Building Information Modeling Applied on a Major CSU Capital Project: A Success Story

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Building projects are becoming more complex, driven by more dramatic building forms, new project delivery standards, and regulatory restrictions. Different team participants are diversifying into areas of special expertise to deliver the end product. The increase in building complexity to meet new building and energy codes requires better collaboration, not only between the architect, structural engineer and MEP consultants, but also between A/E, the general contractor and the sub-contractors during construction. This paper discusses obstacles encountered on a California State University Northridge Major Capital Project. A detailed description of the case study is presented with the different needs that led to use of a 5D Building Information Model (BIM) to solve these different problems. The findings include a discussion of new BIM tools like clash detection, tangible cost reductions like the reduction in Request for Information (RFI) response time, and intangible cost savings. We conclude that the introduction of a BIM model on this Major Capital Project as a solution to problems associated with project complexity and the need to link interdependent project participants was a success. After this project the California State University (CSU) instituted a system-wide requirement that future projects of $3 million or larger, use BIM as part of A/E contract.

Key Words: 5d BIM, Clash Detection, Construction Management at Risk, MEP Systems, ESA Extra Service Authorization.

Introduction

Building projects are becoming more complex driven by more dramatic building forms, with shorter schedules, new project delivery standards and regulatory restrictions. As a result team participants diversify into areas of special expertise to deliver different portions of the end product. This diversification in turn requires communication, collaboration, and coordination between the different trades to facilitate the network between different parties involved in the construction project (Nuntasunti et al. 2006). A recent study showed that the mechanical, electrical, and plumbing (MEP) systems of a building can be as much as 40% of the scope of a commercial project (Dossick and Neff 2010). Until recently, the essential means to deal with this complex and broadening body of knowledge was human cognition and an organizational review process (Eastman et al., 2009). With the increase of building complexity, the development and implementation of MEP systems requires a more demanding collaboration not only among the MEP specialties, but also with the other key players of any construction project - the architect, contractor, and mechanical and structural engineers. At the same time, the cost of materials has increased and the availability of skilled labor to install these systems is steadily declining. The owners' need for projects to be delivered more quickly and at lower cost has led to the need of project participants to constantly seek newer and better methods to address these challenges. Consequently, one of the biggest areas of improvement is the design and coordination of MEP systems (Kymmell, 2008). On many construction projects the coordination is still done using two dimensional (2D). This method of coordination has proved to be inadequate for more complex projects and has led to many conflicts among systems, lack of confidence among subcontractors to prefabricate, rework in the field, and low productivity installing these systems. The advent of computer application supporting the three dimensional (3D) object modeling of buildings, called Building Information Modeling (BIM), forces a link between the interdependent nature of structure, architectural layout, and MEP systems by technologically coupling project participants together (Eastman et al., 2008).

This paper proceeds as follows. First, BIM is introduced then analyzed for the purpose of this study. Second, a detailed description of the project used in this case is presented with the various challenges that led to use of BIM model as a solution to the different obstacles. Third, an analysis of the findings pertaining to clash detection and decrease in RFI's are presented and discussed. Finally, we conclude that the introduction of a BIM model on this Major Capital Project as a solution to problems associated with project complexity and the need to link interdependent project participants was a success. After this project the CSU implemented a requirement for the A/E on future major capital projects to use BIM. .

Background

The traditional means of communication among various phases of life cycle of a construction projection is 2D drawings. The introduction of Computer-Aided Design (CAD) software facilitates the use of 3D graphical models between planning and design phases (Goedert and Meadati, 2008). Two dimensional models require multiple views to depict a 3D object in adequate detail for construction. The problem with the traditional CAD arises when each separate 2D or 3D drawing needs to be changed, possibly introducing inconsistencies in the plans (Eastman et al., 2008). Since these documents are created separately, there is little to no correlation or intelligent connection among them. Building Information Modeling (BIM) has recently gained considerable attention as a way to overcome this problem and to communicate information to multiple stakeholders in a visual format that all can understand. Autodesk 2008 defined BIM as an integrated process built on coordinated, reliable information about a project from design through construction and into operation. In BIM, the design is represented as objects that carry their geometry and attributes. When a change to a project is made by a user in one place, the system will propagate that change to all relevant views and documents of the project with no further alteration. The creation of a 3D project model often consists of collaboration and efforts of different team members. The consultants, the general contractors, or the specialty subcontractors will generally model their area of responsibility in the project so that these individual models may then be combined to show a more complete model of the project (AGC, 2006). Having these individual models coordinated in one place will facilitate the process to catch and resolve any existing conflicts. This process is referred to as clash detection. It is a critical task, especially in relation to MEP design. Systems coordination has conventionally been accomplished by overlaying 2D plan drawings on a light table to visualize the location of the system components in 3D space (Kymmell, 2008). Trying to visualize a complex MEP system like the one shown in Figure 1(VPAC Case Study) using conventional methods leaves room for many misunderstandings and oversights, and will generally result in potential conflicts that will ultimately be discovered and addressed by the installation crews in the field. On the other hand, a 3D model of the MEP for the same project shown in Figure 1 provides a visual clue about the dimensions and locations of the drawn objects. The use of BIM is not limited to 3D modeling. In BIM, the schedule can be linked to the 3D building, creating a four-dimensional (4D) view of the building allowing multiple building construction simulation scenarios (Koo and Fischer, 2000). This will facilitate the visualization of the construction process and allow the consideration of alternative approaches to sequencing during the construction process. The five-dimensional (5D) model integrates a 3D drawing with time and cost estimates. A 5D model will provide schematic quantities from which an outline cost estimate can be generated. The 5D model highlights the impact of changes on the project and assists decision-making for owners, project engineers, or managers (Tanyer and Aouad, 2005).

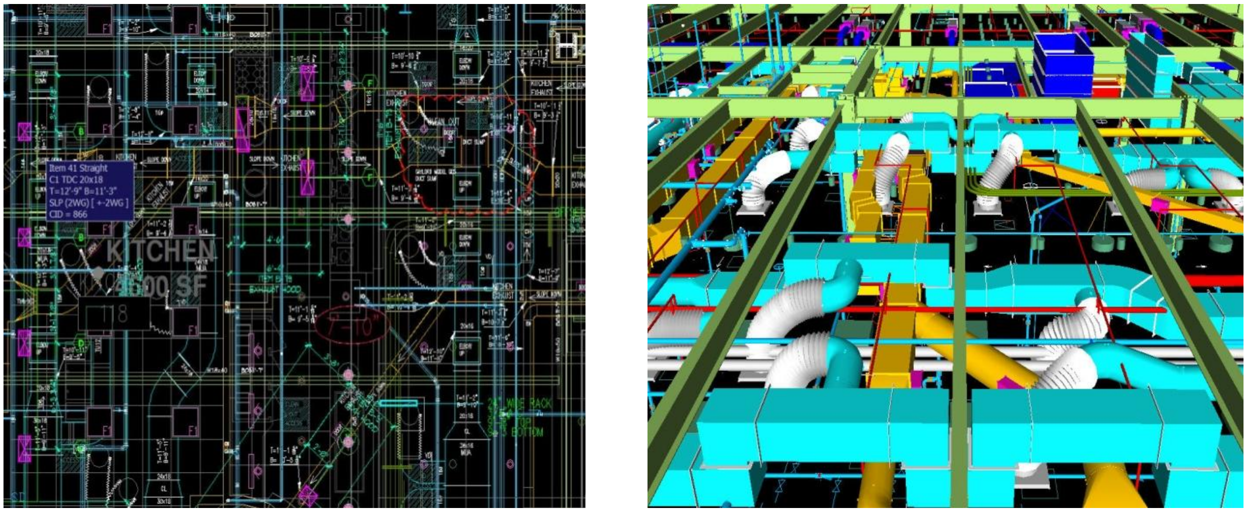


Figure 1: 2D vs. 3D from VPAC project

Software Options

There are several major software developers that supply products with functionality in the BIM world. The authors do not sponsor any specific software product, and the companies whose products are represented here are not the only ones producing software of this type. These descriptions are guidelines for the reader to compare different products available in the market place. They represent the primary BIM tools for the construction industry. A summary of the relevant software and companies as presented in literature (AGC 2006, Eastman et al. 2008, Kymmell 2008, Dzambazova et al. 2009) is presented below:

Autodesk

Autodesk's main platform for BIM is Revit. Their market share with AutoCAD is enabling them to simply offer Revit as the next upgrade for their customers. Revit was designed from the ground up as a BIM platform to specifically address problem areas of the architecture, engineering, and construction (AEC) industry. It is a complete discipline specific building design and documentation system supporting all phases of design and construction documentation. Revit is a serious BIM tool (it was already a modeler with good potential before Autodesk purchased it). Revit has very similar functionality to the other major solid modelers. It is able to link to MS Project and exchange scheduling information bi-directionally. Revit is a technological platform that currently supports architectural, structural, and mechanical disciplines. These modules are designed to create specialty components to address the representation of the components for these disciplines. In summary, Revit is a young, but potentially powerful tool for the planning and management of construction projects.

Autodesk purchased Navisworks in 2007 to add it to its list of BIM component. The primary function of Navisworks is to provide 3D model interoperability for the building design and construction field. It is a project review software for 3D coordination, 4D planning, photorealistic visualization, dynamic simulation, and accurate analysis. Clash Detective is the most popular of the functionalities of Navisworks and the one that provides a quick return on investment. It is capable of finding and identifying all instances where model parts. This is invaluable for the coordination among building systems. The clashes are not only found and listed, but also can be managed through the same software until they are dismissed or resolved. Another functionality of Navisworks is Time Liner, which is very useful in providing a simulation of the construction (or installation) sequence of a project. By either importing a construction schedule from an outside software or building a new schedule in Time Liner, the 3D model components can be linked to a scheduled task.

Bentley

The main product of Bentley is called MicroStation TriForma, an extremely robust and stable 3D platform that Bentley has thought through the BIM approach very carefully and recommends an evolutionary approach for its clients to fully transit to BIM from the traditional 2D environment. Built on a single platform that supports industry standards, MicroStation TriForma integrates design with engineering, and facilitates multi-disciplinary collaboration to address the fragmentation of the construction industry. This fragmentation is experienced in project teams that consist of disconnected people, in the construction processes that are fragmented into disconnected tasks, and in the fragmented tools that evolve out of the disconnected construction disciplines. Bentley developed the "build as one motto" within a managed information environment for a collaborative approach to planning and construction.

Tekla

Tekla software addresses structural steel, steel reinforcing in concrete, and precast concrete modeling. The software is capable of taking the project from the design phase through detailing, into production and assembly. The engineer can create the model that begins the design and structural analysis process and pass it on for use in fabrication and installation. The software also has the ability to model reinforcing steel and precast concrete components for concrete construction. The modeling in Tekla is parametric; this means that the components of the model can be customized and edited at any time to suit the requirements of the project. An advanced graphical input interface makes Tekla an excellent modeler and model manager, as well as making it very effective for navigation through the model and its various views in model or drawing format. The construction schedule can be simulated visually by the model and connected to both the location and time quantities of the model components.

Graphisoft

ArchiCAD is a BIM tool that offers surface & solid parametric modeling of both generic geometric objects and BIM objects. In 2007 Graphisoft sold ArchiCAD to a German software developer and Constructor, its construction industry software suite, spun off to Vico Software, a newly formed company with the design and construction industry as its primary focus. The suite consists of the modeling engine ArchiCAD, and several modules that facilitate construction project management, including Estimator, which is a cost database, a Line of Balance scheduling software called Project Control, and 5D Presenter which facilitates project presentations, all with a bidirectional link to each other and the model. The modeling is simple and straightforward to learn; the file structure is based on layers and stories that contain all the objects either created by the modeling tools or imported from object libraries.

VPAC Case Study

The Valley of Performing Art Center (VPAC) is a signature building for California State University Northridge (CSUN) and a new architectural icon for the San Fernando Valley. The VPAC was recently constructed, with an occupancy date of November 2010. Its 168,000 square feet includes a 1,700-seat hall acoustically adjustable to accommodate all types of performances, a 178-seat black box theater for experimental and smaller-scale student productions, and support spaces including dressing rooms, green room, scene shop, costume shop, recital spaces, a lecture hall, labs, and other academic spaces, full studio/administrative space for campus radio station. Construction costs for the facility are $100 million or $595/sf. The planning and construction of the building has been carefully crafted from the inside out. The designers of the structure HGA Architects and Engineers, have created an environmentally conscious and energy efficient project that uses a new satellite plant on campus to meet heating and cooling loads from a hydrogen fuel cell.

The owner, CSUN, utilized a Construction Management at Risk (CM @ Risk) project delivery method with HGA Architects & Engineers as the A/E and C.W. Driver Company as CM and general contractor. Design and preconstruction services began in April 2005, construction began in May 2008, and completion in November 2010. Under CM @ Risk, the CM/Contractor is responsible for a Constructability Review and Cost Estimate at the 50%, 95% and 100% Construction Document stages. The Schematic (SD), Design (DD), and Construction Documents (CD) were done "old school" by the A/E, with hand sketches provided by a project architect with 30 years of experience. An exceptional and experienced design team with years of project history on similar projects worked to create 7 volumes of contract documents and specifications. Building sections and details were first drawn by hand and then entered into Auto Architect to generate plans, elevations, sections, and details. Separate HVAC, acoustic and structural models were generated to inform the design process.

The Challenge

Large assembly occupancies like this 1,700 Seat Performance Halls are notoriously inefficient regarding energy use. At the same time, CSU requires that all of their new buildings be a minimum of 15% more energy efficient than the State Title 24 energy conservation requirements. Filling up the ceiling of a performance hall with variable air volume (VAV) and ductwork creates another set of resonance problems for the acoustician. The HVAC system design resolved these challenges with a displacement ventilation system that supplies a large volume of air at low velocity from a plenum space beneath the main hall to individual registers under the seats. At the time this type of system was considered cutting edge and not many HVAC subcontractors had experience with this type of design.

Recall the construction climate in 2005, sub-contractors had all the work they wanted on conventional projects so something new like this project was a risk and not attractive to bidders. As a result, the 50% CD cost estimate was over budget. The HVAC estimate alone was $3 million over budget and only one subcontractor was interested in bidding. Without good bid coverage to assure competitive bidding, there was a risk of not having a project in 6 months when final subcontractor bidding was scheduled.

The Owner and CM decided to use BIM to improve bid coverage and facilitate the 95% & 100% constructability reviews. At 50% CDs, the owner executed an extra service authorization (ESA) with the CM to use Vico Constructor (Graphisoft) and Navisworks. The primary objective was to create an effective visual reference for the seven volumes of construction documents. The Navisworks model would be provided for reference to all sub contractors so that they could view the project in 3D with a simple fly around inter-phase. Separate models of concrete, structural steel and HVAC were constructed in Graphisoft to facilitate constructability and clash detection. BIM had clearly demonstrated superiority in clash detection. The results of the clash detection along with the CMs traditional constructability review were provided to the A/E so that the 2D contract documents could be revised accordingly. This approach allowed the A/E to continue with the design and agency approvals using their traditional approach. The CM @ Risk delivery method allows the CM, A/E and Owner to determine how best to address each known issue. This provided the flexibility to either change drawings, specifications or where there would not be a cost issue wait to make the change during construction. To help prioritize changes each item in the clash detection report was assigned a priority value.

The BIM model essentially started from scratch using some Autoarchitect 2D files for plan and elevation areas. The majority of the input came from reentering the information from the paper drawings. This approach, though time consuming, provided valuable cross checks. If the information to construct the BIM could not be determined from the paper documents then there was an issue with the paper documents. This process of virtual construction by an independent party gave the A/E valuable feedback regarding their design intent. One of the most challenging requirements of the Owner/CM @ Risk contract is that the contractor provides the University a letter indicating that all constructability comments have been incorporated into the project documents and that the project is ready for bid. Further, the contractor, in sending the letter, agrees that the plans and specifications are complete, free of omissions, and the scope of work contained herein is biddable and complete; hence the contractor can guarantee the documents and a maximum price. Using BIM and the process described above to complete the 100% constructability review, back check verification and agency approvals certainly made the issuance of the letter referenced above less onerous for the CM.

Benefits

The primary goal was realized at bidding. There was good bid coverage and the guaranteed maximum amount was not exceeded. There were 5 bids for HVAC and the lowest responsible bid was just under the cost estimate, saving the project $3 million. The cost of the ESA for BIM was $80,000. Providing financial calculation of all the benefits is a challenge. At the time of bidding, the sunk costs for design and agency approvals on this project were over $4 million. Additional quantifiable cost savings are generated from the following: one month faster constructability reviews and resolution, two weeks faster cost estimates, one week shorter time to normalize bids, and improved bid coverage from subcontractors.

After the initial visualization uses of the 3D models, C.W. Driver began to utilize the models for clash detection analysis. This BIM application enabled them to identify potential collisions or clashes between various structural and mechanical systems within the building design during the design development which avoided costly design changes once actual construction begins in the field. Clash detection is an iterative process in which all noted project conflicts are addressed and reevaluated (often on a weekly basis) until the desired level of coordination has been achieved. Navisworks identified the clash between the ductwork and structural steel beam in the center of the image by coloring the duct. The software located and identified all clashes found between model elements. Examples of clash detection the GC was able to catch before the start of construction are shown in Figure 2. At 95% CD stage, 2000 clashes were identified resulting in avoided RFIs for the project. The resolved collisions were tracked resulting in a cost avoidance of $5 million. Just this stage alone yielded a return savings of $4.2 million on the original $80,000 BIM expense. At the 100% CD phase, the model was updated and resolved collisions were tracked. Each critical clash was shared with the design team via the model viewer and a numbered collision log with a record of individual images of each collision per the architectural or structural discipline (Figure 3). The collision cost savings value were based on estimates for make design change or field modifications had the collision not been detected earlier and clash would have need to be addressed in the field.

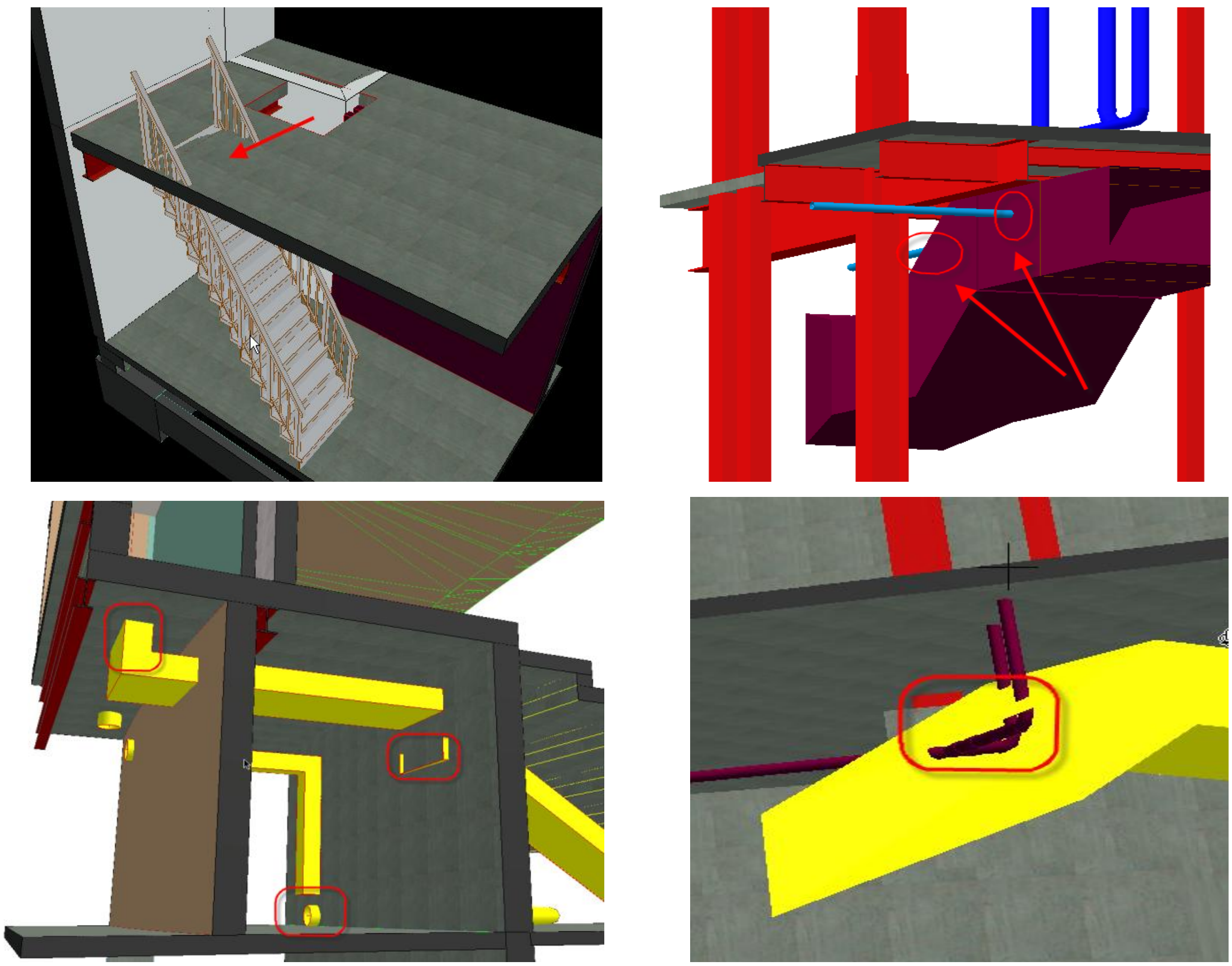


Figure 2: Examples of clash detection

Throughout the project, the contractor identified other applications of the 3D model which improved project execution. One of the weekly uses was trade contractor coordination. In the field, the 3D models were used to identify and coordinate trade contractor work in order to avoid delays caused by poor scheduling. The model also enabled the various trade contractors to coordinate amongst themselves on precise locations for specific MEP systems. Simply seeing the project in 3D space and being able to virtually move through and around generated a new level of visualization and understanding. The model enabled preparation for the component installation in tight spaces, and the installation sequence of such components could also be simulated in the form of a movie. Figure 4 presents an example of coordination accuracy of the HVAC system and the steel structure. The ability to coordinate the details ahead of time provided for more efficient construction scheduling on the job site, enabled conflicts to be resolved well ahead of the scheduled tasks, and reduced on-site conflicts. During construction, out of the 1,555 RFIs generated by the GC, 75% were clarification. Screen shots from the BIM model were used in RFIs. This speeded up the response and facilitated the resolution by the A/E.

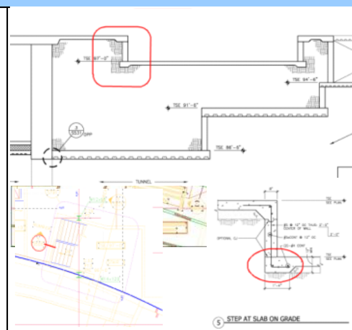
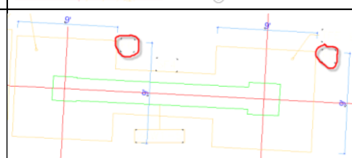
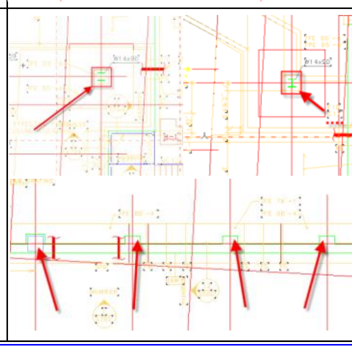
Structural Plans	Problem Description	Location	Grid Re	Sheet Ref	Screenshot	ing Assum	Owner	Severity	Rating	Cost Impact
S01 - Foundation										
S01-002	structural. Section and detail are different	Loc A, basement level	AA-G/5	S322/1 S500/5		modeled according to detail drawing			3	Issue could be corrected after award of contracts, Probable cost impact
S01-003	The footing sizes are not matching with footing schedule (F6-F9)	Loc C, basement level	D-30.1-31	S200C		Modeled according to floor plan			2	Issue could be corrected after award of contract, Cost to correct is :
S01-004	The marker of the pier is missing. At some locations the TPE is missing as well.	Loc B, basement level	K-29;J-29; GRID L-; GRID-32	S200B		modeled according to floor plan drawing contour			1	Issue needs to be corrected before going to bid. Cost impact to be determined after solution

Figure 3: Page from constructability report

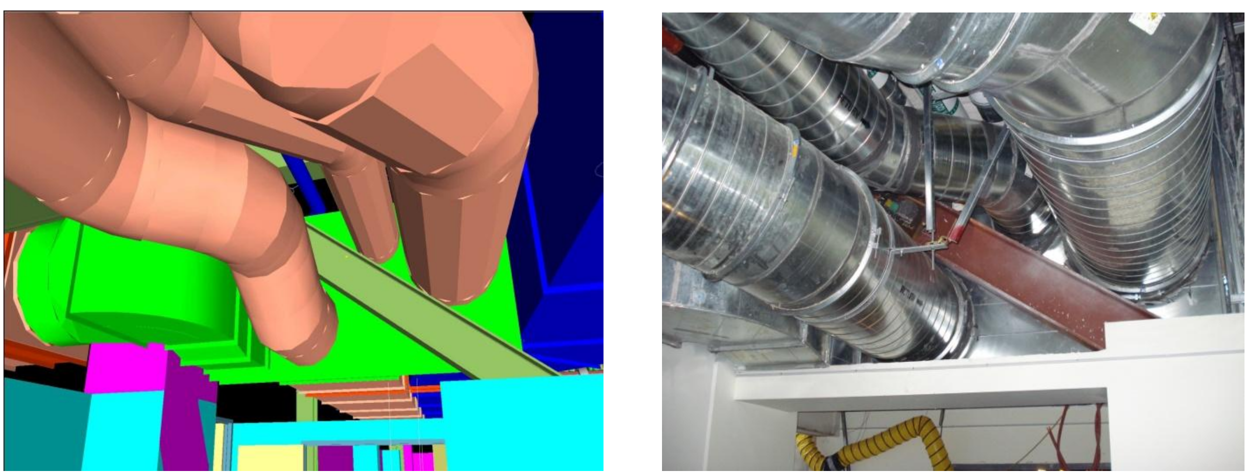


Figure 4: Coordination accuracy

Conclusion

The Owner's choice to use BIM on the Valley of Performing Art Center project provided an excellent example of the benefits that Building Information Modeling can bring to a project. The use of BIM by the CM changed their approach to the construction process and precipitated rapid changes in their company. The documented cost benefits to the owner were substantial; however, the intangible benefits were even greater, including avoided costs, improved collaboration, better visualization, early conflict identification and faster resolution of RFIs.

After this first use of BIM in the design and bidding phase of the project, C.W. Driver continued to utilize and update models for clash detection analysis. This BIM application revolutionized the contractor's approach to construction. The contractor hired an in-house BIM Manager who has been promoted to Director of BIM with responsibility for over 20 BIM projects.

CSUN's second BIM project, The Student Recreation Center started with full expectation of using BIM. When the top four architecture firms from those who had submitted for the project were interviewed, each one of them was asked about their experience with BIM. The topic was never discussed five years earlier during the A/E selection for the Valley Performing Arts Center. Four years after the first successful use of BIM on the VPAC project, the CSU has revised their A/E and CM @ Risk contracts to include BIM on all projects of $3M or greater.

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