1. OVERVIEW OF BIM

1.1 What is BIM?

BIM stands for Building Information Modeling and refers to any computer aided design software that can represent the 2 dimensional design data in a 3 dimensional view of the various design elements. The American Institute of Architects defines BIM as “a model-based technology linked with a database of project information” and this reflects the general reliance on database technology as the foundation.

3D modeling was an emerging technology in 1987 with AutoCAD® Version 2.6 (Autodesk®). This technology rapidly increased in the following year with the advent of release 10 that yielded 3D modeling capabilities that we take for granted today such as rotating objects in space and “zooming” capabilities.

In 1997, Revit® introduced a revolutionary new 3D design tool that used relational databases. These relational databases allowed a change made anywhere in the design to be automatically revised in the other related design documents. For example, a door deleted in a plan view would delete the same door in the related section and the door count would also be automatically updated in the door schedule. The database can also be shared among multiple users so that independent models such as Architectural, Structural and MEP can be developed independently and merged periodically.

Audodesk purchased Revit in 2002 and then conceived the term Building Information Modeling (BIM) in 2003. Autodesk coined BIM to describe a 3D model that provided an accurate 3D representation of any part of the structural elements as well as finishes, furnishings and even people inside the finished structure. BIM covers geometry, spatial relationships, geographic information, quantities and properties of building components (for example manufacturers’ details). BIM can be used to demonstrate the entire building life cycle from planning and design through the processes of construction and facility operation. Quantities and shared properties of materials can easily be extracted. Scopes of work can be isolated and defined. Systems, assemblies, and sequences are able to be shown in a relative scale with the entire facility or group of facilities.

BIM is able to achieve such improvements by modeling representations of the actual parts and pieces being used to build a building. This is a substantial shift from the traditional computer aided drafting method of drawing with vector file based lines that combine to represent objects.

BIM can be utilized to bridge the information loss associated with handing a project from the design team, to the construction team and ultimately to the building owner/operator, by allowing each group to add to and reference back to all information they acquire during their period of contribution to the BIM model. For example, a building owner may find evidence of a leak in the building. Rather than exploring the physical building, s/he may turn to BIM and see that a water valve is located in the suspect location. S/ he could also have in the model the specific valve size, manufacturer, part number, and any other information ever researched in the past so long as that information has been incorporated into the BIM.

About the Author

Craig Halvorson has more than 20 years of professional experience in project management, cost estimating and cost monitoring/control systems, project controls, project scheduling, master scheduling, and claims mitigation and resolution.

Mr. Halvorson has been a Project Controls Manager on several large public works programs for the Port of Los Angeles, Los Angeles County Metropolitan Transit Authority, Los Angeles World Airports, City of Los Angeles Wastewater Construction Management Division, and the Metropolitan Water District of Southern California.

He is currently an Associate Vice President at ARCADIS and oversees the Program and Construction Management Division in the Orange County, California area.
1.2 BIM Software

a. General Description

There are a number of software available that have the capacity to convert 2D design data into a 3-D model. These models are capable of rotating the entire structure to view any side or zooming in on a particular design element.

BIM softwares are not design analysis softwares and are not intended to evaluate the structural integrity of the design, but rather are intended to analyze potential errors or omissions and conflicts within the various design elements.

The industry recognized softwares are as follows: Revit by Autodesk, Bentley® Systems and Graphisoft®. These software's are compared and contrasted below:

b. Revit

Revit Architecture software is Autodesk's brand of BIM software, it is designed to work the way you think, so you can create naturally, design freely, and deliver efficiently. And because it is purpose-built for BIM, any change you make—anytime, anywhere—is automatically coordinated throughout your project. Designs and documentation stay coordinated, consistent, and complete. Revit offers the following compatible modules:

- Revit Architecture
- Revit MEP
- Revit Structure

c. Bentley

The Bentley system is based upon the Microsoft Station technologies. Bentley has certain capabilities that Revit is not able to perform very efficiently, but these additional capabilities have limited applications. It is considered a more robust program than Revit, but it requires more programming and developmental costs to implement the systems. The Bentley systems are used extensively by the Army Corps of Engineers.

d. ArchiCAD by Graphisoft

ArchiCAD started in the early 1980s for the Apple Macintosh platforms. ArchiCAD was the first computer-aided design (CAD) product designed to be used on a personal computer that had 2D / 3D capabilities. The Graphisoft product allows its users to create 3-D structures with “smart objects” such as walls, slabs, roofs, doors, windows and furniture. 2-D drawings (plan and elevation views) can be created from 3-D creations.

e. Other BIM Softwares

Other softwares that can be used are Google™ SketchUp and 3ds Max® (formerly 3D Studio Max). These softwares are much less expensive, easier to learn, and can be produced fairly rapidly.

1.3 Design Analysis Software

a. Software Options

The design analysis softwares provide the structural engineers with the analysis and evaluation of the size and number of the structural members in a design. There are a number of softwares with varying capabilities. Most of these softwares are compatible with the various BIM softwares, as information and data can be exported and imported between the softwares.

Revit Structure helps you analyze all or part of a structure with bidirectional linking to industry-leading analysis and building code design software. Revit Structure can be linked with any of the following Analysis Partner Software:
• Adapt™
• CSC™
• Tekla
• CSI (ETAB)
• Oasys
• RISA
• Robobat
• SOFiSTiK
• SOFTEK

In addition to the analysis software above, Extensions for Revit extend the capabilities of the Revit products in several key areas, including structural analysis and reinforced concrete drafting. Extensions for Revit provide immediate value to Revit users and are easy to download, install and use.

b. ETABS

CSI ETABS is an example of an extension for Revit. CSI ETABS 2008 links with Revit Structure and provides a seamless path for the exchange of data between the two products. Models can be prepared in the Autodesk Revit Structure 2008 environment, and then model information can be exported to ETABS for analysis, design and optimization. After the execution of ETABS, the Autodesk Revit Structure 2008 model can be automatically updated with the latest design information produced by ETABS.

c. Tekla Structures

Other BIM software solutions are available including Tekla Structures which is intended to be used as a construction management tool from design through construction. Tekla Structures is a structural analysis software with BIM capabilities. Tekla Structures software is a tool that streamlines the delivery process of design, detailing, manufacturing, and construction organizations. While integrating openly with architectural models, the strength of this single-model environment lies in the contractor end of the process. Thousands of Tekla Structures software users in more than 80 countries have successfully delivered BIM-based projects across the world.

Tekla Structures’ ability to process extensive amounts of data offers the possibility to create a detailed 3D model that applies to every stage of design and construction. From planning and design development through to fabrication and installation, Tekla models naturally develop in parallel, representing the “as-built” condition of a building. Tekla Structures effectively integrates into any best-of-breed software driven workflow, while maintaining the highest levels of data integrity and accuracy. Such collaborative workflows are the cornerstone to minimizing errors and maximizing efficiency, resulting in high profitability and on-time project completion. Tekla Structures encompasses specialized configurations for structural engineers, steel detailers and fabricators, precast concrete detailers and manufacturers, as well as contractors.

1.4 Applications / Advantages of BIM

BIM can be used throughout the lifecycle of the facility; Design, Bidding, Construction and throughout the operational life of the facility.

The most obvious use of BIM is the design advantages that it offers. The 3-D model provides the benefit of visualization of the design that will facilitate a more accurate design with fewer errors and omissions. BIM packages offer clash detection tools that identify the conflicts between the various disciplines in the design documents.

BIM files can also be used during the bidding process. Perspective bidders can use the BIM files to provide an accurate and consistent measure of quantities. This will improve the accuracy of the bids and reduce contractor contingencies since the material quantities will be consistent between contractors.

The Construction Contractor can also use the BIM files during construction. Design information can be provided directly to the fabricator facilitating the shop drawing and fabrication process.
The biggest advantage of using BIM throughout the lifecycle of the Facility is that it would produce an “Integrated Project Delivery” method were the Owner, Construction Manager and Construction Contractor can provide input on the design earlier than in traditional delivery methods. The BIM can also be used to interface directly with the Contractor’s estimate and the Contractor’s schedule, which could greatly improve communication between all the parties during construction.

2. OVERVIEW OF 4D MODELING

2.1 What is 4D Modeling?

The 4D Computer Modeling Process integrates three dimensional building model database information with the fourth dimension; time, to improve communication, coordination, and planning of construction projects. In other words, Visual 4D models combine 3D models with construction sequencing activities to display progression of construction over time, often dramatically improving the quality of construction documents and schedules. The process can reduce coordination problems among subcontractors and between the owner’s operations and construction. Figure 2.1 shows the schedule at the top of the window and the 3D model at the bottom of the window. Each element of the 3D model can be linked with the schedule to create a 4D model.

![Figure 2.1: Schedule above, 3D representation below](image-url)

2.2 4D Software: Navisworks®

Navisworks was developed to link the BIM files with the Primavera files. This creates the 4th dimension of the BIM analysis - time. Navisworks can assign a group of objects in the BIM file to a schedule activity ID and then display the objects in the sequence portrayed in the construction schedule. The output in Navisworks is a 3D video that can be rotated during playback.
The Timeliner plugin adds 4D schedule simulation to Jetstream. Timeliner can import schedules from a variety of sources (Primavera, Microsoft Project etc.), allow you to connect objects in the model with tasks in the schedule, simulate the schedule showing the effects on the model, including planned against actual schedules, and exports images and animations based on the result of the simulation. Timeliner will automatically update the simulation if the model or schedule changes.

Setting up and running a 4D schedule requires the following steps:

1. Organize the model by activity codes in the schedule. (Departure, Arrival etc.) Break the model into small groups and into each Activity ID in the Primavera Schedule. Organizing and breaking the model into smaller selection sets will make the 4D task more simple and user friendly.

2. Import the Primavera Schedule into Jetstream.

3. Timeliner defines some default task types for you (Construct, Demolish & Temporary) or you can define your own using the Configuration.

4. Link Activity ID with related 3D elements in the model.

5. Make sure all the Activity IDs are linked with appropriate 3D elements in the model.

2.3 Applications / Advantages of 4D Modeling

4D Modeling can be applied in the design and construction phases. 4D modeling allows the owner to leverage the greatest value out of their BIM during the design phase by visualizing construction sequences in order to develop a phasing sequence to include in the construction documents. 4D Modeling in the construction phase can provide both the Contractor and the Owner a better visualization of the planned construction sequences compared to the actual construction sequences.

BIM is not only a powerful design tool, it is also a powerful construction planning and construction management tool. When the BIM is combined with the construction schedule, it becomes a 4D modeling tool where time is the 4th dimension. We will discuss this further in the next section. Hand-in-hand with that value is the ability to use the clash detection capability throughout the construction process. As the BIM information is further refined through shop drawings and actual construction as-built conditions, the clash detection capability provides a powerful management tool for analyzing and resolving the causes of construction phase clashes. This allows the owner to realize an added value of the time and effort that went into the development of the BIM in the first place. Furthermore, placing the BIM model in the hands of the contractor can greatly reduce the number of RFIs and resulting change orders.

By extending the BIM into the 4th dimension, the owner gains the following advantages:

- Improved design document quality by testing the design against construction sequencing and thereby eliminating or reducing difficult sequence issues
- Improved site use planning and coordination with ongoing operations
- Improved lead time identification which can reduce total construction duration
- Improved constructability and safety issue identification
- Greatly improved ability to monitor actual progress vs. planned progress and to thereby identify and resolve issues more quickly, thereby reducing claims
3. CLASH DETECTION

As discussed earlier we have 3D models for different trades like Structural, Civil, Architectural & MEP. When we combine all these different trades to create a complete BIM model there is a possibility of clashes between these trades. Figure 3.1 is a prime example of clash between Structure and Mechanical. Figure 3.1 shows a beam going through a duct.

![Figure 3.1: Structural steel / ductwork conflict](image)

Revit software provides clash detection capabilities where objects conflicting with other are highlighted for correction. This capability is however, limited in that it does not develop reports or track changes.

Navisworks software provides a Clash Detection module that checks your BIM and shows you any areas where items interfere, or “clash”, with each other. This BIM tool will allow you to set up the rules and options for your clash tests, view the results, sort them, and produce a report as a text file or in HTML or XML formats.

Managing a series of clash tests can get very complicated, especially if you have a set of different layers you want to clash detect separately. Clash Detection in Navisworks is designed to help you control these clash tests and maintain an audit trail of clashes throughout the life of the project.

Setting up and running a clash test requires the following steps:
1. Select Groups and create folders for each group. The Select tab of the Clash Detective control bar allows you to refine your clash test by only testing sets of items at a time, rather than the whole model against itself. This will produce faster and more sensible results. For example Mechanical Ducts with Fire Sprinkler Lines.

2. Set the rules for the test.

3. Select the required items to be included in the test and set the test type options.

4. View the Results.

5. Produce a clash report.

6. Managing/Status clash tests for future use. Navisworks will update this status automatically, informing the current state of the clashes in the model.

Advantage of Using Navisworks for Clash Detection:

1. Revit vs. Navisworks: Revit has its own clash detection process. Revit clash detection identifies the places where clashes occur. It does not create reports and does not have any tools to manage the clash detection process as design progresses. Navisworks provides greater flexibility for controlling the clash detection parameters and will identify clashes, generate reports which can help the design team to resolve the clashes, and track resolution with an automatic audit trail.

2. Managing the BIM Clash Detection Process: Managing clash tests for a big project can get complicated. One simple but timesaving way Navisworks does this is by remembering the names of clashes throughout the project’s life so you don’t have to go through each clash every time you run a test to figure out whether it’s a new clash or one you have already seen. Clash Detective also allows you to assign a status to a clash and can update this status automatically, informing you of the current state of the clashes in the model.

In conclusion see Table 3.1 below giving the comparison of clash detection features in Navisworks and Revit.

<table>
<thead>
<tr>
<th>Things It Can do</th>
<th>Navisworks</th>
<th>Revit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify clashes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Generate Reports</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Trace Clashes (Location)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Status Clashes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Manage Clashes (Folders and batches)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Set Rules</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Custom Clash Tests (User Defined)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Clearance Tests</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Time Based Clashing</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

*Table 3.1: Clash detection feature comparison*

4. OVERVIEW OF 5D / 6D MODELING

5D Models

- BIM Softwares can calculate the material quantities that are linked with RS Means & Timberland (Currently, this is difficult and time consuming to do because BIM softwares requires pre-mapping between design objects and cost items)
- Innovaya Visual Estimating allows BIM quantities to be dragged and dropped into cost assemblies

6D Models

- Risk
- Efficiency
5. CONTRACTUAL CONSIDERATIONS OF USING BIM

- BIM Model Manager
- Conflicts between 2D and 3D Models
- Contractual Standards
  - AIA – new consensus documents
  - Army Corp of Engineer Standards

6. RISK CONSIDERATIONS OF USING BIM

- Software Issues or Technical Limitations
- Conflict between 2D and 3D
- Waiver of Consequential Damages / Privity
- Who Assumes Risk?
- Insurance Requirements

7. USE OF BIM DURING DESIGN

Preconstruction/Design Phase: During the preconstruction phase of the project it would be fruitful for the CM to work in concert with the Architect/Engineer to ensure optimal design within the stipulated budget parameters. Utilization of 4D technology provides for improved communication and design productivity and quality in numerous ways:

**Better communication of the demolition and construction sequence**
- Visually communicate project schedule to all project stakeholders
- Visually assess impact to ongoing facility operations
- Communicate and show flow of work

**Better Site Planning & Logistics**
- Easily review site access, parking, staging areas, transportation routing etc.
- Plan & review site work and interactively view site issues
- Evaluate what-if scenarios and solicit feedback from tenants and occupants. (Renovation of Existing Terminals A&B)

**Better Analysis of Move Management & Site Management**
- Quickly view multiple perspectives
- Analyze different alternatives and view different options simultaneously
- Focus on specific flow and sequence of work

8. USE OF BIM DURING THE BIDDING PROCESS

**Benefits/Risks of Providing the BIM Model to Bidders:**

The question of whether or not to provide the actual BIM model to all of the bidders is really a question of perceived vs. actual liability risk. As BIM is a relatively new technology, there is a lot of concern as to whether or not it presents new levels of liability for both the designer and the owner. These concerns will have to be largely addressed by legal counsel, but conceptually, BIM is a more accurate representation of the actual elements of the building than traditional CADD or manually drafted construction documents which should actually reduce liability risks over those traditional methods. Some of the key Benefits and risks are outlined below.

Benefits – Giving bidders the BIM model provides greater accuracy and consistency in material quantity takeoffs resulting in:

- More accurate estimates
- Less variability in bids
- Reduced need for the bidders to build in contingencies for the unknown
Risks:

Increased dimensional responsibility for the design team may result in additional legal liability – as noted above, this is a perceived risk that can be reduced through language about reliance on the BIM model being the same as reliance on traditional 2D drawings and specifications.

9. USE OF BIM DURING CONSTRUCTION

Construction Phase: During the construction phase the monitoring, analysis and evaluation of the project schedule are critical to the ability of the CM to understand and interpret project progress, current status, and pending schedule developments. With 4D scheduling, this capability will be enhanced and refined as per the following points.

Schedule Development

- Assist in development of the initial project construction sequence
- Improve trade coordination, less interference and congestion areas
- Visualize multiple construction sequence options (optimization)
- Anticipate hazards and improve safety
- Analyze scenarios and compare alternatives
- 4D schedule visualization can help in the analysis of the contractor’s Baseline Schedule. Refer to the following two examples.

Figure 9.1 shows a situation where a Concrete Masonry Unit (CMU) wall was scheduled too early while steel was being erected directly overhead. Because the wall that is framed by the steel leans outward, the steel erection requires shoring (not modeled), which would not only interfere with the construction of the CMU wall but also cause a dangerous situation.

Figure 9.2 shows an Air Handler Unit (AHU) being installed too late after the steel is completely erected. There would no longer be the access necessary for the large AHU.
Schedule Analysis
- Analyze constructability
- Validate complex sequencing
- Identify spatial constraints
- Productivity and manpower analysis

Schedule Review
- Compare planned vs. actual (performance evaluation & project controls). Figure 9.3 shows comparison of Baseline schedule (Yellow) with Monthly update (Purple). You can see the contractor caused delay or identify the problems/issues which need to be resolved in order to overcome this delay.

*Figure 9.2: Air Handler Unit in red scheduled too late*

*Figure 9.3: Planned vs. Actual*

- Review time impact for change orders
- Review alternative schedule to make up for delays
Benefits/Risks of Providing the BIM Model to the Successful Contractor for Construction (including use for shop drawings and fabrication):

Working with BIM software tools has opened up new methods of communication with contractors and subcontractors that were unheard of just a few years ago.

For example, within the steel industry the vast majority of fabricators and detailers have, for many years, been using 3D detailing software for the preparation of steel shop drawings – creating those models based on the 2D drawings provided by the designers. As a result of an American Institute of Steel Construction (AISC) initiative a few years ago, a digital standard for electronic communication, CIMSteel Integration Standards, 2nd edition (CIS/2), was established. Consequently, the primary detailing software packages have a unified standard for electronic transfer of data. Therefore the structural steel design that is developed and presented in any of the primary BIM software packages can easily be exported into the steel detailing packages.

This method of data transfer has now become commonplace for steel-framed structures and has resulted in significant time savings. A typical project scenario would entail the following process: At the final stages of completion of the construction documents, the conversion process of our BIM model into one of the primary steel detailing software formats would commence, either the Tekla Structures (formerly X-steel) format or the SDS-2 format. The steel bid documents would include the paper documents and the digital model.

Providing the digital model in one of these two formats enables the steel bidders to avoid the time-consuming process of recreating the building digital model. By using the model provided to them, the time for the bidding process is shortened significantly, and there is uniformity in the bids. The confusion of bidders presenting differing steel tonnages is eliminated; the digital model clearly defines the piece count and tonnage. Refer to figure 9.4 which shows the full structural model created by IDS for the John Wayne Airport, Terminal C project opened in Navisworks. The window on the left shows the details (size and section) of the steel column selected in the BIM model (in blue).

Figure 9.4: JWA Terminal C structural model opened in Navisworks
The only significant information that is missing from the BIM at this stage is the material quantities associated with the connections (plates, bolts, etc.). Otherwise all of the information necessary to quantify steel shapes and tonnage is clearly reflected in the BIM model. Refer to Figures 9.5 and 9.6 which shows there are no connection details in the BIM model provided by IDS.

Figure 9.5: Connection not designed

Figure 9.6: Connection not designed
Given access to the BIM, the structural steel fabricator will take the model and design those connections. Furthermore, changes to the steel structure for bid alternates and updates are easily communicated via changes to the digital model. Refer to Figure 9.7.

Finally, upon project award, the updated detailing model in either Tekla Structures or SDS-2 format is provided. Shop drawing creation begins immediately with no lag time for model preparation. Upon a recently completed WSP project in New York, the steel fabricator stated that this process easily reduced the shop drawing process by one month, facilitating the early start of steel fabrication and erection. We have also found that providing the digital model to the detailers significantly reduced dimensional RFIs, which often plague the shop drawing review process. The dimensional gaps that usually occur upon paper documents are nearly eliminated on digital documents unless deliberately included.

Summary of the Benefits of Providing the BIM Model to the Contractor:

- Owner doesn’t pay twice for the 3D model to be built
- Reduced shop drawing preparation and approval time
- Earlier start of fabrication and erection
- Reduced Number of dimensional RFIs
- Time and space conflict resolutions
- Subcontractor coordination
- MEP coordination

10. FINAL CONSIDERATIONS

Although the benefits of BIM are many, there are issues to overcome:

- BIM standards are not fully defined. The multiple BIM products do not all have the ability to communicate with one another.
- New methods of team collaboration require new definitions for individual responsibility and liability.
- Legal ownership of collaborative digital models must be defined.
- Increased dimensional responsibility for the design team may result in additional legal liability.
11. RECOMMENDATIONS

We recommend that JWA take actions on three main points:

Use Clash Detection during constructability process. In current practice, many conflicts (steel, ductwork, conduits, piping, etc.) are not discovered until the shop drawing and coordination process has been initiated by the contractor. At this point, these conflicts could result in design changes which may ultimately lead to claims due to field required re-work. In addition, and as is current practice, many of the designers who for months maintained intimate knowledge of the project, may have been assigned to new projects and are not available months down the road to assist when these issues come up.

Provide BIM files to bidders for estimation purposes. By so doing, quantity variation will be lessened as all bidders would be basing their costs off the same information. The BIM files should be better able to represent the intent of the design and by reducing misunderstandings of this nature and therefore lower contractor contingencies should result.

Provide BIM files to construction contractor for scheduling and RFI process. By so doing, the RFI process can be improved as actual BIM sections could be produced which more fully outlines the question being asked in the RFI. The A/E can “see” what the contractor “sees” rather than relying on RFI verbiage alone. Also, the scheduling aspect of the project will be improved as contractors and schedulers are able to better the affect of their proposed scheduling logic (Predecessors and successors can be understood better as well as work inside locations with large amounts of equipment being installed and assumptions regarding availability of access can be “seen.”)

About ARCADIS

ARCADIS’ Program & Construction Management Division (PMCM) is comprised of more than 300 seasoned professionals focused on providing program, project and construction management, as well as claims and cost management services to its clients. These experts – which include architects, engineers, project and construction managers, accountants, attorneys and technical consultants – can guide owners through every phase of the design and construction processes. The division specializes in a variety of markets including education, government buildings, roads and transit, water/wastewater and healthcare.

For more information, please visit arcadisccs.com or contact us at 800.229.9050.