Teaching the Need for Design-Build Coordination and Understanding of Building Systems

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Design-Build Contracting Services are becoming increasing more common. Thus, as educators we are responsible for training architects, engineers, and construction managers for this new work environment. This paper focuses on the teaching strategies and techniques used to train students to function in interdisciplinary work groups that are required to successfully complete Design-Build Projects. This paper uses Mechanical, Electrical, and Plumbing (MEP) Coordination for building systems as an example case. The case example begins by first addressing the students' prior knowledge of the building systems. Second, the case explains how students are introduced to the appropriate background knowledge required to work together (without becoming an expert in each building system). Third, classroom exercises are designed to encourage group work (specifically coordination of building systems). The paper concludes by addressing the results of the classroom effort and need for improved design of lessons and exercises for the future.

Key Words: Design-Build coordination, Building systems, Heating, Ventilating, and Air-Conditioning (HVAC), Mechanical, Electrical, Plumbing (MEP) coordination

Introduction

Design-Build is a form of construction contracting where a single entity provides the owner with both the design and construction services needed to meet the owner's needs. Thus, the owner is provided with both design and construction services under a single contract [Quatman 01]. Most are familiar with the traditional method of construction contracting, Design-Bid-Build, which consists of an owner hiring a design professional, usually an architect or engineer, under one contract, and hiring a general contractor under a separate contract. Under a design-build contract, the owner interacts directly with the design-build contractor for the complete project delivery process (design through construction). The design-build team may be Architectural/Engineering led or Construction contractor led. The team is responsible for coordinating the design and construction processes; this includes forming the design team, which is then contractually linked to the contractor and the client.

In recent years, prior research has stated many advantages of Design-Build over traditional contracting methods. These include [Modern 00]:

- development of better relationships between the construction and design team
- early involvement of the contractor for input on construction methods and cost control
- single-point responsibility during the project delivery process
- active involvement of the contractor during the design phase
- increased construction rate and decreased schedule durations.

As mentioned above, the design-build contractor is responsible for forming the entire project team, which provides design and construction services. The success of a Design-Build project is dependent on the assembly of a good team. The team must be formed in such a way that its members bring expertise, assets, value, experience, and standing to the project; however, in addition they must be able to work together in numerous coordination efforts throughout the project [Beard 01].

One of the most critical coordination efforts that a Design-Build team undertakes is the coordination of the mechanical, electrical, and plumbing (MEP) systems. MEP systems are the active systems of a building that temper the building environment, distribute electric energy, allow communication, enable critical manufacturing process, and provide water and dispose of waste [Barton 83]. MEP systems have increased in scope and complexity 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 mechanical, electrical, and plumbing systems. It is common for these MEP building systems to cost from 40 to 60 percent of the total building cost [Tao 01]. The MEP scope now includes additional systems such as energy management, controls, process piping, and telephone/data communications. Although many of these systems may 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 architecture and structure. It is a critical activity for efficient construction and acceptable system operation. The 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 [Riley 97].

Ideally, the result of the MEP coordination effort is the most economical arrangement that meets critical design criteria and performance specifications. System components must fit within the constraints of the envelope defined by the architectural and structural systems, and meet performance expectations for comfort and safety. Many construction industry professionals have cited MEP coordination as one of the most challenging tasks encountered in the delivery process for construction projects [Tatum 00].

Overview of Design-Build Coordination for Building Systems

To fully understand why MEP coordination is required, one must first understand the process that specialty contractors follow to procure, design, and build work. The process begins with the owner's decision to construct a facility and ends with the contractor turning the system over to the owner. It includes the following phases: conceptual design, selection of specialty contractors, and award of contract, engineering, submittal and approval, pre-construction, fabrication, installation, start-up, and turnover.

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 a sequential overlay comparison process evaluation (SCOPE) method. This must involve all the specialty contractors, including HVAC, process piping, plumbing, electrical, fire protection, and controls.

This multi-disciplinary and iterative activity requires input from many contractors and requires many revisions. These individuals each have a different interest in the coordination process. Design consultants act as guardians of the preliminary design to assure that systems satisfy code requirements and will function properly once installed. General contractors focus on the project schedule and on avoiding delays in both pre-construction and installation [Hanna 99]. Specialty contractors are concerned with the fabrication and installation cost of their specialty system. They try to reduce material, fabrication, and labor cost. The owner tries to make sure the facility materializes on budget, on time, and at the best quality. On some projects, suppliers may become involved when unfamiliar specialized equipment is to be installed.

Currently, this process occurs only after preliminary design drawings are completed and results in a final set of coordination drawings (see Figure 1). The preliminary design is considered complete when all components (e.g., conduits, pipe, HVAC duct) are sized, the engineering calculations completed, and the diagrammatic drawings produced; however, specific routing is not defined. Representatives from each of the specialty contractors then hold a series of meetings around a light table to coordinate their drawings by defining the final routing for each system.

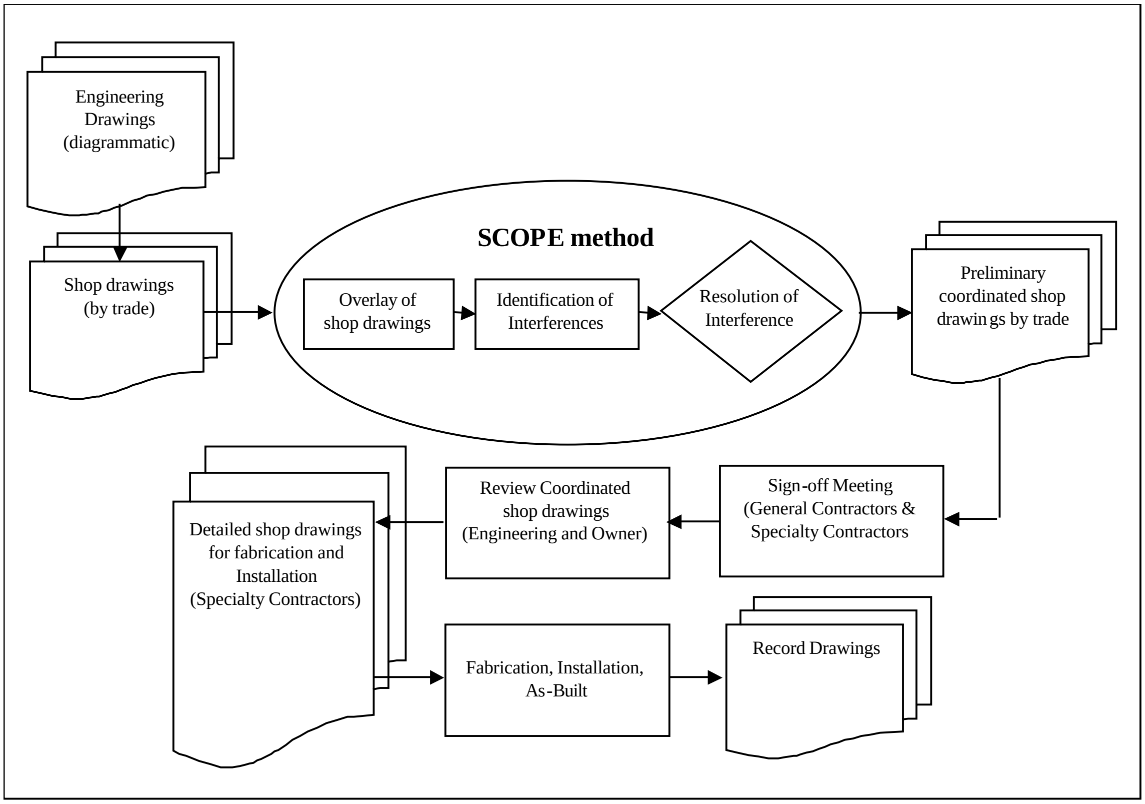

Figure 1 - Current practice for MEP Coordination

Common constraints for the group 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 specialty contractors compare preliminary routing for their systems to identify and resolve conflicts. They typically overlay transparent design drawings on a light table. The SCOPE method continues until all interferences are resolved. This often requires preparing section views for highly congested areas to identify interferences. They also decide which contractor(s) will revise their design and submit requests for information (RFI) regarding problems that require an engineering resolution. The product of this process is a set of coordinated shop drawings that the participants submit to the design engineer for approval.

Upon completion of the SCOPE method, all specialty contractors involved sign-off on each other contractors' drawings, indicating that they accept the coordinated design for the specific area of the facility. Specialty contractors then prepare cut sheets for duct fabrication and spool sheets for piping, based on the coordinated shop drawings. Once construction and installation of the systems is completed, the contractors prepare as-built or record drawings by marking and editing the shop drawings or by consolidating electronic files.

Design-Build Coordination Classroom Exercise

A new course designed and taught at the University of Nevada, Las Vegas seeks introduce construction management students to MEP systems and provide them with the skills needed in practice to work with others during coordination efforts. The course titled CEM 350 – Facility Systems Design and Construction. The course is designed to introduce students to the scope and impact of mechanical and electrical systems for facilities including heating, ventilation, air conditioning, plumbing, fire protection, electrical systems and equipment, electrical design and wiring, illumination, and lighting design.

The course provides students with detailed knowledge of the active building systems, which form a key part of buildings and plants. This course analyzes the need, scope, design, and construction of these systems as well as addresses the design-construction integration issues for each system. The course was developed with the following educational objectives:

- understand what are active building systems and why they are needed and important
- understand how building systems work, how they are designed, how they fit with architectural and structural systems, and what they include
- understand 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 building system to understand the design, materials, installation, and level of knowledge needed for technical support in the field

During the second half of the course, after students learn about the major MEP systems, students are assigned a group project, which is designed to create a work environment where students must work together to coordinate a set of MEP systems. Students are divided into five groups representing the HVAC dry, HVAC wet, Electrical, Plumbing, and Fire Protection trades. They are given the following materials for the coordination exercise:

- a complete set of design drawings, which includes all MEP trades
- a set of calculations for their individual trade
- estimated bill of materials for their individual trade
- project specifications

The student groups are given the following instruction: Over a 2-week period, 4 coordination periods (meetings) will be designated in class for students to identify coordination interferences and determine specific resolutions for each conflict. The overall goal is to create a solution that benefits all parties involved without favoring one trade over another.

The students are guided through the coordination process in a manner that resembles industry practice. The process begins with the HVAC dry team laying down a transparent drawing of the HVAC dry system on the light table for comparison with all other shop drawings. The drawing displays the preliminary routing for the system. Specialty contractors commonly use the HVAC dry system as a base because it has the largest components, primarily composed of large ductwork and variable-air-volume (VAV) boxes. They are the hardest to relocate. Large duct sizes restrict the routing to a few locations where adequate space is available.

The HVAC wet (hot and cold-water) system is the first system students overlay on the HVAC dry system because it directly feeds into the HVAC dry system. The HVAC dry and HVAC wet systems work together and must be tightly coordinated. Routing of the HVAC wet system is based on the HVAC dry system routing and location.

Next, the plumbing system, including all graded lines, waste lines, and vent lines, enters into the coordination process. 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 wet system. The gravity drain lines typically slope 1/8 inch for every foot (1cm per meter). 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.

Where process piping is included as a building system, it is coordinated following the plumbing system. Most 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 process-piping system.

Next in the coordination process is fire protection. 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. Engineers and contractors compare drawings individually with HVAC dry, HVAC wet, and plumbing systems.

Consideration of the electrical system follows the fire protection 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. However, this is only true for branch conduits which are 1/2-inch (15 cm) diameter and smaller. Larger electrical main conduits receive priority. This is because the greater the number of elbows and bends, the more difficult it becomes to pull cable.

The control systems and telephone/datacom systems enter the coordination effort last, because the control system is considered to be the most flexible because of its smaller diameter tubing and conductors. Components in the control system run along other systems, such as HVAC dry and process piping. Therefore, specialty contractors usually coordinate the control system in the field. The primary problem with the telephone/datacom systems is routing these lines adjacent to electrical distribution cables. Engineers usually avoid this problem by segregating telephone/datacom lines from transmission lines by at least three feet.

Common Problems Encountered during MEP Coordination

During the classroom exercise, students learn that there are many places in facilities that repeatedly cause coordination problems. These include building corridors, points of entry and exit, openings in shear walls, and vertical chases. Student groups are then asked to categorize the interferences by the five most common type of interferences found in MEP coordination [Korman 01].

- Actual interference - occurs when two or more components physically interfere.
- Extended interference - occurs when a component interferes with an extended space that is associated with another component.
- Functional interference - occurs when engineers position two or more components such that their location in relation to each other jeopardizes the intended function of the component.
- Temporal interference - occur when engineers position components in a manner that prevents efficient construction sequencing and scheduling.
- Future interference - occurs when engineers position components in locations that they do not allow space for routine operations and maintenance tasks or space for future expansion.

Evaluation of Student Effort and Results

Upon commencing the MEP coordination classroom exercise, students are also given guidelines for use during the coordination effort. The guidelines help students understand what makes the results of one coordination effort better than another and assist them in determining the most effective resolution for individual coordination conflicts. Table 1 lists these guidelines that industry professionals deem to be indicators of good coordination. The indicators are classified by project phase [Korman 01].

Table 1 – Indicators for evaluating the quality of MEP coordination efforts and determining resolutions for MEP coordination conflicts

Project Phase	Indicator
Design	• minimize number of fittings and connections • group and centralize similar systems • group similar systems at same elevation • route systems on grid pattern, perpendicular to building walls • minimize the number of diagonal lines
Construction	• decrease cost for installing components • decrease schedules for installing systems • maximize number of prefabricated components • minimize level of rework in the field • consider installation sequence
Operations and Maintenance	• provide adequate access space for operations and maintenance • reserve adequate space for future expansion

Conclusions and Need for Future Education

There are many challenges to improving Design-Build coordination. The classroom exercise at UNLV is an attempt at teaching the need for design-build coordination and increasing the understanding of building systems. It provides an opportunity for students to utilize their technical skills and improve their communication (coordination) skills by allowing interaction of representatives from many disciplines and construction trades to gather and discuss configuration alternatives. The process helps students to recognize the need to align goals and define requirements when working together. By forcing students to consider the big picture, it is less likely that they will just focus on their own design and construction requirements, which is why many design and construction professionals are unaware of unique installation requirements for other trades. This exercise promotes shared knowledge between the different systems.

In addition, the exercise instigates discussion of construction scheduling, and the installation sequencing exercise serves as a training ground to consider all the phases of a project life-cycle – design, construction, and operations and maintenance. As described above constructability issues are not considered, and designers must make assumptions about constructability or ignore the issue totally. Because of the lack of communication between designers, builders, and operations personnel, it is difficult to integrate knowledge about operations and maintenance of the facility. Operations and maintenance personnel often are not involved in coordination decisions; therefore, designers must make assumptions concerning the user's needs.

Overall, the Design-Build coordination exercise has been a successful venture at UNLV. There is however, a need for future education. In subsequent course offerings, it is our desire to incorporate architecture and structural engineering students into the process. These disciplines are also to key to successful coordination efforts, because of the many constraints they impose on MEP systems.

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