Enhancing Student Learning of Mechanical, Electrical, and Plumbing Coordination through the use of Building Information Modeling

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Abstract

The coordination of mechanical, electrical, and plumbing (MEP) systems has always been a major challenge for the specialty contractors who fabricate and install these systems. The coordination of these systems involves locating equipment and routing Heating, Ventilating, and Air-Conditioning (HVAC) duct, pipe, and electrical raceway 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 the numerous systems. This multi-discipline effort is time-consuming and expensive. With the recent development of Building Information Modeling (BIM), which is able to provide a virtual construction solution where the design (3-D), schedule (4-D), cost (5-D), and life-cycle analysis (6-D) can be interlinked, the process has been able to evolve with the software technology. However, students and practitioners alike still face similar problems as they have in the past. Entry of incorrect data or faulty assumptions into the BIM system results in project personnel being misled by the output from the system. While most BIM technology software solutions have the ability to contain information and data regarding a project, they do not contain knowledge-based logic and reasoning structures to assist users during the planning and design and therefore lack the capability to assist in the resolution of conflicts. This paper demonstrates how the use of BIM technology has enabled new teaching methods to teach students how to perform MEP coordination process using a work process utilizing modeling software and information technology.

Keywords

Mechanical, Electrical, Plumbing, Coordination, Building Information Modeling.

1. INTRODUCTION

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. 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 and their scope now includes additional systems such as fire detection/protection, controls, process piping, and telephone/datacom (Tao 2001). Although many of these systems seem similar in nature, different specialty contractors often install them. MEP coordination has been defined as the arrangement of the building system components that must fit within the constraints of the building architecture and structure (Korman 2006).

MEP coordination is a critical activity for the efficient construction and acceptable system operation. As mentioned above, building systems must fit within the constraints of the envelope defined by the architectural and structural systems; however, they must also 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 designed for a facility. 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.

2. USE OF BIM TECHNOLOGY FOR MEP COORDINATION

In the past, there has been a wide variation in the level of technology used to perform MEP coordination. At the low-tech end of the spectrum, specialty contractors draft plan-views on translucent media and overlay them with other system to defect interferences and may prepare section-views when necessary. At the other extreme, progressive contractors have used three-dimensional (3-D) computer-aided-design (CAD) software to virtually model their systems. With the recent development of BIM technology software, the process has gravitated toward the use of BIM technology. BIM has now become the standard practice for large-scale projects. Using BIM technology software as a tool, specialty contractors are able to provide a better-coordinated set of plans. 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 associate schedule and cost data to assemblies and individual components in the model. Therefore, it is ideal for being able to assist and 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. Being the BIM is becoming a industry wide standard, it was the authors' idea to utilize BIM technology software to enhance student-learning experience as it relates to MEP coordination.

3. MEP COORDINATION LABORATORY EXERCISE

MEP coordination is the arrangement of various building system components, which are critical to the building functioning properly (Tatum 2000). 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. 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, which requires input from many people. Iterative in nature, the process requires many revisions and the process involves input from all specialty contractors who will be fabricating and installing a system in the facility. This may include: HVAC, process piping, plumbing, electrical, fire protection, controls, etc. The authors developed a laboratory exercise for use in their specialty contracting construction management course to introduce students to the scope and impact of MEP systems for buildings and require students to virtually model an HVAC, plumbing, fire protection, power, lighting, and fire detection, and then perform a virtual coordination for the facility.

3.1 Learning Objectives

The MEP coordination laboratory exercise was designed to expose students to the detailed knowledge of the active building systems that form a key part of facilities. 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

3.2 Teaching Methodology

The MEP coordination laboratory exercise was introduced in the Specialty Contracting Construction Management course at California Polytechnic State University. In a typical course section offering, student count ranges from 20 to 24 students. Therefore the teaching methodology employed student-centered instruction creating student work groups of 3 to 4, each representing a different MEP specialty contractor. The methodology selected to teach the MEP coordination process utilizing BIM technology software. This 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 was required to be built from. The student work groups were then required to produce a model of their system using the BIM technology software. Using a software integration tool, the student teams were required to merge the individual models into a common BIM model. A clash detection software application was then activated to identify physical interferences. Within the software integration tool, the BIM model can then be modified to resolve interferences. The process was repeated until all clashes and interferences were resolved. In practice, the specialty contractors would then use the coordinated model for fabrication and installation of their systems.

The suggested methodology presented to the student work groups to follow began with the HVAC sheet metal to be compared against the structure, sanitary drainage, process piping, water distraction, and electrical. The 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. We observed that each student group, representing a different trade, initially routed 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 weekly coordination meetings, the student work groups compared 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. As the instructors of the course, we served as the “engineers” for the systems and the responsibility for answering the RFI’s as means to ensure that the system were coordinated in manner that they still would met performance specifications.

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™ file, 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.

3.3 Outcomes Assessment

Compared to students being taught via the traditional lecture mode, the cooperative environment provides a forum in which a deeper understanding of the material can take place and motivation can be placed on learning and achieving a common goal (Boswell 1991). 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 allows 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 encourages students to work with their peers and the faculty member to achieve the above listed learning outcomes. It also encourages active learning by experimentation and gives students prompt feedback by allowing students to identify interferences throughout the coordination laboratory exercise.

It also allows 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.

4. CONCLUSIONS AND RECOMMENDATIONS

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. 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. 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. 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.

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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