VI. 3D MEP COORDINATION (CRITICAL INDUSTRY ISSUE)

BACKGROUND:

Building Information Modeling can take many forms in the planning, design, construction, and facilities management after the building is complete. Many design firms, builders, and owners are embracing this trend in this use of BIM technology and are exploring BIM uses to assist them reach their project goals. As the industry becomes more familiar with the ways they intend to use BIM, efficiencies and cost of technology will continually decrease. Also resistance to change from traditional techniques will be overcome establishing this as the standard medium to view drawings.

Evidence of continued exploration of this topic, was Penn State's Computer Integrated Construction Research Program and their recent release of the BIM Project Execution Planning Guide. Research such as this will help the industry utilize different technology to help improve overall project planning and increase process efficiencies. The planning process will especially help to pinpoint exact BIM uses that would be the most effective to the reach goals of the project and the goals of the parties involved with its construction.

Understanding the project goals, and defining detailed plans for BIM will help make a project more efficient in its implementation of BIM. This is especially true of the capabilities of BIM when using 3D models to help coordinate the MEP system of a building. It is important for the entire team to be aware of their responsibilities and "on-board" for the entire coordination process. Working together as a team is integral in order for each participant to realize the efficiencies of 3D MEP coordination.

GOAL:

The goals of this analysis will be: to define the processes that need to occur to successfully coordinate the MEP systems in 3D; to analyze the hypothetical implementation of the process to the project compared to the traditional 2D method; to analyze overall advantages/disadvantages of the process; and to assess the final return on investment of implementing a 3D coordination process. Finally, a project specific plan will be generalized based on the best practices and capabilities of the Carderock project members.

TYPICAL 2D MEP COORDINATION:

On a typical Design/Bid/Build project, there are low levels of team integration and coordination to create the final product of a finished building. They traditionally rely on old, but proven processes and techniques to get the work completed on time. Whether it be a high technology lab building, office, or school, they will generally use the same 2D coordination processes using light tables or overlaying CAD drawings and time consuming meetings to coordinate the work. This process relies heaving on the experience and intuition of each team member to identify conflicts. However, this almost always results in conflicts in the field when the building is constructed.

After contracts are awarded on a Design/Bid/Build project, the specialty contractors involved with the MEP work will create detailed shop drawings of an area that will be used for coordination, fabrication, and installation. Typically, coordination of the systems will be prioritized in the following order: HVAC duct, HVAC pipes, plumbing, fire protection electrical, and telephone/data. Contractors will then lay a transparent drawing over a light table or use multiple layers within an AutoCAD software to look for clashes with the design. It is important to note that with this coordination technique there is no automated system to search for conflicts in the MEP systems. This process relies on the instincts and experience of the parties involved with process.

Typically, a building will be divided into zones with each area's coordination built into a Critical Path Method Schedule (CPM). This schedule should be followed to ensure that each area is coordinated and approved before being released for fabrication. Each zone will require at least one meeting to ensure the design is coordinated to minimize errors in the field. However one meeting per area is not commonplace in industry practice. Research published in the Journal of Architectural Engineering by Tatum and Korman said that a basement floor of a laboratory building required 15 coordination meetings over a 3 month period. It was estimated that it required about 520 work hours and cost around $260,000 to complete the coordination. This demonstrates that the amount of time required by key personnel, such as foreman, draftsman, and project managers, is extremely high for a 2D coordination process.

Clear observations of the 2D coordination process reveal its inefficiencies. As previously noted, the process requires large time commitments from critical project members. These time commitments come at a substantial cost to each contractor. The 2D process typically does not catch every coordination issue, leading to a high amount of RFI's, change orders, and re-work of installed assemblies. Re-works and change orders often come at a premium cost mark-up, inflating the project budget. In an interview conducted with a project manager, it was noted that he prioritized his time to deal with change order management which primarily stemmed from the issues in the coordination process and MEP conflicts. He noted that out of all of his responsibilities, change order management was the most time consuming. The following figure represents a generic process used for 2D coordination.

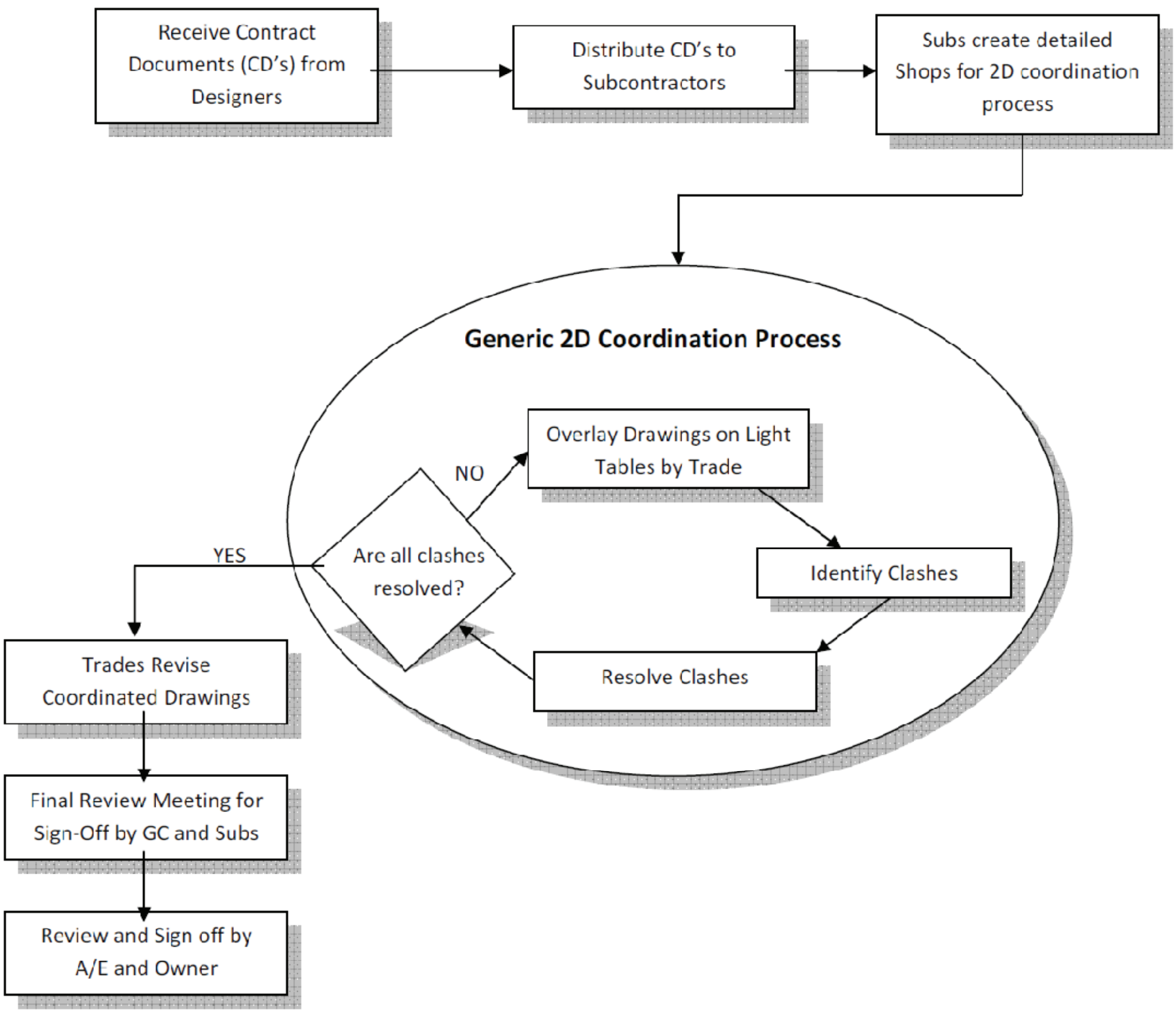

Figure 14 - Generic 2D MEP Coordination Process

2D Coordination Summary:

- Consumes large amount of time
- Generally does not identify all systems conflicts
- No clash reports are produced

- Requires multiple meetings for same areas
- Issues with MEP coordination lead to change orders and further consumption of time
- Change orders come with a cost premium to an owner causing the budget to grow

3D MEP COORDINATION:

Over the past 10 years, there has been a significant investment into BIM technology, both in industry and through institutional research. This investment has yielded significant results on actual projects and through the form of research publications. In the area of 3D MEP coordination, there have been numerous positive results that have improved the efficiency of the coordination on actual projects, thus saving time and money.

In practice, the largest benefits of 3D MEP coordination are achieved in a Design/Build or another type of integrated delivery approach. These delivery methods inherently increase the collaborative and team approach to the design and construction process. However, an integrated approach is not a necessity to use 3D coordination as a tool to achieve project efficiencies. It is possible to implement it in a Design/Bid/Build environment. The Design/Bid/Build approach will be the hypothetical study on Carderock Elementary School elaborated upon later in this section.

Before any process or BIM technology is applied to a project, a plan must be developed to guide the users through each step. This will help eliminate conflicts and will provide a reference to parties not familiar with the entire process. The following items from Staub-French and Khanzode were identified as essential steps in setting up a 3D design and coordination process. They were developed in researching a Design/Build project and are rooted in a more integrated delivery method. Each of these steps has its own set of processes and checklists that need to be completed to implement a 3D coordinated MEP systems process.

1. Identify the Potential Uses of 3D Models
2. Identify the Modeling Requirements
3. Establish the Drawing Protocol
4. Establish a Conflict Resolution Process
5. Develop a Protocol for Addressing Design Questions
6. Develop Discipline-specific 3D Models

7. Integrate Discipline-specific 3D Models
8. Identify Conflicts between Systems
9. Develop Solutions for the Conflicts Identified
10. Document Conflicts and Solutions

Although each step is important in the 3D MEP coordination process, defining each step in its entirety for application to Carderock is outside the scope and intent of this analysis. Instead a more generalist approach will be utilized. There is currently focused research being performed in each step of the list. The following figure is a graphical representation this approach.

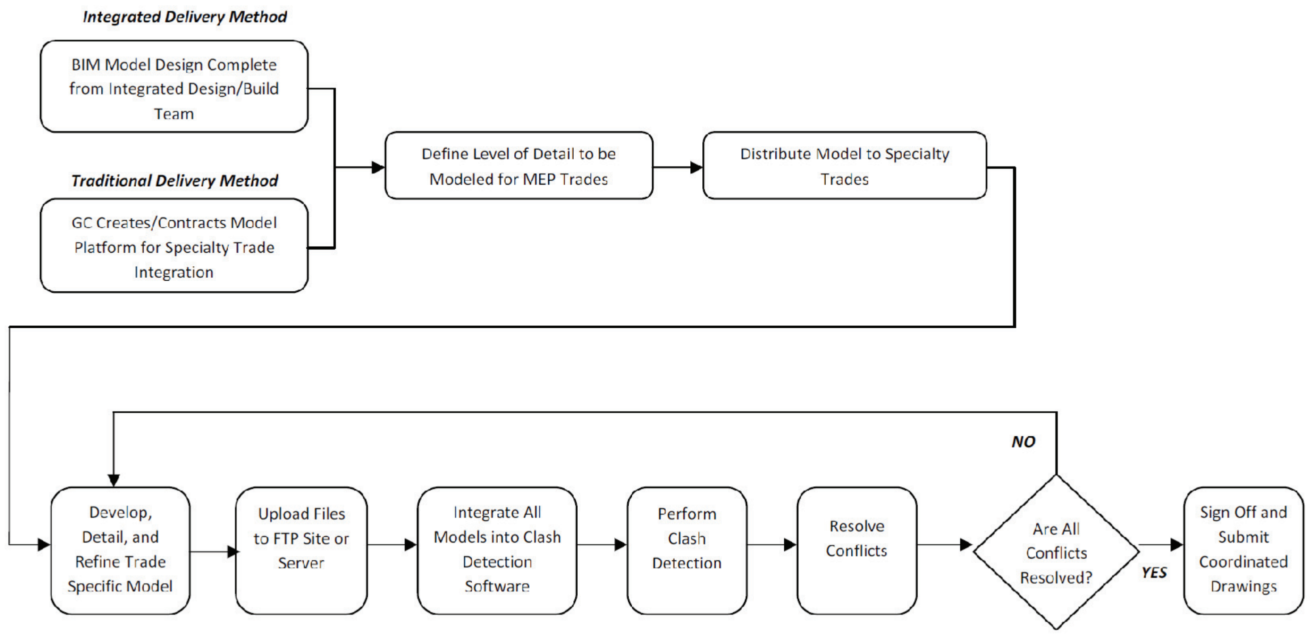

Figure 15 - Generic 3D MEP Coordination Process

The first step of this coordination process begins with the type of project delivery method that will be utilized. In an integrated approach, the owner is calling for the GC/CM and specialty trades to be involved early during the design stages. This would result in a substantially coordinated design in the contract document stage. A disadvantage in this approach is a longer design phase; however, the benefits from this approach, according to a case study by Staub-French and Khanzode, show less change orders and RFI's, less re-work, and enhanced cost control amongst other benefits.

A traditional method would begin coordination upon issuance of the 100% Construction Document stage. The GC/CM would lead this coordination process. When awarding contracts, specialty contractors would have additional 3D modeling and coordination requirements to go along with the traditional 2D submittal requirements. It is important to note that in this scenario, the 2D submission is the legal binding document since BIM was not utilized in the contract between the Owner, A/E, and GC/CM. The GC/CM is calling for additional capabilities of its subcontractors to obtain the benefits of BIM technologies specifically relating to 3D MEP coordination. It would be up to the GC/CM to identify the trades and the systems they would choose to coordinate in a 3D environment.

Also in these initial stages the level of detail must be determined. An example of defining detail would be the decision to model duct insulation or the corrugations of a metal deck. For clash detection purposes a duct could be modeled as a single entity that accounts for the insulation thickness or the insulation could be modeled separately. With the decking, the slab could be modeled at its nominal thickness and not include the corrugations. When creating models, file size and usability must always be considered. Incorporating more detail will slow the models and increase file sizes which could lead to technical issues such as slow file download speeds or computer compatibility issues. It is important to consider the hardware capabilities of each specialty contractor to ensure they can properly support the modeling software platform.

Next, in an integrated approach, the master model from the designers would be distributed to the specialty contractors to begin the detailing and refining stages. In a traditional delivery method, the GC/CM would have to create the initial architectural or spatial model. In a case study performed by Leicht and Messner at Penn State, it was found that the CM had created a spatial grid based on the surveys performed by the surveying contractor. Other options would be to create an architectural model "in house" or through a 3rd party contract. This would depend mostly on the capabilities of the GC/CM. It is safe to assume that in this situation, the GC/CM would have some type of capabilities in BIM modeling to choose to incorporate in their construction processes. This model would then be distributed to the specialty contractors involved in the 3D coordination.

Once the trades have received the base model, they would use this to model their respective scope to the appropriate level of detail. These detailed modeling phases would most likely take place by quadrant or area of the building. It is rare and unadvisable to coordinate an entire building at once since this requires extremely powerful computer hardware and would take an extremely long time to complete. Coordination is best performed using smaller sections of the building similar to a 2D process. These areas of coordination should be built into the Critical Path Method Schedule (CPM) if possible. The schedule should set specific milestones for area coordination, 3D model completion, upload to server/FTP website, and resolution of conflicts.

Next, the files must be compiled into a single clash detection program such as Navisworks. This would most likely be done by the GC/CM or the Mechanical contractor. The party responsible would have to be identified in the contract to avoid unnecessary disputes. In this stage, technical issues regarding file formatting can arise when combining different authoring software into a single model. It is critical that the contract spells out specific file formats or compatibility with the clash detection program. Once all of the MEP models are loaded, clash detections will be run to generate a report.

A clash detection report should be distributed to all MEP coordination parties prior to attempting to resolve the issues. This will give all parties a chance to review and note the collisions that arose to begin thinking how to address them. The meeting format must also be decided. This can take the form of teleconferencing, in-person, or independent coordination without any formal intervention. Although it may not be necessary to meet in-person during the resolution step of every collision report run, it is recommended that these face-to-face meetings do occur. Studies have shown that communication is richest and fullest in person.

Other things to consider regarding the meeting place and format are travel times, ensuring attendance commitments from all critical personnel, and technology capabilities. Through speaking with industry members, it was said that trailers with projector screens and adequate computer hardware tend to work best. This ensures that coordination team members are all on the same page and can lead to more efficient meetings. It also lends to the opportunity of physically entering the building area to further visualize the model information in the field.

Clashes can occur in different forms when using 3D BIM technologies. One type of conflict could arise from lack of model detail. An example of this could be a pipe going through a wall that does not require a sleeve. This type of clash should be noted and ignored in future reports. The next type of collision is a coordination issue such as a piece of duct that runs through a plumbing pipe. In this scenario, the specialty trades would have to determine a solution. Last, there are collisions that occur due to design issues. This type of clash would occur if a pipe of a certain diameter did not fit within a chase. This would have to be submitted to the designer as a RFI for further clarification or design changes.

In this stage it is extremely important to document and log the results of the meetings. The minutes along with the clash report and proposed solutions should be distributed to all parties as a reference in the event field issues arise or further clarification is needed.

When all of the areas have been coordinated and clash detection has yielded no collisions, the process is complete. During this step the final coordinated plans will be submitted to the designers for approval. Most likely each section was submitted individually after each quadrant or area was coordinated with no clashes detected.

Implementing 3D MEP Coordination at Carderock:

Much of this section will take lessons and processes derived from other research for application to this project in a hypothetical sense. It will describe the general method to implement a 3D coordination process utilizing BIM technologies.

It has been shown that utilizing BIM technologies such as 3D coordination utilizing an integrated project team delivery has the maximum benefits and efficiencies. Although this is true, a Design/Bid/Build project such as Carderock Springs Elementary School can also obtain some of the benefits of 3D MEP Coordination as well. In this implementation, Hess Construction + Engineering Services assume the lead role in the process since they hold all subcontracts.

In order to implement this process, specific requirements for 3D modeling will have to be implemented into the contractual language that will supplement the owner's requirements of a 2D process. This means that the specialty contractors will build their models from the 2D contract documents since there will be no preceding 3D model from the architect and consulting engineers. It is critical to note that 2D shop drawings and submittals will still be necessary to meet contract requirements. 3D modeling software will only be used to increase the efficiency of the coordination process. In order for the contractors to obtain the maximum benefit they should use the 3D software to obtain their 2D required drawing submittals. However this does not always occur, in the Dickinson School of Law Case Study by Leicht and Messner, they reported some contractors had hired a 3rd party modeling company to perform the 3D requirements of the contract with the CM. They then took the results of the 3D modeling and coordination process to maintain their own 2D drawing set. This was inefficient since the same drawings were created twice.

Technology capabilities and limitations should be considered when choosing the contractors to work on the project. Often, a pre-qualification method would be used with metrics based, not only on past performance, but also in 3D coordination and BIM capabilities. Considering this when awarding contracts would be important since you would want commitment to the 3D coordination process. Another important aspect of this would be to reach out to the subcontractors to attempt for them to assemble teams with experience with BIM technologies. This would help to decrease the learning curve compared to team members who have no experience. Having no experience does not necessarily disqualify a contractor. In the BIM Execution Plan by the Computer Integrated Construction Research Program at Penn State, they highlight the importance of identifying capabilities and supplementing inexperienced members with training to put them on a level with the rest of the construction team.

At this stage it would be important to identify which contractors would be required to model in 3D and implant the 3D MEP coordination requirements within their contract. At Carderock, the traditional MEP trades and Steel contract would be required to model in 3D for coordination purposes. These trades would be the following:

- Steel
- Mechanical/HVAC
- Plumbing
- Electrical
- Fire Protection

The contractors that were actually chosen at Carderock had some exposure to 3D modeling, although not all had participated in a truly 3D MEP Coordination process. The steel contractor had used a 3D model of the structure for shop drawing and detailing purposes. That would make their inputs into the process relatively minimal. It is also important to note that the steel contractor does not fully participate in the process since their system is of the highest priority. The mechanical and plumbing contracts were awarded to the same company. This introduces an added efficiency to the process since there are be less variables to consider and less points of contact to maintain. This contractor already has 3D modeling capabilities that they use to produce shop drawings and automated fabrication within their shop. This is typical of mechanical contractors of the Washington, D.C. area. Their inputs into the process would also be minimal. The fire protection contractor also has significant modeling experience and would need little training if any to participate in the modeling process.

The contractor of primary concern would be the electrical contractor. This contractor had the least amount of 3D modeling experience and would need the most amount of investment into the project. In this scenario they would have the option to invest in software and train personnel or hire a consultant to perform the modeling.

Once all the contracts were awarded, it would be important to establish a clear and well documented execution plan for the project. This would benefit the project since none of the contractors have had experience with a true 3D MEP Coordination process in the past. This would follow similar conventions to figure 15 found previously in this section. For example, in defining the level of detail, it would have to be spelled out that a duct should be modeled including the thickness of its insulation. Another example of this would be to say that all hangars and seismic supports should be modeled for all systems. Also, in the early stages it would be determined which file formats and software compatibility requirements would be necessary to ensure interoperability of MEP models.

After the requirements of the models and compatibility concerns are addressed, a process for sharing the files needs to be established. Through interviews with industry members about the ease of sharing files it was reported the best method is through a FTP site. They said that these sites have the least technical issues and allow for large files to be shared with faster upload and download speeds. They explicitly noted that e-mail was to be avoided at all costs since large files often get rejected by companies e-mail filters or takes a long time to send and receive.

Once all details regarding the technical software and information technology are understood, the building can finally be analyzed for coordination. To begin, the building should be broken down into logical sections that correspond with the CPM schedule. This will allow for modeling and coordination requirements to be built into the schedule by area to ensure that all areas are coordinated and released for fabrication as early as possible so that the contractors can realize the maximum benefit of the 3D MEP coordination process and make their investment worthwhile.

Table 6 - Building Area Breakdown

<table>
<tr><th>Area</th><th colspan="3">Components of the Area</th></tr>
<tr><td>Area 'A'</td><td>A Lower Level</td><td>A Main Level</td><td>A Upper Level</td></tr>
<tr><td>Area 'B'</td><td>B Lower Level</td><td colspan="2">B Main Level</td></tr>
<tr><td>Gym</td><td colspan="3">One Logical Area</td></tr>
<tr><td>Multipurpose Room</td><td colspan="3">One Logical Area</td></tr>
</table>

Table 6 demonstrates how Carderock was broken down into different areas. The construction schedule should then be adjusted to reflect when areas should be coordinated according to when construction activities will take place. This will drive the meeting and the clash detection cycle of the process.

At Carderock, for Areas 'A' and 'B', meetings were held on the first Wednesday of the month approximately a month and half before the first MEP trades were schedule to begin work. The schedule typically followed Area 'A' Lower to Upper, followed by 'B' Lower to Main, and then the Gym and last the MPR. Once again, to maximize the benefits of a 3D coordination process, the contractors would be required to begin modeling almost as soon as they are awarded the contract. This would provide them with two primary benefits. First, a learning curve will most likely exist, therefore running a "mock-up" type coordination process would benefit the team to test the process and refine steps if necessary. Next, it creates opportunities for prefabrication which can improve the efficiency of work output and even accelerate the schedule without any direct inputs to schedule acceleration scenarios.

Once the modeling is complete, the models will be uploaded to the FTP site and Hess would compile the models and run clash detection for the area being coordinated. The collision report would be distributed and a meeting would be scheduled. The best place would either be the construction field office or the corporate office of Hess. If the corporate office is used, no additional technology such as computers and projectors. If the field office is chosen, then an investment into a computer that can handle the collision software and projector will be needed. At this meeting the collisions would be assessed and solutions to the problems would be proposed. Again, the collisions would either yield a detail issue, a coordination issue, or a design issue. The contractors would then be given time to refine their models.

The coordination meetings at Carderock using the 2D AutoCAD overlay process lasted 4-6 hours. They were very time consuming and not every contractor had actively participated. The 3D process would allow for the meetings to concentrate only on the detected clashes and less on the searching of conflicts within the 2D drawing set. They were given 3 weeks to make changes and compile the coordinated drawing set. This was the responsibility of the Mechanical contractor. Using a 3D process it is realistic to accomplish revisions in half the time. After this time, the refined drawings would be loaded into the clash detection software and reports would be distributed. At this stage, a majority of the conflicts should be resolved. It is safe to assume that another in-person meeting will not be required and that the coordination toward zero conflicts can take place using phone calls and emails between the specialty trades.

After the initial coordination meeting for each area, a review cycle should be set up for the collision detection of the specific areas. For example, after five working days, the models are posted back to the FTP site to be compiled for another clash report. This would provide feedback as to whether there is significant improvement in the conflicts within the models. The collision report can be sent to the contractors for comparison to the original coordination meeting. If necessary another meeting could be required in person to discuss the new results. This would have to be a judgment call based on the severity and depth of the conflicts that occur. For example, a main supply duct branch conflicting with a large and critical structural member could require a meeting to discuss potential solutions.

Once the zero conflict milestone is reached, a 2D set would be exported from the 3D model for approval from the A/E designers. When approved, the specialty contractors can begin pre-fabrication plans to benefit from the enhanced quality control of their shops. This should increase the quality and tolerances of the workmanship. It would also cut down on labor within the field with the opportunity to finish ahead of schedule.

Summary of Implementation Strategy:

The goal of this analysis is to identify best practice techniques to establish a process for 3D MEP Coordination on a project that was not initially set up to support such a procedure. The analysis is created through critical industry research relating to the topic. Using the results and recommendations of industry professionals and researchers, a plan was derived that strived to achieve the maximum benefits of time, efficiency, and budget: while minimizing risk and inefficient practices.

It is impossible to say whether or not the 3D coordination plan would prove to be better in practice than the 2D method employed on the project since there is no way to apply a new process and analyze it without actually performing the steps. The best way to analyze its impact is to make generalizations from case study projects and find similarities that can support evidence of a 3D MEP Coordination plans effectiveness compared to a 2D process.

Currently, there is research that supports the case for using a 3D MEP Coordination process on construction projects. In research performed by Staub-French and Khanzode, they highlighted many benefits of the process including increased cost control, fewer change orders, and increased quality and efficiency due to prefabrication. In another publication by Leicht and Messner, they also noted the reduction in change orders and RFI's specifically related to MEP systems. They also reported that there was increased cost control due to fewer field conflicts as a result of implementing MEP systems. Each report concluded that the overall 3D MEP Coordination process and experience was positive for all parties involved.

The main barrier to success using this process is a lack of thorough initial planning. Each step in the process must be documented carefully. Therefore, it is a recommended that a project specific manual be made to guide the project. This should include details regarding all aspects of the coordination process such as file compatibility to conflict resolution processes as was discussed earlier in this section. Perhaps the most important aspect of the manual should be to define the goals of using BIM technologies on the project. For Carderock Springs Elementary School, an example of a project goal relating to this analysis would be "To enhance the efficiency of the project through commitment to the 3D MEP Coordination process." It is important to think about what the expected output and end goal would be. In this case it would be to reduce coordination conflicts that could result in RFI's, Change Orders, and Re-work in the field. All of these activities are very time consuming for all parties, from the specialty contractor to the owner, who must review all changes to the original contract scope.

The last recommendation is a commitment to the refinement of the MEP coordination processes. Within any industry, new technology provides an opportunity for innovation and creativity. It must be understood that there will be inherent difficulties that arise from using a new technology. This is especially true in the architecture, engineering, and construction industries, since there is no project that is identical to another. No precedent can be truly established. The uniqueness of each project lends itself to innovation as managers and project team members must refine "best practice" type guidelines to work on their own unique project. This commitment to the overall goals of the project would allow each team member to realize the efficiencies of the 3D MEP Coordination process and save time and money while gaining experience and knowledge that can be applied to future projects.

Section Specific References:

C. B. Tatum, T. K. (2000). Coordinating Building Systems: Process and Knowledge. *Journal of Architectural Engineering , Vol. 6* (No. 4).

Computer Integrated Construction Research Program. (2009). “BIM Project Execution Planning Guide – Version 1.0.” October 8, The Pennsylvania State University, University Park, PA, USA.

Messner, J., & Leicht, R. (2008). Moving Towarrd an Intelligent Shop Modeling Process. *Journal of Information Technology in Constrcution , Vol. 13*, pg. 286-302.

Staub-French, S., & Khanzode, A. (2007). 3D and 4D Modeling for Design and Construction Coordination: Issues and Lessons Learned. *Journal of Information Technology in Constrcution , Vol. 12*, pg. 381-406.