# ANALYSIS 1| IMPLEMENTING BIM

## BACKGROUND

Building Information Modeling (BIM) is fast becoming a more integral part of the construction industry.  With several leaders pushing the envelope of BIM integration into the design and construction processes, the technology is continuing to gain momentum.  With this gaining momentum, more companies are turning to BIM to help improve their projects and companies through its many uses: 3D MEP Coordination, Automated Quantity Take-offs and Cost Estimating, Phase Planning, 4D Modeling, and Energy Analyses to name a few.  With all of these new tools and opportunities presenting themselves, the process in which to implement these new tools can become vague and unclear.

One research project that is currently underway to address this issue is the BIM Execution Planning Guide being headed up by the Computer Integrated Construction (CIC) Research Program at The Pennsylvania State University.  The goal of the research is "to develop a method to create a BIM Execution Plan in the early stages of a project".

Defining expectations of the model and outlining the process to utilize these BIM uses are necessary steps in order to successfully implement BIM on a project with positive results.  Not all uses are critical, or even useful, to a project; therefore, being able to understand the needs of the project and the processes that are to be used are important pieces of the puzzle. Understanding the process involved with implementation will allow owners and other early project team members to make informed selections on the BIM uses they wish to use on the project.

## GOAL

Three main goals exist as part of this analysis:

1) Develop a generic process model that defines and illustrates best practices for the 3D MEP coordination process utilizing BIM
2) Compare methodologies from "traditional" 2D design coordination as used on DCH to 3D design coordination as defined in the generic process model
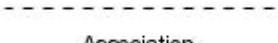3) Define project specific process for implementing 3D MEP coordination at DCH

Analyzing BIM processes and their implementation is also demonstrating influence from a master's level class, AE 597G, BIM Execution Planning.

## BUSINESS PROCESS MODELING NOTATION

The process model is illustrated in Business Process Modeling Notation (BPMN), which was developed by the Business Process Management Initiative.  BPMN was selected as the notation for this research in order to closely correlate this work with the ongoing research that is being conducted by the CIC.

BPMN, like other process modeling notations, has a goal to graphically represent an abstract process in order to clearly articulate it to a given audience.  BPMN attempts to be an intuitive format; hence, the audience does not necessarily have to be of a technical nature or be overly familiar with the process in order to understand it.  Some understanding of the notation is helpful, and is laid out in Table 5-Explanation of BMPN Symbols.

TABLE 5-EXPLANATION OF BMPN SYMBOLS

| Notation | Explanation |
|---|---|
| Start  Intermediate  End | **Events-** Something that "happens" during the process model.  They can be start, intermediate, or end events.  Different symbols can be inside the circle further indicating the type of event (an email, a timed event, multiple trigger events, etc.) |
| Task  Process | **Activity-** Generic term for work that is performed by a single entity, or multiple entities, either companies or individuals |
| Gateway  Fork/Join  Inclusive Decision/Merge | **Gateway-** Represents convergence or divergence in the flow of activities.  It may represent a choice that must be made or be dependent on the outcome of the preceding activity to determine which way the model will flow |
| Sequence Flow | **Sequence Flow-** Shows the order in which activities and events move |
| Association | **Association-** Used to link information to Flow objects.  Allows non-flow objects (such as a data object) to be associated to Flow Objects (Activities and Events)  Associations can have arrows indicating directionality of the non-flow object |

| | |
|---|---|
|  Name | **Data Object-** Demonstrate movement of information in or out of items, but do not impact the flow of the model.  Can be used to show what information/resources are required for events or activities to be performed. |
|  | **Lane-** Used to categorize and organize activities into areas of similar functionality |
|  Trades | **Annotation-** Used to add additional information to a graphic.  In this particular model, they represent agents who will be executing the tasks which they are under. |

## 3D MEP COORDINATION PROCESS MAP

While BIM is not commonplace yet in the construction industry, it is continuing to improve its foothold and there are several companies that have taken to the forefront with integrating it into their projects.

In order to develop best practices for the generic process of 3D MEP coordination, discussions have been held with representatives from these companies.  Through phone discussions and email correspondences, industry members from Balfour Beatty, Jacobs, and Gilbane offered lessons learned and insight for successful 3D coordination processes.  Additional information was gathered from academic resources, such as previous classes, graduate students who are familiar with and have run 3D coordination on industry projects, and journal papers.  This information was then compiled and common traits examined to develop the 3D coordination process map.

TIBCO Business Studio is the software in which the process map is created.  During original trials of developing the map, multiple swim lane configurations were examined.  One such model was developed defining swim lanes as the participants on the project.  Another model used swim lanes that looked at Resources, Tasks, and Results/Output as the defining categories.  While each of these models had their own unique value, it was decided that the swim lanes of External Information, Enterprise Information, Process, and Building Information Model in order to keep the results of this work in close agreement with CIC research.

The first section of the 3D MEP coordination model,shown in Figure 5-Section 1 of the 3D MEP Coordination Process, represents the steps leading up to the involvement of the sub contractors. (Sections are arbitrary and used only to increase image fidelty for the purpose of discussions.)  Full explanations of each event, task, and data object can be found in Table 22-

Explanation of Tasks as Defined in Process Model and Table 23-Explanation of Events as Defined in Process Model in Appendix IV | Process Model.

Once the model is completed to a specified level by the designers, the start event for this model, it must be transferred to the GC.  This is the first time that external information enters the process in the form of exchange requirements.  In order for the GC to successfully use the model, it must be understood what the file formats will be.  While some level of interoperability does exist in the industry, many challenges can be avoided if these exchange requirements are defined early.  While it is not necessary for the same exact platforms to be used, doing so would prove beneficial.  The exact requirements for this exchange are outside of the scope of this research, but their definition is an aspect that warrants attention and is the focus of the National BIM Standards (NBIMS) which is currently under development.
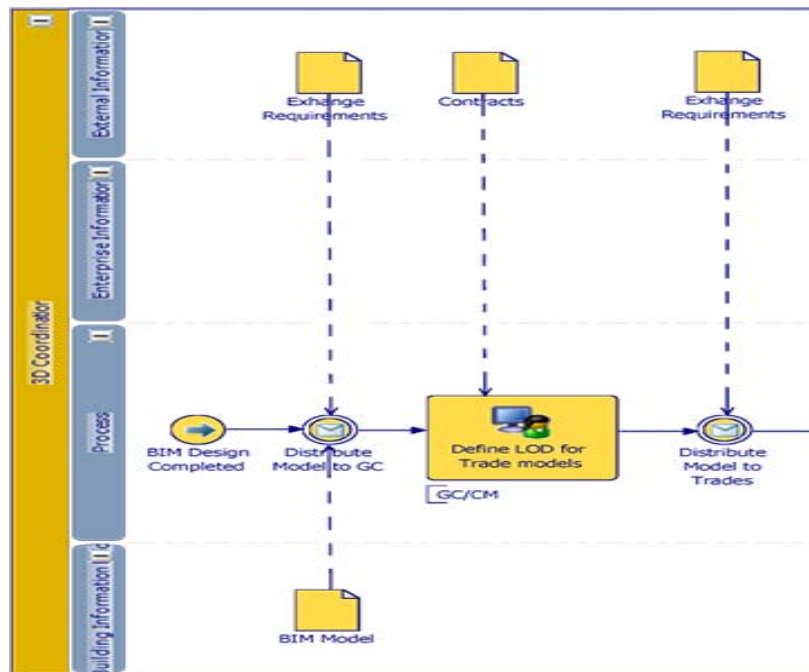


FIGURE 5-SECTION 1 OF THE 3D MEP COORDINATION PROCESS

Once the GC has the model, it is their responsibility to define the Level of Detail that will be expected from the subcontractors for their modeling tasks.  These requirements should be written into the language of the subcontract.  Several different organizations have developed addendums to standard contracts that attempt to address contractual issues arising from BIM. ConsensusDOCS, the AIA, and USACE have all written language to use in contracts, but none have been fully vetted through the courts, so no precedents exist.  This external contract information will affect this event and is shown as information flow in, but the specifics of this impact will be unique to each project.

Once the contract language and expectations are delineated, the GC must distribute the model to the subs. While many parts of the model distributed will be reworked or retooled by the trades, a common "background" for all trades to use with defined coordinate systems is an important part. According to multiple interviewees, it is helpful to run through the entire process once at a very small scale to ensure that idiosyncratic behavior is worked out so that once large scale coordination begins these trouble spots can be avoided. A small area that is indicative of the project scope and involves all trades that will be participating in the coordination process is an ideal area for this first run through. It was noted by one interviewee that after this initial process, though the trade contractors had been initially hesitant, they became very engaged and excited about the coordination process.
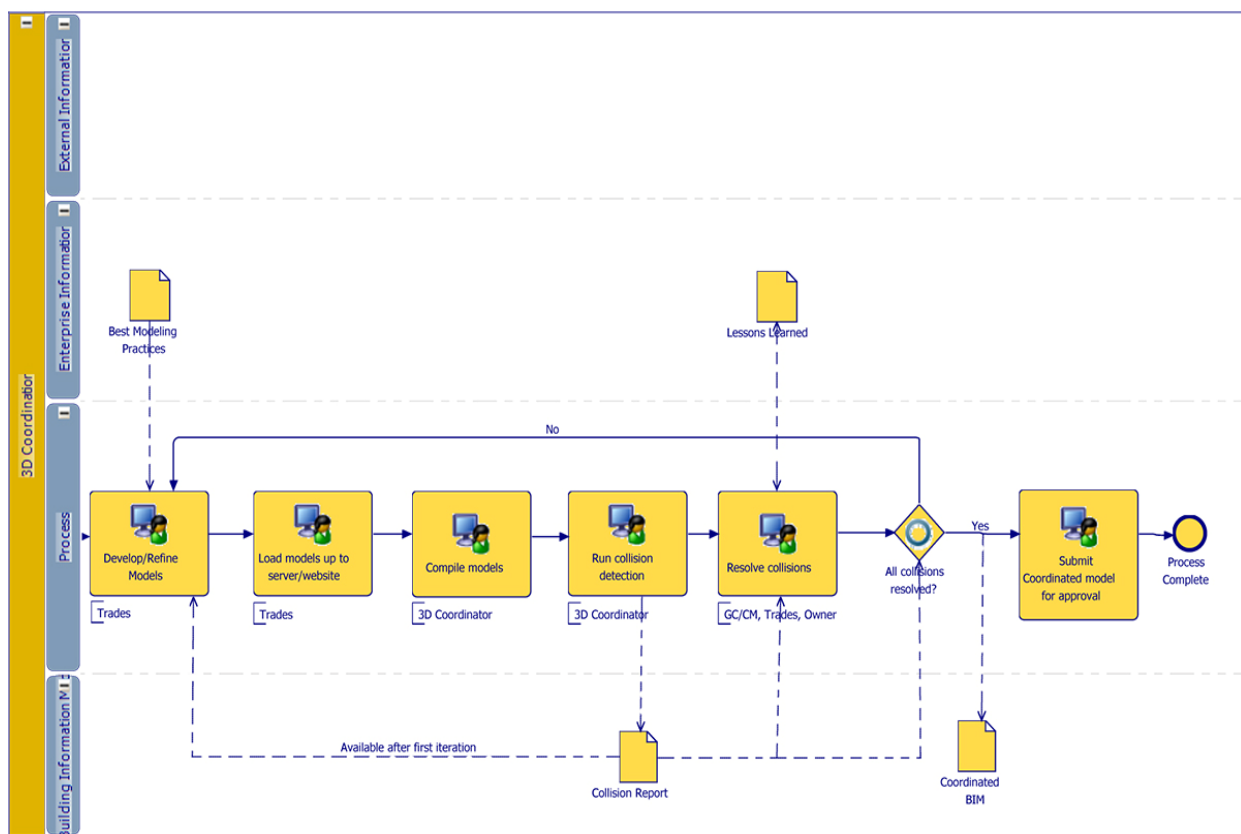


FIGURE 6-SECTION 2 OF THE 3D MEP COORDINATION PROCESS

Figure 6-Section 2 of the 3D MEP Coordination Process illustrates the remainder of the 3D MEP coordination process. The first task of this section is executed by the trades, and it involved actually developing the model that will be used for the coordination. Enterprise information will affect this step in terms of best practices used for modeling. After the first iteration of this process, a collision report will be available in order to specify what modeling must be adjusted prior to the next detection being run.

Project specific processes will govern this task, but a common trait of successful projects as relayed by the interviewees is to proceed by area.  It is unadvisable to coordinate the whole building at once since it could lead to thousands of clashes and could be too cumbersome to efficiently handle.  Furthermore, due to hardware and software limitations, it is unadvisable to have an entire system modeled in one file.  The file sizes will become extremely large and even with high end hardware will still be very slow to run.

Another general consideration that should be made at this point is the sequencing of who models first.  Some industry members propose that it is still beneficial to follow a "2D process" in that HVAC modeling is done first, and then plumbing, followed by electrical, then sprinklers, etc. working down in size in order to help minimize collisions in the initial detection.  This "linear model" was employed after the first coordination area was completed at DSL in order to help reduce conflicts.  Clashes were reduced to almost half in the following iteration of the process for the next areas.

A contrasting view point to this method takes a more contractual stance and is employed on more time critical projects, especially design-build. Contractors are still contractually required to coordinate their work before the 3D coordination process begins.  The work performed by the GC (if they are running the coordination) is in a facilitator role to aid the coordination, not just a passive observer role. The GC in this case expects that modeling work will be conducted simultaneously, "concurrent modeling", by all trades and that the trades still perform their coordination.  The 3D process is not a replacement to the original coordination, but an added level of verification to eliminate collisions.

Based on experience and anecdotal evidence, one interviewee took the time to respond with the following graphic, Figure 7-Comparison of Linear and Concurrent Modeling Practices, comparing the linear method and the concurrent method based on his perceptions and time spent implementing 3D coordination on projects.  While the graphic does not represent concrete data, it is an interesting comparison to consider, especially since the linear method is being given a generous assumption in that the modeling would only take half as long.

| Weeks | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Electrical | | | | | | | | | | |
| Mechanical | | | | | | | | | | |
| Plumbing | | | | | | | | | | |
| TeleCom | | | | | | | | | | |
| Lighting | | | | | | | | | | |
| Sprinkler | | | | | | | | | | |
| Coordination | | | | | | | | | | |

Linear

| Weeks | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Electrical | | | | | | | | | | |
| Mechanical | | | | | | | | | | |
| Plumbing | | | | | | | | | | |
| TeleCom | | | | | | | | | | |
| Lighting | | | | | | | | | | |
| Sprinkler | | | | | | | | | | |
| Coordination | | | | | | | | Time Saved | | |
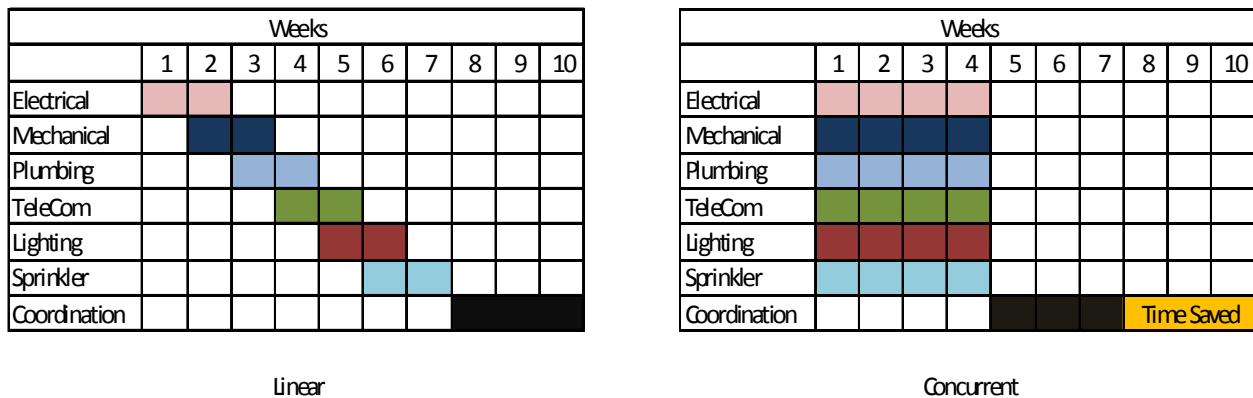
Concurrent

FIGURE 7-COMPARISON OF LINEAR AND CONCURRENT MODELING PRACTICES
(COURTESTY OF BBC)

The next task, again executed by the trades, is to load the models to a server or website in order for the coordinator to retrieve them. E-mail is unadvisable due to the sheer size that these files can reach. FTP servers/websites allow for faster transfer of these large files. All the parties that were interviewed indicated that using a server or website is the preferred method for transfer of files.

Once all the files have been collected by the 3D coordinator, it is their job to compile the files into one master file/file set. Specific steps for this task will depend solely on the software being used by the project team. Collision detection is then run based on the compiled model. The report is generated automatically and then can be distributed to the trades in order to lead into the next step, resolving the collisions.

The task of resolving collisions can take on many forms depending on how the project team elects to define this process. Activities in this step can range from in person meetings at the jobsite trailers, to teleconferencing, to simply disseminating the report and allowing the trades to coordinate on their own outside of any coordinator intervention. The level of involvement of the 3D coordinator at this step will be a decision for the project team. Lessons learned by the companies will influence this task and generally dictate which specific method of collision resolution will be implemented.

According to a case study at Dickinson School of Law performed by Leicht and Messner, the collisions can fall into three categories. First, there are clashes that arrive from insufficient level of detail. Examples of this could be piping penetrating a slab where sleeves were not required to be modeled. It is understood that a sleeve will be present, so this clash can be approved. The next category is a Coordination Issue. This could be conduit conflicting with a pipe, and issue that warrants attention and discussion by the trades involved to establish a resolution.

The final possibility is a design issue, such as inadequate clearance for ductwork as designed. This collision will result in an RFI being issues out to the design team.

The next point in the process is a gateway decision premised on the question, "Are all collisions resolved?" If, for the given coordination area, clashes are still present, the process of refining the model will begin anew and proceed though another iteration of the collision detection process. If all clashes have been resolved for the area, the model may be signed off on by the trades and the coordinated model maybe submitted for approval. The submission of the coordinated model represents the final task in the 3D MEP Coordination Process Model.

## DCH (2D) COORDINATION PROCESS AND COMPARISON TO 3D

The coordination process at DCH did not utilize any 3D modeling for the project, and as such, did not implement a 3D MEP coordination process, but rather moved forward with a more traditional 2D process.

Coordination relied on the overlay of 2D drawings in order to identify conflicts. This task was handled in two ways. The majority of the coordination was done using AutoCAD files and the overlay was done in a computer based environment. In some select cases, hard copy drawings were used on a light table. While the tools used for the coordination on the DCH project differ from the tools used in a 3D coordination, the actual process bears several similarities and overlaps in tasks.

The steps for 3D coordination shown previously in Figure 5-Section 1 of the 3D MEP Coordination Process, closely correlate in terms of general intent, but not in terms of specific data transfers. Electronic drawings are commonly exchanged throughout the duration of construction projects, and due to the relatively universal language of currently used CAD formats, exchange requirements are not as critical to define. However, the general steps of distributing the "model", in this case the AutoCAD files to the GC and to the trades, still has the same intent, the dissemination of information that is critical to the success of the process. The only difference is in the actual information itself that is being passed along. The BIM Model shown as an information input is represented by the CAD files in the process at DCH. Contracts are also much more well-defined in the 2D process than the 3D process, so this consideration is not nearly as important, although it does still exist.

Figure 6-Section 2 of the 3D MEP Coordination Process, shown previously, has many of the same intentions as the 2D method, but there is a difference in tools and end products. Trades at DCH are still responsible for developing the "model" and uploading it to a central server, except the "model" in this case is actually 2D coordination drawings, so the objective of the process remains intact, just the actual deliverables are modified. In order to help limit the

number of conflicts, as mentioned for the 3D process, the project team allowed dry HVAC to layout their system first, and then followed this with plumbing, chilled water/hot water, medical gas, electrical, and finally, sprinklers.  By allowing the largest space needs first, ductwork, it ensured they had the space the ducts needed and allows the other trades to work around them.

The task of compiling the models also changes, but only in execution, not in its goal.  In a 2D world, the software allows quick overlays of layers that all CAD users are familiar with and can quickly complete on their own.  No external software or processes are needed in order to put the 2D drawings together into a coordinated drawing file, unlike a 3D process which requires outside software and significant steps in order to compile all of the separate files.

The step of running the collision detection is not automated in the 2D process.  Instead of relying on algorithms to detect when two objects are in the same space, 2D relies on the eyes, intuition, and experience of the project team.  This change in execution does not mean that this task does not occur.  This task still takes place, but it is in phone calls, emails, and jobsite meetings, not done automatically by software. The task can also not be as easily divided, but instead occurs almost simultaneously with the next task in the process.  The resolution of the collisions is this next step, and it too does not differ greatly from 3D into 2D.  After discussions and meetings to address conflicts, the teams go back to their files and revise them as necessary based on the agreed upon solutions, and try again at the next meeting.  While again lacking some of the automated assistance (clash reports) and clarity (3D views showing the collision), the conflicts will still be resolved and taken back to the "model" (2D drawings) to be changed.  Both of these steps differ in their actual execution and tools used, but again the intent of the process is the same when comparing 2D and 3D coordination.

The gateway is the first major difference in the process because there is no automated output from the 2D coordination process that will inform the team members if there are still collisions to be resolved.  It is left up to the experience of the participants to determine when the coordination process has ended and all clashes have been rectified.  There are still multiple iterations of the process in 2D to ensure that collisions are identified and corrected ahead of time, but the lack of an automated report is a significant deviation from the 3D process.

The final task of submitting the coordinated information, much like the rest of the process, has the same objective in each process, but the methodology is not the same.  The end goal of all of this work is to submit final coordinated drawings or models to the designers for approval.  While the form of the information varies (2D drawings vs. a 3D coordinated model), the content of that information remains relatively unchanged.  The end goal of gaining designer approval for the drawings or model is identical regardless of the medium in which the information is sent.

## IMPLEMENTING 3D COORDINATION AT DCH

Currently, as outlined previously, the Doctors Community Hospital project is only utilizing 2D methods to meet the coordination needs.  Using common successful traits from the interviews and research, an implementation plan for the use of 3D MEP coordination is outlined in the following section.

First and foremost, 3D MEP coordination is often spoken about as the "low hanging fruit" of the BIM world.  This statement holds true because it is one that can be implemented relatively late in the game.  Owners do not need to specify its implementation in early phases in order for it to be utilized.  In fact, a BIM model does not even have to be created in the design phase for this use to be taken advantage of.  While it is easier if at least an architectural model exists so that the trades do not need to create one for a background, this fact is not a prerequisite.  The process outlined for the implementation will be based on the assumption that the entire project is not BIM oriented, and that no design models are available for use by the GC or trades in order to keep it as closely applicable to the project in its current form as possible.

In order to successfully implement 3D coordination, the first task is to assess the abilities and needs of the project team.  In this case, the project team at DCH from Gilbane Building Company does not have experience running a 3D MEP coordination process.  That does not mean that Gilbane as a company does not have experience with 3D MEP coordination.  Both Hershey Medical Center in Hershey, PA, and Dickinson School of Law at University Park were projects run by Gilbane and used 3D MEP coordination.  In order to address the shortcoming of the projects team knowledge pertaining to 3D coordination, they would have to turn to others in the company to supplement their knowledge base.

Next, the team must define the trades that should be involved.  Any trades that will need space in the plenum area of the building are the ideal participants to have involved.  For the DCH project, these trades are outlined in Table 6-Participants Important to 3D Coordination.

TABLE 6-PARTICIPANTS IMPORTANT TO 3D COORDINATION

| Trades for 3D Coordination | |
|---|---|
| •     Steel | •     HVAC |
| •     Plumbing | •     Electrical |
| •     Medical Gas | •     Sprinkler |
| •     Pneumatic Tubing | •     Cable trays |

The steel provider for this project, Steel Fab, Inc., uses Tekla for 3D modeling and creates these models independent of contract requirements as part of their fabrication process.  This fact lends itself well to incorporating 3D coordination since the structure would already be created in

a 3D format.  Hess Mechanical has had some exposure to the 3D coordination process, but it is not extensive.  They do however, recognize it as a valuable tool and are capable of performing the 3D modeling necessary either in house or by subcontracting it out. VarcoMac Electrical and Pevco (Pneumatic Tubes and Cable Trays) have not had previous exposure to a 3D coordination process.  Fireguard Corporation, the sprinkler contractor, has done some 3D modeling for its fabrication process, but has not been involved in a 3D MEP coordination process.  Given the lack of exposure and experience with a 3D process for these subcontractors, a well-crafted and clearly articulated execution plan will be critical to the successes of this BIM use.

Before modeling can take place, Limits of Detail must be defined for each of the trades as well as areas of separation.  Currently, software and hardware have a hard time handling large files without lagging and becoming hard to navigate.  Based on successful coordination conducted at Hershey Medical Center, for this project the boundary separation will be by floor.  This project is not large enough to warrant further separation.  The level to which each of these areas will be modeled will be determined by the project team.  For the purposes of this project in order to clearly articulate expectations, levels of detail will be derived from the "Model Progression Specification (MPS)" that has been developed by Vico Software and been incorporated into the new E202 document from AIA.   Figure 8-Definition of Levels of Detail for MPS shows the breakdown of these levels and what the general requirements are for each level as they specifically pertain to 3D coordination. Figure 9-Examples of LOD based on the MPS goes into further detail and uses specific details and modeled items to further illustrate the levels.

| Level of Detail -> | 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|
| **Model Content** | | | | | |
| Design & Coordination (function / form / behavior) | Non-geometric data or line work, areas, volumes zones, etc. | Generic elements shown in three dimensions<br><br>- maximum size<br>- purpose | Specific elements Confirmed 3D Object Geometry<br><br>- dimensions<br>- capacities<br>- connections | Shop drawing/ fabrication<br><br><br>- purchase<br>- manufacture<br>- install<br>- specified | As-built<br><br><br>- actual |

FIGURE 8-DEFINITION OF LEVELS OF DETAIL FOR MPS

| Level of Detail -> | 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|
| **Element** | | | | | |
| Interior wall | Not modeled. Cost and other information can be included as an amount per s.f. of floor area. | A generic interior wall, modeled with an assumed nominal thickness. Properties such as cost, STC rating, or U-value may be included as a range. | A specific wall type, modeled with the actual thickness of the assembly. Properties such as cost, STC rating, or U-value can be specified. | Fabrication details are modeled where needed. | The actual installed wall is modeled. |
| Duct run | Not modeled. Cost and other information can be included as an amount per s.f. of floor area. | A 3-dimensional duct with approximate dimensions. | A 3-dimensional duct with precise engineered dimensions. | A 3-dimensional duct with precise engineered dimensions and fabrication details. | A 3-dimensional representation of the installed duct. |

FIGURE 9-EXAMPLES OF LOD BASED ON THE MPS

It is advisable that for coordination purposes, at least a 300 level of detail be maintained for all systems in the plenum space.

The sequence in which modeling will occur must also be defined by the project team. In order to keep a fast paced schedule, it is recommended that a concurrent modeling approach be utilized. Each floor will be modeled simultaneously by all trades participating, and then 3D coordination sessions will begin. Since modeling is occurring simultaneously, contractors will still have to be responsible for coordination outside of the 3D sessions since it is still their contractual obligation.

File format exchange requirements must also be defined for a successful implementation of 3D coordination. These requirements will be dependent upon the software that is utilized for the collision detection. File formats do not necessarily have to open natively in the clash program, as long as they can be exported from the subcontractors software and read by the collision program being implemented.

Once the modeling is completed for each area, the subcontractors must post the file to a central server for the coordinator to retrieve. The coordinator can then compile the models to prepare for the first 3D coordination session. Due to the lack of exposure that the majority of the team has, this project should have in-person meetings held at the jobsite using a projector. Prior to the meeting, in order to minimize live navigation of the model which can be difficult and slow depending on the model size, the coordinator should set viewpoints for the clashes so that they can be readily pulled up. Also, any false positives should be filtered out. The GC and the subcontractors will discuss each clash and either resolve them, or issue and RFI depending on

what the options are for the collision.  A report from each meeting will be generated and the changes made to the models.  The process will repeat the following week until the model can be signed off.  The cycle should be clearly illustrated for the contractors so that they understand. Figure 10-Weekly Process Model for Coordination Cycle, shows the time frame that should be expected on a weekly basis.
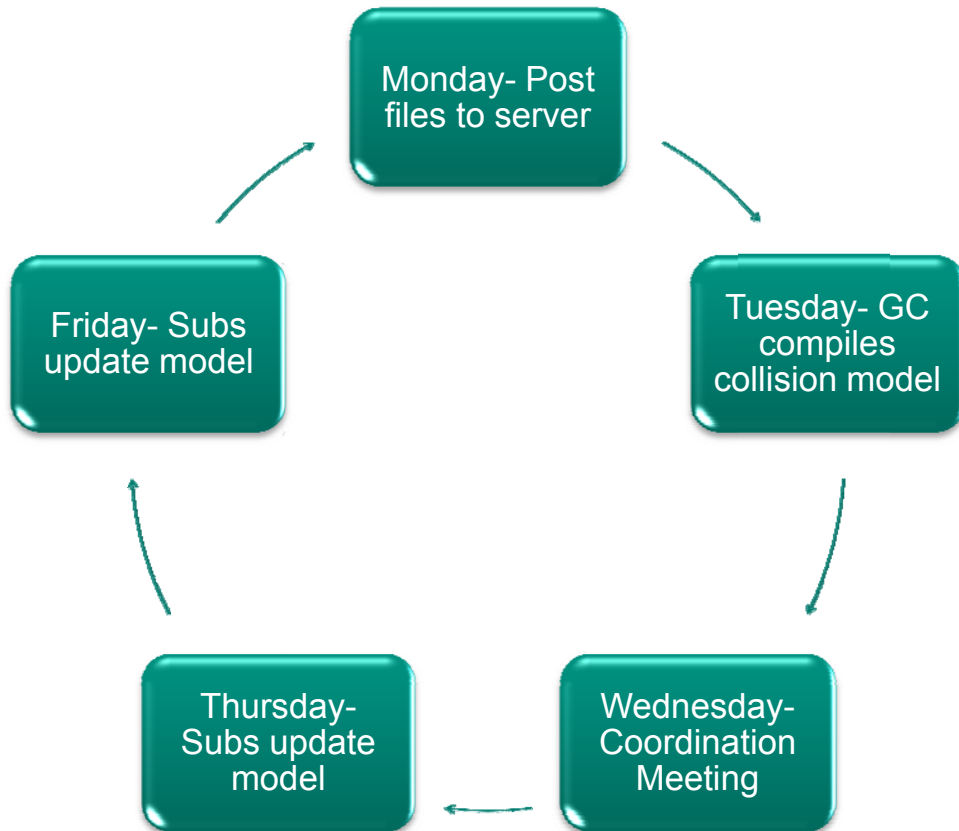


FIGURE 10-WEEKLY PROCESS MODEL FOR COORDINATION CYCLE (COURTESY OF BBC)

Due the contractual arrangement currently in place, the shop drawings will have to be submitted in a 2D format for approval.  However, these drawings should be taken from the model and annotated as necessary to avoid too much duplication of work, and also avoid user error when recreating the drawings which would negate the gains of the 3D coordination.

## IMPLEMENTATION SUMMARY

A detailed implementation as outlined above can be derived by analyzing the questions that it strives to answer.  Focusing on the questions listed below, which have been gleaned from this process mapping and development of a project specific plan, should help to address the issues around implementing 3D MEP Coordination.

Critical Questions to Address:

- What assets does the project team have related to 3D MEP coordination and how can weaknesses be overcome?
- What trades will be involved in the process and what is their previous 3D coordination experience?
- To what level of detail will the systems be modeled?
- What file formats will be required as outputs from the models?
- Where and how will the coordination meetings be run?
- What will the weekly cycle for coordination look like?