AC 2010-23: USING BUILDING INFORMATION MODELING TO TEACH MECHANICAL, ELECTRICAL, AND PLUMBING COORDINATION

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Abstract

The coordination of mechanical, electrical, and plumbing (MEP) systems has become a major challenge for project delivery teams. The MEP coordination process involves locating equipment and routing Heating, Ventilating, and Air-Conditioning (HVAC) duct, pipe, electrical raceway, and fire protection systems in a manner that satisfies many different types of constraints. For the past several years MEP coordination has involved sequentially comparing and overlaying drawings from multiple trades, in which representatives from each MEP trade work together to detect, and eliminate spatial and functional interferences between MEP systems. This multi-discipline effort is time-consuming and expensive. With the recent development of Building Information Modeling (BIM) this process has been able to evolve with the software technology thus enabling new teaching methods. This paper demonstrates how BIM technology can be used to teach students how to perform the MEP coordination process using a work process utilizing modeling software and information technology.

Introduction and Background

In recent years, there has been increasing consideration given to integrated curricula by construction engineering and management faculty and industry advisors. According to Hauck and Jackson[5] each proposal has tried to address core problems associated with an overly segmented curriculum and the lack of project based learning in different ways. A model proposed by Hauck and Jackson[5] attempts to teach construction management as a series of labs integrating the various construction management courses into an active, applied learning experience. Their integrated curriculum proposal for the construction management department is centered on the creation of seven project-based seminars. They are as follows:

- Fundamentals of Construction Management
- Residential Construction Methods
- Commercial Building Construction Methods
- Heavy Civil Construction Methods
- Specialty Contracting Construction Methods
- Construction Jobsite Management
- Interdisciplinary Project Management

A new curriculum recently adopted at California Polytechnic State University, San Luis Obispo (Cal Poly) is based on a model similar to that proposed by Hauck and Jackson[5]. Students receive six (6) quarter-hours of lab credit for a total of sixteen (16) contact hours per week. Similar to a studio in an architecture curriculum, each seminar is taught in a dedicated lab filled with models, samples, contracts, marketing documents, specifications, estimating guides, computer references, and other tools appropriate to that market sector, all available to students in that seminar.

The concept for the specialty contracting construction management seminar was to emphasize the work of specialty contractors who fabricate and install mechanical, electrical, and plumbing (MEP) systems. Their work is characterized by the construction industry as being specialized and requiring a considerable amount of coordination to locate equipment and route connecting elements for each system to avoid physical interferences, ensure system functionality, and remain in compliance with differing types of criteria[6].

During the 2008-2009 academic year, a pilot lab course was developed and offered at Cal Poly for construction management and engineering students. The course curriculum focused on integrating the course content of mechanical electrical and plumbing systems with regard to design, construction, and coordination issues commonly found among specialty contractors. As noted above, the integrated curriculum model described by Hauck and Jackson[5] has the potential to provide tremendous opportunities to engage teaching strategies far beyond the common lecture approach typically utilized in many single subject courses. Various methodologies such as cooperative learning require students to be active participants in their own education[2]. Therefore, to take advantage of the studio-laboratory format of the integrated curriculum, an in-depth laboratory exercise was developed focusing on the use of Building Information Modeling (BIM) technology as a tool to perform MEP coordination in order to enhance student learning. The following sections describe the design of laboratory exercise, including the learning objectives and outcomes assessments.

Mechanical Electrical and Plumbing Coordination

MEP systems are the active systems of a building that temper the building environment, distribute electric energy, allow communication, enable critical manufacturing process, provide water and dispose of waste[8]. MEP systems have increased in scope on many types of projects, due to the increased requirements by building users. With the need for increased functionality of these systems, projects now include much more than the traditional MEP systems. The active systems of a building can cost up to 60 percent of the total building cost[8] and their scope now includes additional systems such as fire detection/protection, controls, process piping, and telephone/datacom. Although many of these systems seem similar in nature, different specialty contractors often install them. MEP coordination is defined as the arrangement of the building system components that must fit within the constraints of the building architecture and structure.

MEP coordination is a critical activity for efficient construction and acceptable system operation. Building systems must fit within the constraints of the envelope defined by the architectural and structural systems, and meet performance expectations for comfort and safety. The MEP coordination process involves defining the locations for components of building systems, in what are often congested spaces, to avoid interferences and to comply with diverse design and operations criteria. The level of difficulty associated with this process directly relates to the complexity and number of building systems in a facility[7]. Ideally, the result of a coordination effort is the most economical arrangement that meets critical design criteria and performance specifications. Many construction industry professionals have cited MEP coordination as one of the most challenging tasks encountered in the delivery process for construction projects[9].

In the past, there has been a wide variation in the level of technology used in the MEP coordination process. At the low-tech end of the spectrum, specialty contractors drafted plan-views on translucent media and prepare section-views when necessary. At the other extreme, progressive contractors have used three-dimensional (3-D) computer-aided-design (CAD) software to improve the process. With the recent development of BIM technology software, the process has gravitated toward the use of BIM technology as BIM is becoming standard practice now for large-scale projects and is able to provide more efficient coordination, scheduling, and cost estimating.

BIM has been defined as the process of creating an intelligent and computable 3-D data set and sharing the data among the various types of professionals within the design and construction team. BIM technology enables the designer, engineer and builder to visualize the entire scope of a building project in 3-D and as well as attached schedule and cost data to the 3-D model and therefore is ideal for being able to assist improve the collaboration among project participants. Designers and builders can plan-out, in precise detail, the location and clearances needed for a complete and successful project. Therefore, the authors' idea was to utilize BIM technology software to enhance student-learning experience as is relates to MEP coordination.

MEP Coordination Laboratory Exercise: Learning Objectives

MEP coordination is only one link in the chain of coordination events. It is the arrangement of various building system components, which are critical to the building functioning properly. The MEP coordination process involves defining the exact location for each building system component throughout the building to comply with diverse design and operations criteria. Often specialty contractors must arrange components in congested areas to avoid interferences with the architecture, structure, or other building system components. The process is a multi-disciplinary effort with input from many people. Iterative in nature, the process requires many revisions. This process occurs only after engineers have completed preliminary design drawings and results in a final set of coordination drawings.

The current practice for MEP coordination is for design consultants, or design-build contractors who perform design, to design each MEP system independently. They prepare diagrammatic drawings indicating desired equipment locations and routing paths for their system. With this background for each type of system, coordination takes place by sequentially overlaying and comparing each system[6]. This involves all the specialty contractors, including HVAC, process piping, plumbing, electrical, fire protection, controls, etc. The integrated course described above was designed to introduce students to the scope and impact of MEP systems for buildings, which included heating, ventilation, air-conditioning, plumbing, and fire protection, while the electrical systems include power, grounding, lighting, communication, and fire detection.

The MEP coordination laboratory exercise was designed to expose students to the detailed knowledge of the active building systems which form a key part of buildings and plants. The approach taken was to analyze the need, scope, design, and construction of these systems as well as address the design-construction integration issues for each system. Therefore, the MEP coordination laboratory exercise was developed and presented with the following learning objectives:

- Define the need and purpose for active MEP building systems
- Describe how building systems work, how they are designed, how they fit with architectural and structural systems, and what they include
- Enhance collaboration and communication between participants in a project
- Describe how building systems are built, how long it takes, how much it costs
- Recognize shared knowledge of building systems for design-construction integration
- Analyze a system design, estimate materials and components used, and create installation work packages for building systems

MEP Coordination Process: Teaching Methodology

In a typical course section offering, student count ranges from 20 to 24 students. Therefore the teaching methodology centered on creating student work groups of 3 to 4, each representing a different MEP system. The methodology selected to teach the MEP coordination process, utilizing BIM technology software, began with the student work groups being provided with project documents (electronically) in 2-D format (dwg, pdf, etc) and a project description from which the model is required to be built from. The student work groups are then required to produce a model of their system in 3-D. Using a software integration tool, the system models are merged into a common 3-D CAD model, where a clash detection software application is then activated to identify physical interferences. Within the software integration tool, the CAD model can then be modified to resolve interferences. Following the resolution of all interferences, separate drawings for fabrication and installation are then produced for each system[6].

There are many good 3-D graphical representation software programs that the designer and builder can use to model their project. Graphisoft's ArchiCAD® allows one to draw in 3-D or import a 2-D drawing and create a 3-D model. This program allows you to toggle back and forth from 2-D to 3-D with the click of a mouse. Autodesk's AutoCAD® is a 2-D drafting program coupled with Revit® creating the 3-D model. Bentley's MicroStation®, Vico's Constructor®, and Tekla Structures® are other powerful 3-D modeling programs.

There are also many examples of BIM technology software integration tools. These are considered to the "Rosetta Stones" that are able to interpret many of the modeling tools mentioned above. Autodesk's NavisWorks® is a software program that interprets all of the other software programs used by various subs and engineers. NavisWorks® has the potential to unlock and or interpret the other 2-D CAD drawings. The program identifies the clashes and the individual specialty contractors need to revisit their own software programs and revise them in order to resubmit. NavisWorks® will then reanalyze the new composite model; ideally, there are fewer or no clashes remaining. Other integration tools include Solibri® and Ideate®.

The suggested methodology presented to the student work groups to follow begins with the HVAC sheet metal to be compared against the structure, sanitary drainage, process piping, water distraction, and electrical. HVAC sheet metal is used as a base because it has the largest components, primarily composed of large ductwork and variable-air-volume (VAV) boxes. It is often the hardest to relocate because the large duct sizes restrict the routing to a few locations where adequate space is available.

The sanitary drainage system is recommended to be compared next. This includes all horizontal graded waste lines, vertical soil stacks, and vent lines. The requirement to slope all graded lines and waste lines to allow for gravity flow gives the plumbing system the next highest level of priority after the HVAC dry system. The gravity drain lines typically slope 1/8 inch for every foot. This requirement forces the drain lines to compete with the large HVAC dry ducts at the higher elevations because they must start as high as possible to maintain the grade without falling below the ceiling tiles. Engineers route HVAC dry ducts at higher elevations because of their large volume.

The HVAC process piping is next, which includes heating and cooling water lines. These piping lines feed directly into the HVAC sheet metal to heat and cool air at various interface points. The HVAC sheet metal and HVAC process piping systems work together and must be tightly coordinated. Routing of the HVAC wet system is based on the HVAC dry system routing and location.

Where manufacturing process piping is included in a building structure, it would be coordinated following the HVAC process piping system. Most manufacturing process piping systems are pressure-driven and thus can yield to larger building system components and gravity-driven system lines that are more difficult to re-route due to the risk of affecting their functionality. In cases where a special routing is required for process piping to function at its optimal performance level, engineers assign priority to the manufacturing process-piping system.

Where fire protection piping system is included in the building structure, it would be coordinated following the manufacturing process piping system. This is a pressure-driven system; however, the fire protection main lines must be slightly graded to allow scheduled draining as required by operations and maintenance. This complicates the coordination of the main lines. Specialty contractors are advised to compare drawings individually with HVAC sheet metal, HVAC process piping, and sanitary drainage systems.

Water distribution piping is recommended to be compared next. This includes potable hot and cold water distribution plumbing lines. Water distribution systems are pressure-driven systems and therefore are easier to re-route around larger components.

Consideration of the electrical system follows the water distribution system. Engineers consider the electrical system to be one of the more flexible systems because the components are generally smaller and installers can easily route electrical conduit in the field. The control systems and telephone/datacom systems should be coordinated last if a CAD file is produced for them. The control system is the most flexible because of its smaller diameter tubing and conductors. Components in the control system run along-side other systems, such as HVAC dry and process piping. Representatives from each of the student work groups then hold a series of meetings to coordinate their drawings by defining the final routing for each system.

Common constraints for the student work groups to consider in routing MEP systems are corridors, openings in shear walls, and architectural requirements, such as ceiling type and interstitial space. Each trade initially routes their system to their own advantage. This includes decreasing overall length, routing close to support points, choosing prime locations for major components, and locating system runs to facilitate the construction needs of their own trade.

During coordination meetings, the participating student work groups compare preliminary routing for their systems to identify and resolve conflicts. They also decide which trade(s) will revise their design and submit requests for information (RFI) regarding problems that require an engineering resolution. Deliverables of the project include the following: the building information model, coordinated utility relocation plan, constructability/discrepancy report, and survey/layout points. The student groups are required to submit the deliverables in native format, as well as a Navisworks™ Document), 3D DWG, or IFC for Model and PDF for all other documents. The student work groups are also required to present their results at the end of the project as well as demonstrate the model, the processes, and how it is incorporated into the deliverables.

MEP Coordination Challenges: Outcomes Assessment

Integrating the course content of MEP systems for construction management students is one approach to help change students' and future constructors' thinking to look at MEP systems as a whole, rather than as independent systems, which helps to enhance and reinforce learning by arranging content around overlapping concepts and themes[1]. The increased use of the BIM technology software in the classroom is able to reinforce connection points between the multiple systems.

The student work groups using BIM technology emulated the MEP coordination process where representatives from each specialty construction trade work together to detect, and eliminate, spatial and functional interferences between MEP systems[9]. To accomplish the laboratory goals, the students were forced to consider design, construction, and operations and maintenance criteria in order to achieve proper functioning systems.

Compared to students being taught via the traditional lecture mode, the cooperative environment provided a forum in which a deeper understanding of the material could take place and motivation could be placed on learning and achieving a common goal[3]. The use of BIM technology software encompasses many of the seven principles of good practice for education by encouraging contact between students and faculty, developing reciprocity and cooperation among students, encouraging active learning, giving prompt feedback, and respecting diverse talents and ways of learning.

It allowed an enhanced level of student-faculty contact by allowing the students and faculty to work together in a fashion other than the traditional lecturer-listener relationship that is most commonly found. It encouraged students to work with their peers and the faculty member to achieve the above listed learning outcomes. It also encouraged active learning by experimentation and gave students prompt feedback by allowing students to identify interferences throughout the coordination laboratory exercise.

It also allowed students to learn in a multitude of ways by allowing students of all learning styles to develop from the laboratory experience. From our observations kinesthetic learners benefited from the data entry, visual learners benefited from being able to observe the clash detections, and auditory learners benefited from working in student groups by either giving or receiving instructions and negotiating coordination changes.

Discussion and Recommendations for Future Implementations

MEP coordination has become a major challenge for projects. The need for MEP coordination has grown out of the lack of detailed design provided for fabrication and installation of building systems. The current conditions in the design and construction industry drive current practice for MEP coordination and create an opportunity for improvement. MEP coordination requires considerable time from scarce experts who have specialized knowledge about the design, construction, operation, and maintenance of these systems. Thus, the current work process offers major opportunities to improve, and BIM provides a foundation in which the process can be improved. There are many challenges in teaching MEP coordination to students using the current work process; however, BIM technology software provides a new method of instruction.

As described above, effective MEP coordination requires recalling and integrating knowledge regarding design, construction, operations, and maintenance of each MEP system. Missing from BIM models is that knowledge regarding each system. A revised work process utilizing BIM still requires individuals to meet and share knowledge regarding their system. Currently, BIM can only assist in resolving physical conflicts; however, coordination must satisfy critical design criteria, evaluate constructability issues, and address operations and maintenance concerns. During coordination, trades must consider all aspects from design, construction, and operations and maintenance. Currently, it is difficult to integrate construction knowledge, and operations and maintenance into the MEP coordination process. Often the parties involved do not take the opportunity to align goals and define requirements. In addition, constructability issues are not considered part of the MEP design consultants' scope of work, and designers must make assumptions about constructability or ignore the issue totally. Furthermore, there is a lack of understanding between the different MEP trades. Each discipline focuses on its own design and construction requirements. Failing to consider the big picture, many MEP contractors are unaware of unique installation requirements for other trades and are reluctant to learn more about or consider each other's systems. Implementing a revised work process that uses information technology that is able to integrate a number of knowledge bases – design criteria, construction, operations, and maintenance – into a BIM system could provide valuable insight to engineers and construction personnel assisting them in resolving coordination problems for multiple MEP systems.

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