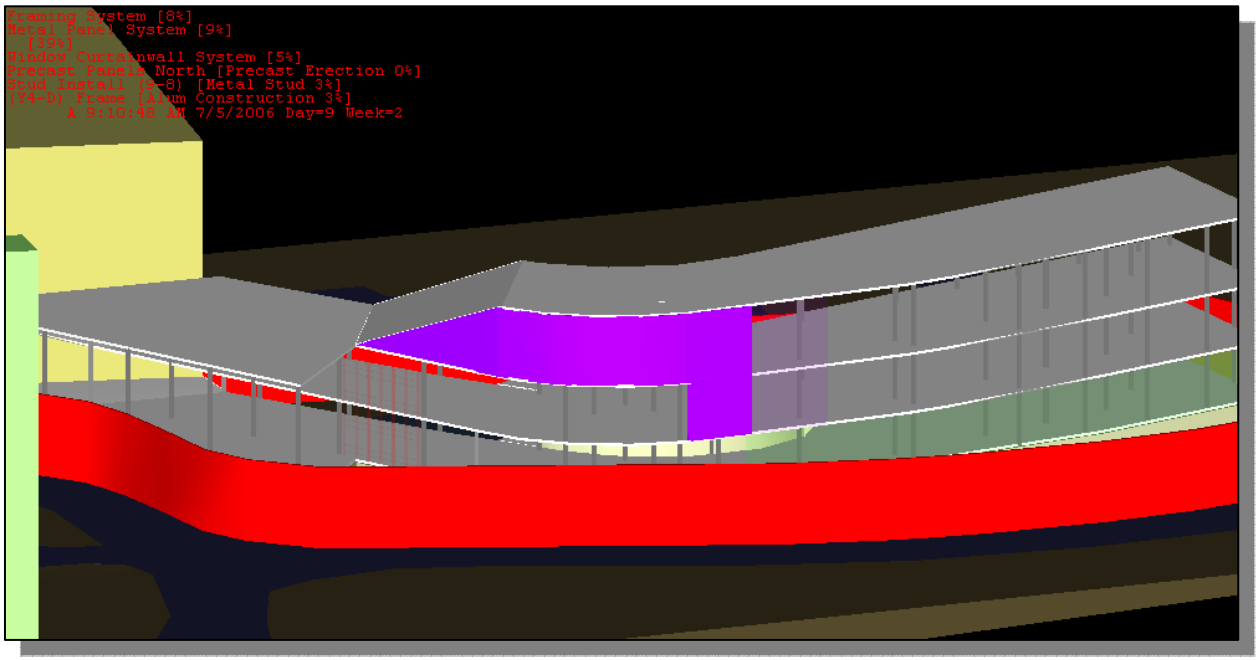


Figure 2.5 Color Legend for 4D Model



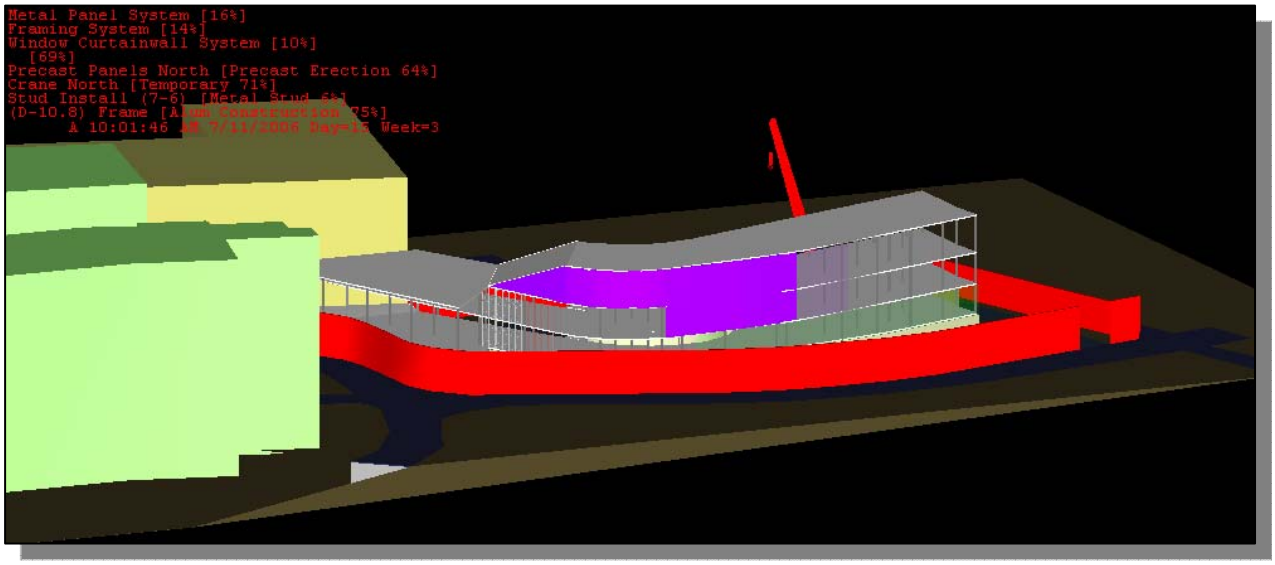
(6/27/06)

The figure above shows the project at completion of the structural frame on June 27, 2006. The fence is represented by the eight foot red line running perpendicular to the north face of the building. In front of that fence in the foreground is Centre Street, which as stated earlier, is to remain fully operational throughout construction. Construction will begin on the North elevation of the project which is the one shown above.



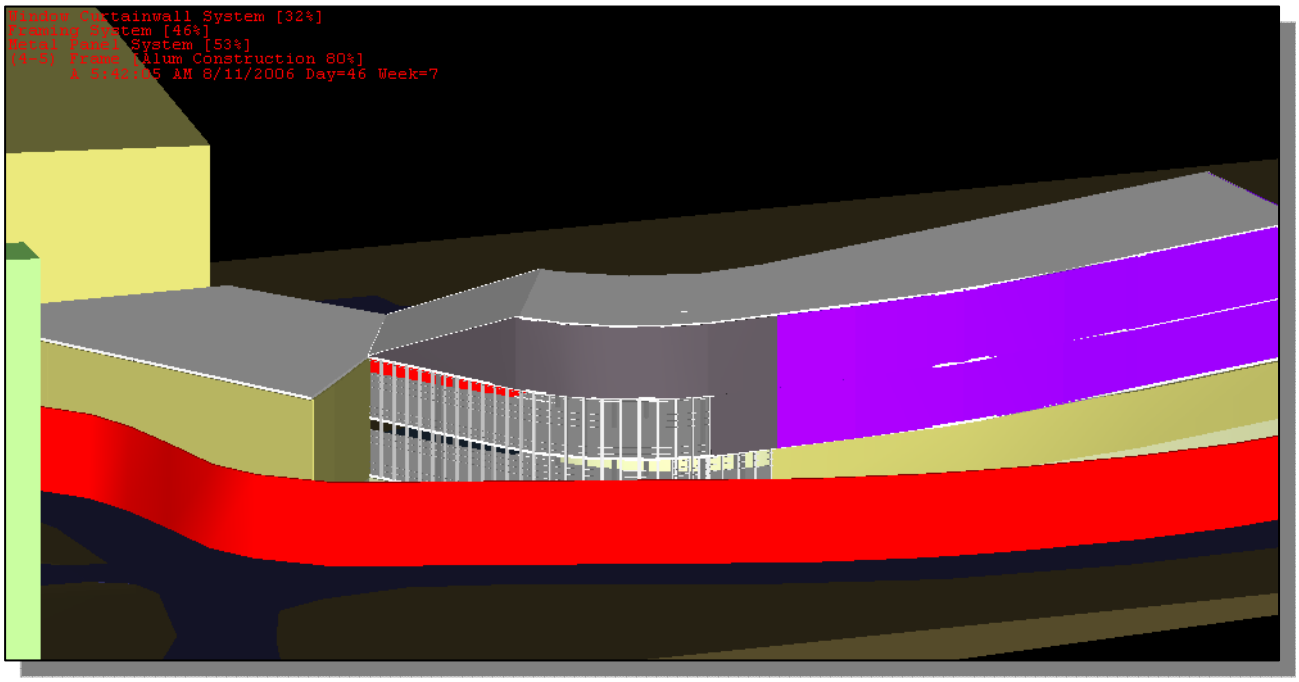
(7/5/06)

Construction has begun on the North elevation with all three of the façade systems starting to be installed. Metal studs have been erected across the third floor space, with the aluminum curtain wall framing constructed underneath the finish studs. Pre-cast installation has started on the first floor as well.



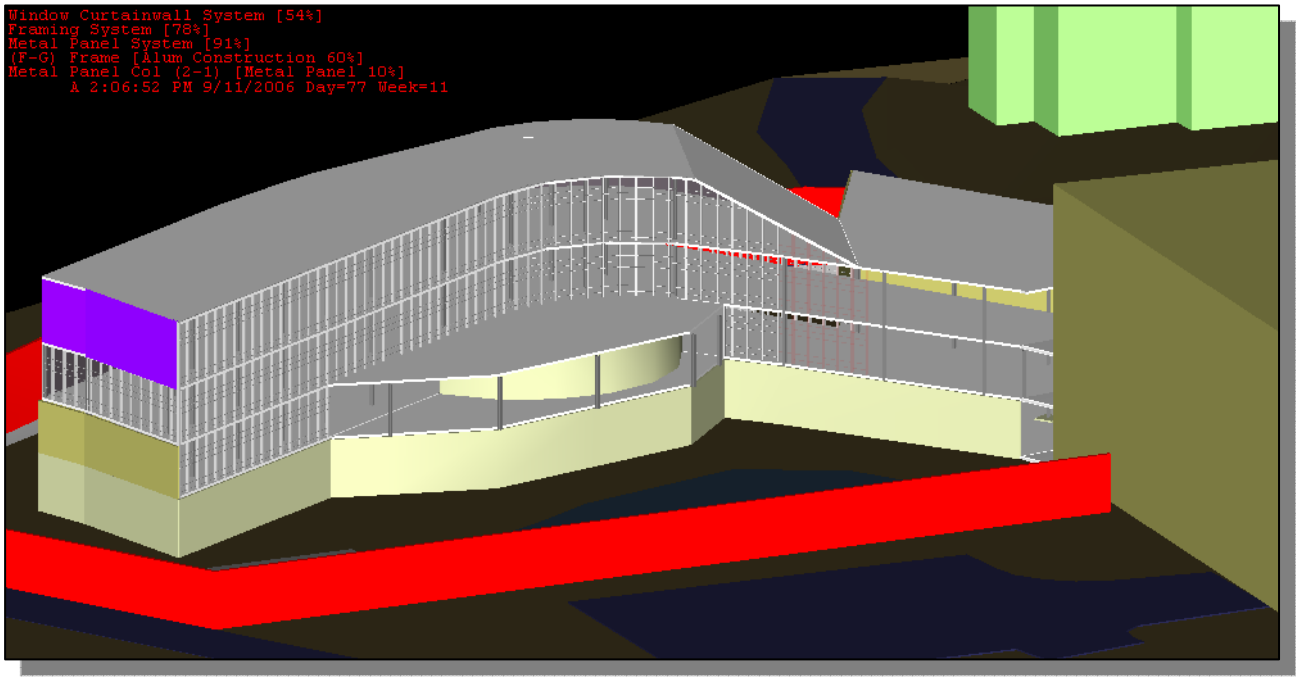
(7/11/06)

The crane has been mobilized for the pre-cast panel erection. Stud framing is being installed on the second and third floors of the north elevation and the aluminum framing is still being erected near the lobby entrance. There is a flurry of activity on the north elevation and this may cause some headaches for the crew foreman for each of the subcontractors.



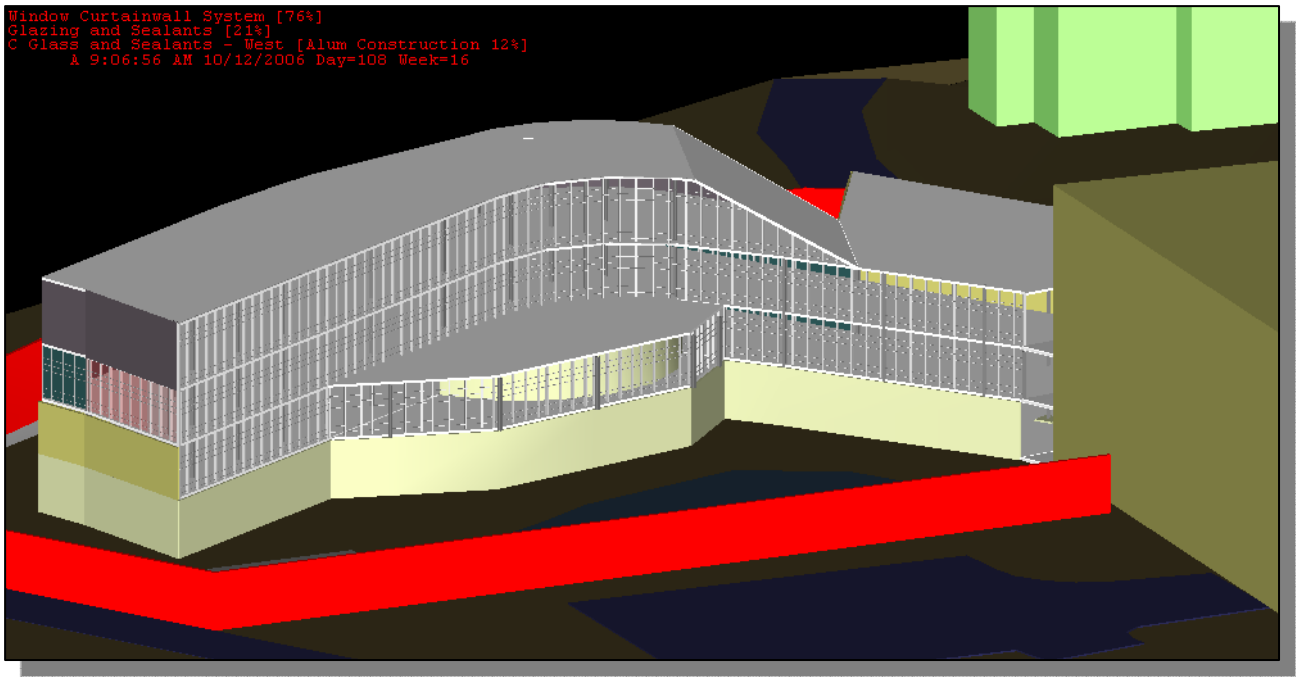
(8/11/06)

Envelope construction has gotten into full swing with the completion of the pre-cast panel installation on the North and West elevations. Aluminum framing has been completed at the lobby area and is waiting for glazing and sealants. Metal panels are being installed on the third and second floors of the North Elevation.



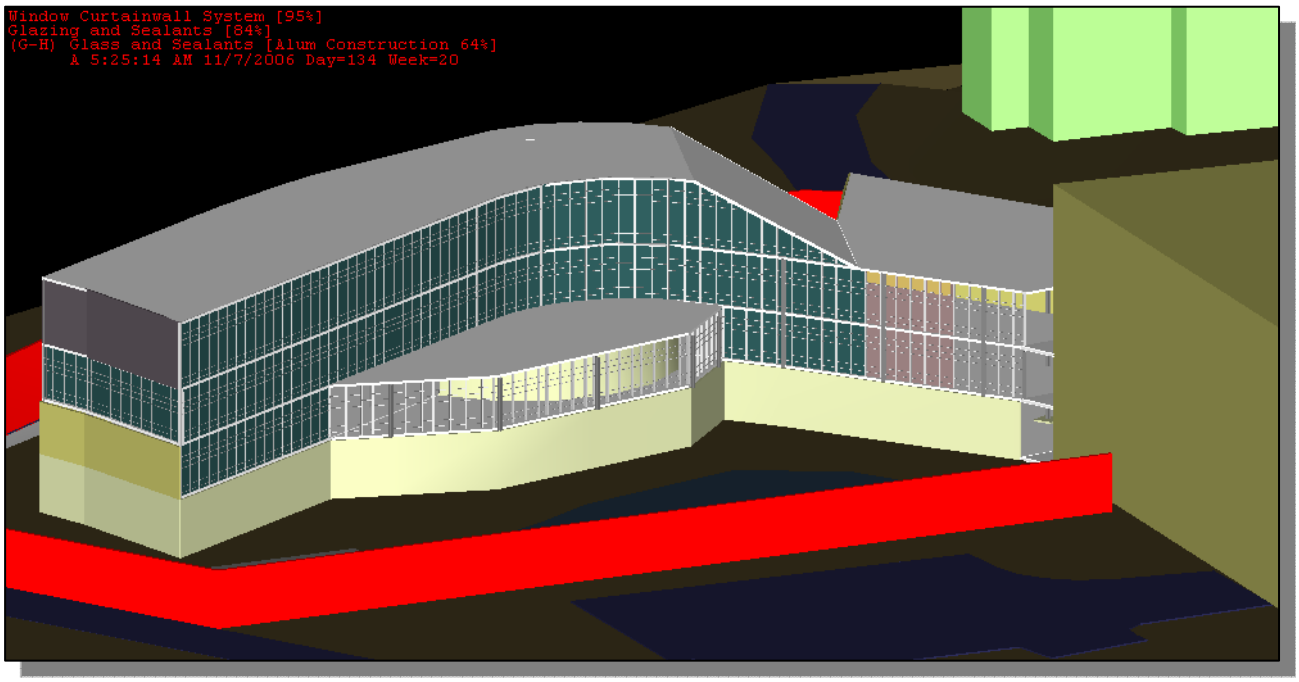
(9/11/06)

Framing for the expansive aluminum curtain wall system on the South elevation of the project is almost completed. Metal panels need to be installed on the third floor of the East elevation.



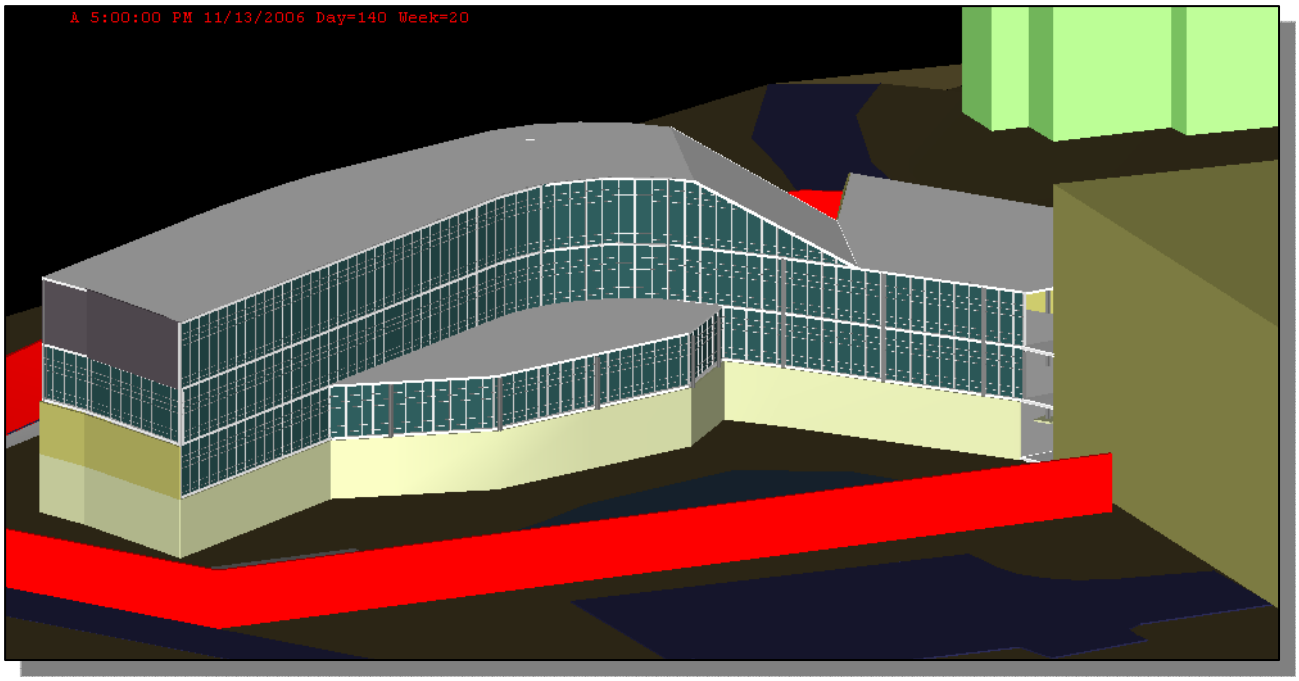
(10/12/06)

Glazing is currently being placed on the second floor on the East elevation. The framing of the aluminum curtain wall is completed and awaiting the remainder of the glazing to finish the exterior envelope system.



(11/7/06)

The signature aspect of the project is starting to come together. Four months since starting the façade construction the CHHRA skin system is almost completed. The South elevation needs to be finished as well as the open café area on the first floor.



(11/13/06)

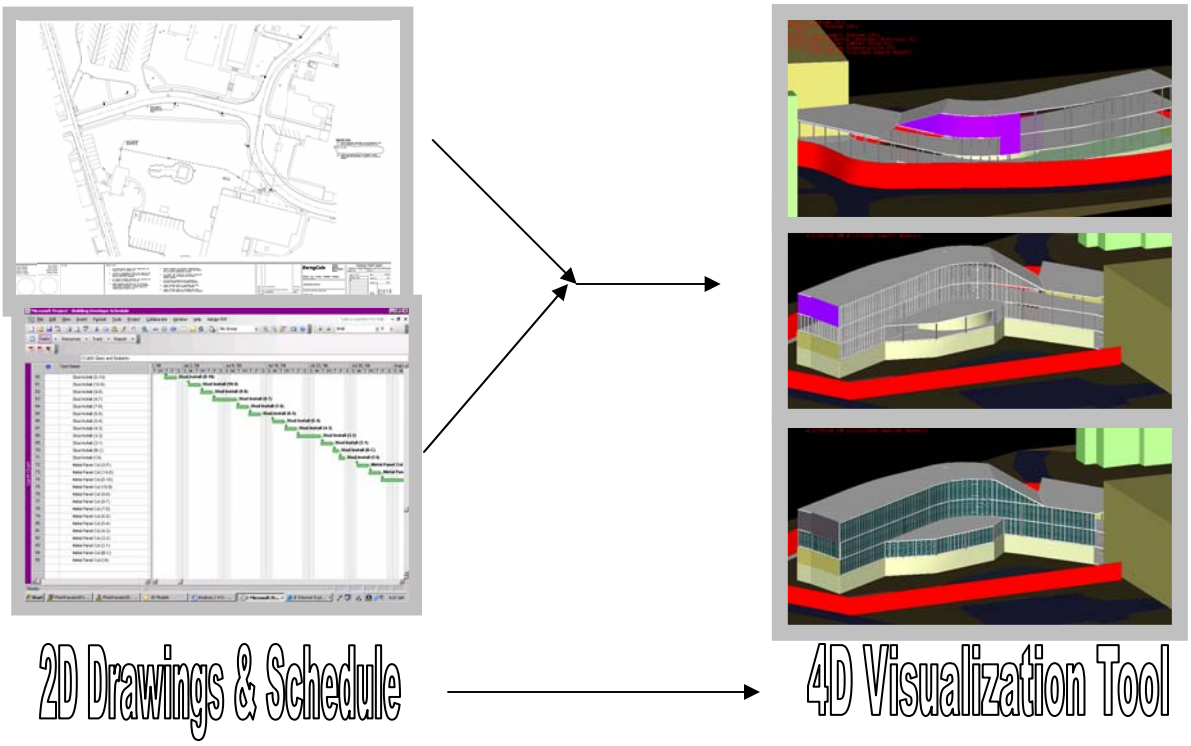
Building envelope has been completed for the Center for Health Research and Rural Advocacy and thus completed the enclosure of the facility. All interior work can begin on schedule and with protection from the harsh Pennsylvania winters.

Any project participant can take a look at this representation of the sequence and quickly see the progression of trades around the building perimeter. To reach the same conclusion would take some intuition and experience reading architectural plans and the project schedule. This example demonstrates the ease of displaying a linked schedule to a 3D model for a project. 4D models can be used for any sort of construction activity, ranging from site development and foundations, to MEP installation or finishes. The limits of this type of application are endless, and can bring even more benefits to complex projects.

2D Drawings & CPM Schedule vs. Developed 4D Model

Even with all the potential benefits of utilizing a 4D model on every project, some construction managers still believe the costs outweigh the potential advantages. So why is this misconception leading to the underutilizing of such a powerful tool? Some team members may just be intimidated by the technology and are worried about relying on a computer instead of personal experience. These models are developed to assist with project management on construction projects, and to find issues that may have not been addressed. 4D models can act as a check to

the schedule to ensure that many of the challenges are considered and addressed. Others still insist that developing the model and linking the schedule will be too expensive. This may be true if a construction manager is requiring all activities in a two-thousand plus activity schedule be linked to an object or solid in a CAD model. Compiling all that information is time consuming and costly, and most likely will not outweigh the benefits accrued. Creating summary activities and linking them to a basic model can be done relatively quickly and can have large impacts on a project sequence. The model created for the Center for Health Research and Rural Advocacy project took approximately 15 hours by one individual. Linking the model created to a cut-down version of the CPM schedule already developed for the project is quick and easy. Once the model is linked with activities on the schedule, changes or multiple iterations on that schedule can be done virtually instantaneously. The 4D model can be viewed interactively with all party members, to ensure that everyone is looking at the same conflict. As is seen in the following diagram, the combination of the 2D drawings with the schedule allows the management team to view the building at any moment in time and from any location.



Along with the added value of visualizing the sequence of trades, materials, deliveries, etc. is determining future challenges and taking steps to prevent or alleviate future headaches. There have been numerous examples where 4D CAD models have saved contractors weeks from the

schedule, such as the Shirlington Condominium project in Viriginia. Building construction was behind schedule and the interaction of project participants with a 4D CAD model help to initiate positive ideas to gain time on the project. This interaction between project members in a closed environment with a tool such as a 4D model fosters innovation and fresh ideas.

Utilizing the 4D Model

A few issues were prevalent while viewing the façade sequencing for the Center for Health Research. With all the flurry of activity occurring on the North Elevation at the start of the façade construction, there will most likely be space related issues such as material lay down or adequate work space. This can easily be addressed by starting the erection of the aluminum framing on the South Elevation which is predominately made up of the aluminum curtain wall. Moving opposite of the metal panels and pre-cast, the curtain wall crew will be able to work with adequate material and work areas.

Another issue is related to possible hazardous work areas which are often difficult to find when simply comparing the schedule with the contract drawings. As is seen on the following Figure 2.6, the crane which is utilized to place the architectural pre-cast panels must make the lift from the opposite side of the facility, since there are no acceptable crane locations on the North side of the building. Thus the crane will be placing the pre-cast panels while the metal panel crew is installing studs on the floor directly above. This will create a hazardous work environment for the metal panel crew working above. Proper safety precautions need to be addressed before July 12, 2006 or the crew will need to move to a different location on the building. Not taking care of this issue will result in slower production rates for the week the crane is operating or worst case a stoppage of work for one of the crews.

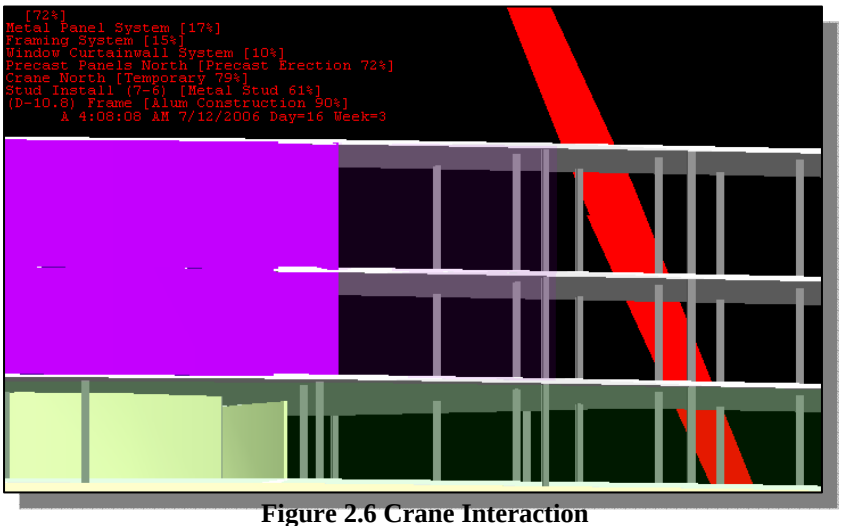


Figure 2.6 Crane Interaction

Conclusion

With the trend of owners and building operators requiring 3D models or building information models with standard operation and maintenance documentation, the industry will have to deal with the new role the 3D model will play in the construction process. Developing 4D models may be a typical role designated to a project engineer and utilized by upper management to make difficult decisions regarding the success of a project. Since creating the model of the project is the most time and labor intensive activity when developing a 4D model, if an owner requires a 3D model for the facility the additional time required to merge the schedule is minimal. With the steps GSA is taking to require building information models on all their projects, it may be soon that the industry embraces the possibilities with virtual documentation.

Since some issues were already addressed on the Center for Health Research and Rural Advocacy project, it is easy to see that the tool can be implemented on any aspect of construction. Simply modeling and linking the schedule for the envelope construction raised some issues of safety and trade congestion.

All the advantages associated with implementing a 4D CAD model on commercial and government projects are hard to ignore. Whether using the tool for trade sequencing, project documentation, safety and hazard analysis, or just for owner visualization, the price tag on this technology will be minimal compared to the value added to the project. The impacts on project scheduling for phased projects may be even more significant, since they require the most diligent of schedule and sequencing attention. With the slow evolution of technology through the construction industry, it will be exciting to see the impacts that 4-dimensional models have on construction projects worldwide.