CHAPTER 1

BIM Handbook Introduction

1.0 EXECUTIVE SUMMARY

Building Information Modeling (BIM) is one of the most promising developments in the architecture, engineering and construction (AEC) industries. With BIM technology, an accurate virtual model of a building is constructed digitally. When completed, the computer-generated model contains precise geometry and relevant data needed to support the construction, fabrication, and procurement activities needed to realize the building.

BIM also accommodates many of the functions needed to model the lifecycle of a building, providing the basis for new construction capabilities and changes in the roles and relationships among a project team. When implemented appropriately, BIM facilitates a more integrated design and construction process that results in better quality buildings at lower cost and reduced project duration.

This chapter begins with a description of existing construction practices, and it documents the inefficiencies inherent in these methods. It then explains both the technology behind BIM and recommends ways to best take advantage of the new business processes it enables for the entire lifecycle of a building. It concludes with an appraisal of various problems one might encounter when converting to BIM technology.

1.1 INTRODUCTION

To better understand the significant changes that BIM introduces, this chapter begins with a description of current paper-based design and construction methods and the predominant business models now in use by the construction industry. It then describes various problems associated with these practices, outlines what BIM is, and explains how it differs from 2D and 3D computer-aided design (CAD). We give a brief description of the kinds of problems that BIM can solve and the new business models that it enables. The chapter concludes with a presentation of the most significant problems that may arise when using the technology, which is now only in its earliest phase of development and use.

1.2 THE CURRENT AEC BUSINESS MODEL

Currently, the facility delivery process remains fragmented, and it depends on paper-based modes of communication. Errors and omissions in paper documents often cause unanticipated field costs, delays, and eventual lawsuits between the various parties in a project team. These problems cause friction, financial expense, and delays. Recent efforts to address such problems have included: alternative organizational structures such as the design-build method; the use of real-time technology, such as project Web sites for sharing plans and documents; and the implementation of 3D CAD tools. Though these methods have improved the timely exchange of information, they have done little to reduce the severity and frequency of conflicts caused by paper documents.

One of the most common problems associated with paper-based communication during the design phase is the considerable time and expense required to generate critical assessment information about a proposed design, including cost estimates, energy-use analysis, structural details, etc. These analyses are normally done last, when it is already too late to make important changes. Because these iterative improvements do not happen during the design phase, *value engineering* must then be undertaken to address inconsistencies, which often results in compromises to the original design.

Regardless of the contractual approach, certain statistics are common to nearly all large-scale projects ($10 M or more), including the number of people involved and the amount of information generated. The following data was compiled by Maged Abdelsayed of Tardif, Murray & Associates, a construction company located in Quebec, Canada (Hendrickson 2003):

- Number of participants (companies): 420 (including all suppliers and sub-sub-contractors)
- Number of participants (individuals): 850
- Number of different types of documents generated: 50

- Number of pages of documents: 56,000
- Number of bankers boxes to hold project documents: 25
- Number of 4-drawer filing cabinets: 6
- Number of 20 inch diameter, 20 year old, 50 feet high, trees used to generate this volume of paper: 6
- Equivalent number of Mega Bytes of electronic data to hold this volume of paper (scanned): 3,000 MB
- Equivalent number of compact discs (CDs): 6

It is not easy to manage an effort involving such a large number of people and documents, regardless of the contractual approach taken. Figure 1-1 illustrates the typical members of a project team and their various organizational boundaries.

There are two dominant contract methods in the U.S, Design-Bid-Build and Design-Build, and many variations of them (Sanvido and Konchar 1999; Warne and Beard 2005).

1.2.1 Design-Bid-Build (DBB)

A significant percentage of buildings are built using the DBB approach (almost 90% of public buildings and about 40% of private buildings in 2002) (DBIA 2007). The two major benefits of this approach are: more competitive bidding to achieve the lowest possible price for an owner; and less political pressure to select a given contractor. (The latter is particularly important for public projects). Figure 1-2 illustrates the typical DBB procurement process as compared to the typical Design-Build (DB) process (see section 1.2.2)

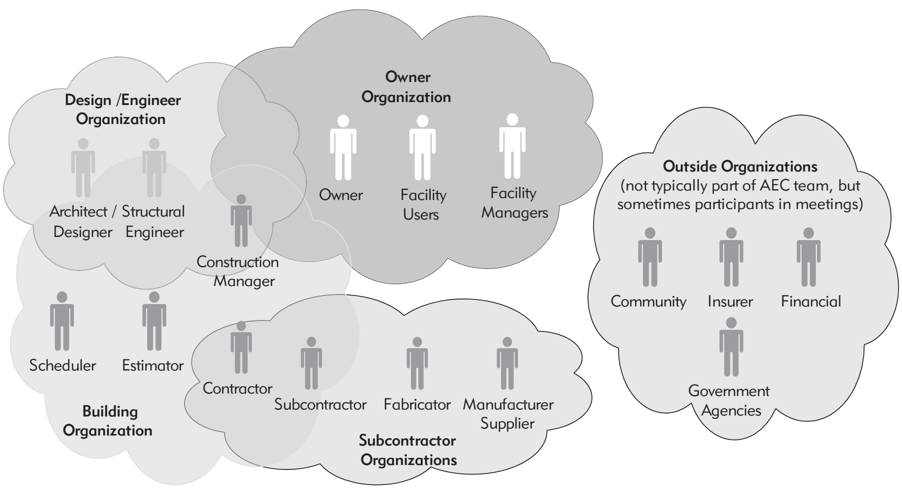

FIGURE 1-1 Conceptual diagram representing an AEC project team and the typical organizational boundaries.

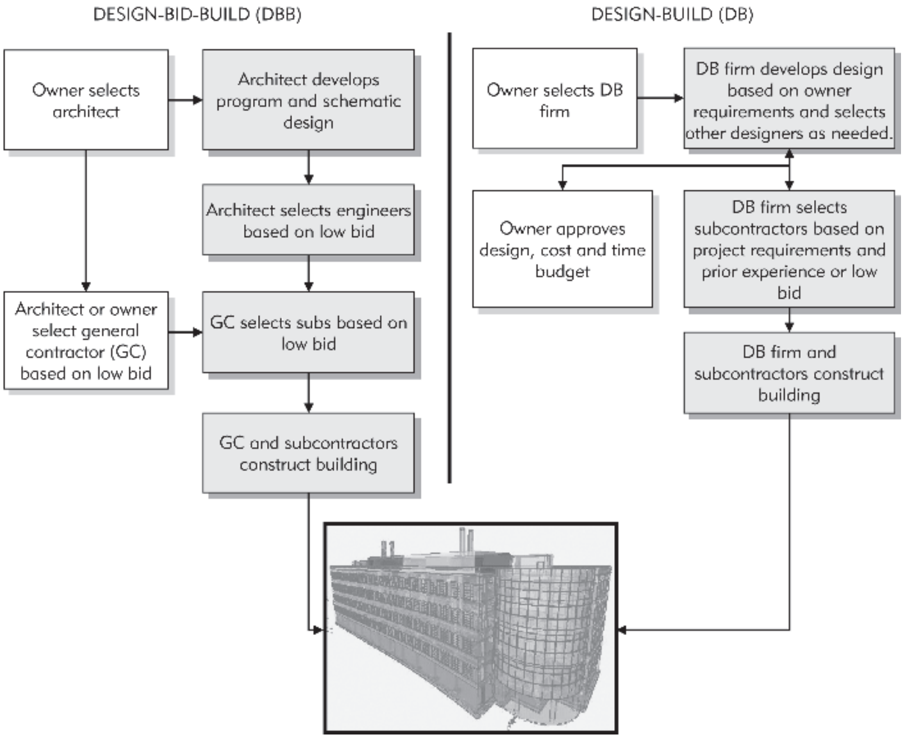

FIGURE 1-2 Schematic diagram of Design-Bid-Build and Design-Build processes.

In the DBB model, the client (owner) hires an architect, who then develops a list of building requirements (a program) and establishes the project's design objectives. The architect proceeds through a series of phases: schematic design, design development, and contract documents. The final documents must fulfill the program and satisfy local building and zoning codes. The architect either hires employees or contracts consultants to assist in designing structural, HVAC, piping, and plumbing components. These designs are recorded on drawings (plans, elevations, 3D visualizations), which must then be coordinated to reflect all of the changes as they are identified. The final set of drawings and specifications must contain sufficient detail to facilitate construction bids. Because of potential liability, an architect may choose to include fewer details in the drawings or insert language indicating that the drawings cannot be relied on for dimensional accuracy. These practices often lead to disputes with the contractor, as errors and omissions are detected and responsibility and extra costs reallocated.

Stage two involves obtaining bids from general contractors. The owner and architect may play a role in determining which contractors can bid. Each contractor must be sent a set of drawings and specifications which are then used to compile an *independent quantity survey*. These quantities, together with the bids from subcontractors are then used to determine their *cost estimate*. Subcontractors selected by the contractors must follow the same process for the part of the project that they are involved with. Because of the effort required, contractors (general and subcontractors) typically spend approximately 1% of their estimated costs in compiling bids.* If a contractor wins approximately one out of every 6 to 10 jobs that they bid on, the cost per successful bid averages from 6% to 10% of the entire project cost. This expense then gets added to the general and subcontractors' overhead costs.

The winning contractor is usually the one with the lowest responsible bid, including work to be done by the general contractor and selected subcontractors. Before work can begin, it is often necessary for the contractor to redraw some of the drawings to reflect the construction process and the phasing of work. These are called *general arrangement drawings*. The subcontractors and fabricators must also produce their own *shop drawings* to reflect accurate details of certain items, such as precast concrete units, steel connections, wall details, piping runs, etc.

The need for accurate and complete drawings extends to the shop drawings, as these are the most detailed representations and are used for actual fabrication. If these drawings are inaccurate or incomplete, or if they are based on drawings that already contain errors, inconsistencies or omissions, then expensive time-consuming conflicts will arise in the field. The costs associated with these conflicts can be significant.

Inconsistency, inaccuracy, and uncertainty in design make it difficult to fabricate materials offsite. As a result, most fabrication and construction must take place onsite and only when exact conditions are known. This is more costly, more time consuming, and prone to produce errors that would not occur if the work were performed in a factory environment where costs are lower and quality control is better.

Often during the construction phase, numerous changes are made to the design as a result of previously unknown errors and omissions, unanticipated site conditions, changes in material availabilities, questions about the design, new client requirements, and new technologies. These need to be resolved by the project team. For each change, a procedure is required to determine the cause, assign responsibility, evaluate time and cost implications, and address

*Based on the second author's personal experience in working with the construction industry. This includes the cost of duplicating the relevant drawings and specs, transporting them to each subcontractor, and the quantity takeoff and cost estimating processes. Electronic plan rooms are sometimes used to reduce the requirement for duplicating and transporting the plans and specs for each bidder.

how the issue will be resolved. This procedure, whether initiated in writing or with the use of a Web-based tool, involves a *Request for Information* (RFI), which must then be answered by the architect or other relevant party. Next a *Change Order* (CO) is issued and all impacted parties are notified about the change, which is communicated together with needed changes in the drawings. These changes and resolutions frequently lead to legal disputes, added costs, and delays. Web site products for managing these transactions do help the project team stay on top of each change, but because they do not address the source of the problem, they are of marginal benefit.

Problems typically arise when a contractor bids below the estimated cost in order to win the job. He will then abuse the change process to recoup losses incurred from the original bid. This, of course, leads to more disputes between the owner and project team.

In addition, the DBB process requires that the procurement of all materials be held until the owner approves the bid, which means that long lead time items cannot be ordered early enough to keep the project on schedule. For this and other reasons (described below), the DBB approach often takes longer than the DB approach.

The final phase is commissioning the building, which takes place after construction is finished. This involves testing the building systems (heating, cooling, electrical, plumbing, fire sprinklers, etc.) to make sure they work properly. Final contracts and drawings are then produced to reflect all *as-built changes,* and these are delivered to the owner along with all manuals for installed equipment. At this point, the DBB process is completed.

Because all of the information provided to the owner is conveyed in 2D (on paper), the owner must put in a considerable amount of effort to relay all relevant information to the facility management team charged with maintaining and operating the building. The process is time consuming, prone to error, costly and remains a significant barrier.

As a result of these problems, the DBB approach is probably not the most expeditious or cost-efficient approach to design and construction. Other approaches have been developed to address these problems.

1.2.2 Design-Build (DB)

The design-build process was developed to consolidate responsibility for design and construction into a single contracting entity and to simplify the administration of tasks for the owner (Beard et al. 2005). Figure 1-2 illustrates this process.

In this model, the owner contracts directly with the design-build team to develop a well-defined building program and a schematic design. The DB contractor then estimates the total cost and time needed to construct the building. After all modifications requested by the owner are implemented, the plan is approved and the final estimate cost for the project is established. It is important to note that because the DB model allows for modifications to be made to the building's design earlier in the process, the amount of money and time needed to incorporate these changes is also reduced. The DB contractor establishes contractual relationships with specialty designers and subcontractors as-needed. After this point, construction begins and any further changes to the design (within predefined limits) become the responsibility of the DB contractor. The same is true for errors and omissions. It is not necessary for detailed construction drawings to be complete for all parts of the building prior to the start of construction on the foundation, etc. As a result of these simplifications, the building is typically completed faster, with far fewer legal complications, and at a somewhat reduced total cost. On the other hand, there is less flexibility for the owner to make changes after the initial design is approved and a contract amount is established.

The DB model is becoming more common in the U.S. and is used widely abroad. Data is not currently available from U.S. government sources, but the Design Build Institute of America (DBIA) estimates that, in 2006, approximately 40% of construction projects in the U.S. relied on a variation of the DB procurement approach. Higher percentages (50%–70%) were measured for some governmental organizations (Navy, Army, Air Force, and GSA). The trend toward increasing use of DB is very strong (Evey 2006).

1.2.3 What Kind of Building Procurement Is Best When BIM Is Used

There are many variations of the design-to-construction business process, including the organization of the project team, how the team members are paid, and who absorbs various risks. There are lump sum contracts, cost plus a fixed or percentage fee, various forms of negotiated contracts, etc. It is beyond the scope of this book to outline each of these and the benefits and problems associated with each of them (see Sanvido and Konchar 1999 and Warne and Beard 2005).

With regard to the use of BIM, the general issues that either enhance or diminish the positive changes that this technology offers depends on how well and at what stage the project team works collaboratively on the digital model. The earlier the model can be developed and shared, the more useful it will be. The DB approach provides an excellent opportunity to exploit BIM technology, because a single entity is responsible for design and construction and both areas participate during the design phase. Other procurement approaches can also benefit from the use of BIM but may achieve only partial benefits, particularly if the BIM technology is not used collaboratively during the design phase.

1.3 DOCUMENTED INEFFICIENCIES OF TRADITIONAL APPROACHES

This section documents how traditional practices contribute unnecessary waste and errors. Evidence of poor field productivity is illustrated in a graph developed by the Center for Integrated Facility Engineering (CIFE) at Stanford University (CIFE, 2007). The impact of poor information flow and redundancy is illustrated using the results of a study performed by the National Institute of Standards and Technology (NIST) (Gallaher et al. 2004).

1.3.1 CIFE Study of Construction Industry Labor Productivity

Extra costs associated with traditional design and construction practices have been documented through various research studies. Figure 1-3 developed by the second author at CIFE, illustrates productivity within the U.S. field construction industry relative to all non-farm industries over a period of forty years, from 1964 through 2004 (the last year for which data is available). The data was calculated by dividing constant contract dollars (from the Department

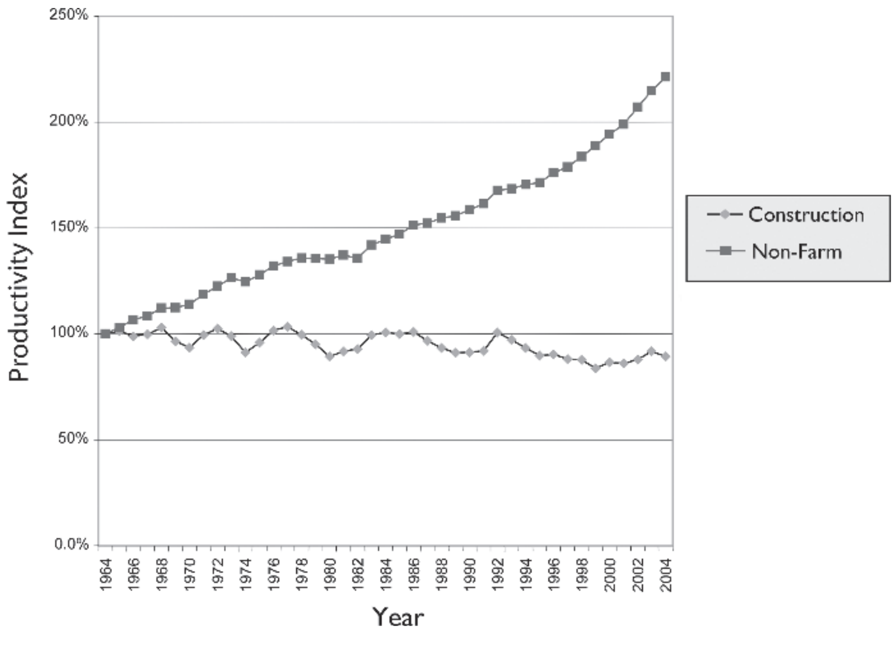

FIGURE 1-3 Indexes of labor productivity for construction and non-farm industries, 1964–2004. Adapted from research by Paul Teicholz at CIFE.

of Commerce) by field man-hours of labor for those contracts (from the Bureau of Labor Statistics). These contracts include architectural and engineering costs as well as cost for materials and for the delivery of offsite components to the site. Costs associated with the installation of heavy production equipment, such as printing presses, stamping machines, etc., are not included. The amount of man hours required for labor excludes offsite work, such as steel fabrication, precast concrete, etc. During this 40-year-long period, the productivity of non-farm industries (including construction) has more than doubled. Meanwhile, labor productivity within the construction industry alone is estimated to be 10% less than what it was in 1964. Labor represents about 40%–60% of construction's estimated costs. Owners were actually paying approximately 5% more in 2004 than they would have paid for the same building in 1964. Of course, many material and technological improvements have been made to buildings in the last four decades. The results are perhaps better than they appear, because quality has increased substantially. On the other hand, manufactured products are also more complex than they used to be, but they now can be produced at significantly lower cost. The replacement of manual labor with automated equipment has resulted in lower labor costs and increased quality. But the same cannot be said for construction practices.

Contractors have made greater use of offsite components which take advantage of factory conditions and specialized equipment. Clearly, this has allowed for higher quality and lower cost production of components, as compared to onsite work. Although the cost of these components is included in our construction cost data, the labor is not. This tends to make onsite construction productivity appear better than it actually is. The extent of this error, however, is difficult to evaluate because the total cost of offsite production cost is not well-documented.

While the reasons for the apparent decrease in construction productivity are not completely understood, the statistics are dramatic and point at organizational impediments within the construction industry. It is clear that efficiencies achieved in the manufacturing industry through automation, the use of information systems, better supply chain management and improved collaboration tools, have not yet been achieved in field construction. Possible reasons for this include:

- Sixty-five percent of construction firms consist of less than 5 people, making it difficult for them to invest in new technology; even the largest firms account for less than 0.5% of total construction volume and are not able to establish industry leadership (see Figure 6-1 in Chapter 6).
- The real inflation-adjusted wages and the benefit packages of construction workers have stagnated over this time period. Union participation has declined and the use of immigrant workers has increased, discouraging the

> need for labor-saving innovations. While innovations have been introduced, such as nail guns, larger and more effective earth moving equipment and better cranes, the productivity improvements associated with them have not been sufficient to change overall field labor productivity.

The adoption of new and improved business practices within both design and construction has been noticeably slow and limited primarily to large firms. In addition, the introduction of new technologies has been fragmented. Often times, it remains necessary to revert back to paper or 2D CAD drawings so that all members of a project team are able to communicate with each other and to keep the pool of potential contractors and subcontractors bidding on a project sufficiently large.

Whereas manufacturers often have long term agreements and collaborate in agreed upon ways with the same partners, construction projects typically involve different partners working together for a period of time and then dispersing. As a result, there are few or no opportunities to realize improvements over time through applied learning. Rather, each partner acts to protect him or herself from potential disputes that could lead to legal difficulties by relying on antiquated and time-consuming processes that make it difficult or impossible to implement resolutions quickly and efficiently. Of course, this translates to higher cost and time expenditures.

Another possible cause for the construction industry's stagnant productivity is that onsite construction has not benefited significantly from automation. Thus, field productivity relies on qualified training of field labor. Figure 1-4 shows that, since 1974, compensation for hourly workers has steadily declined

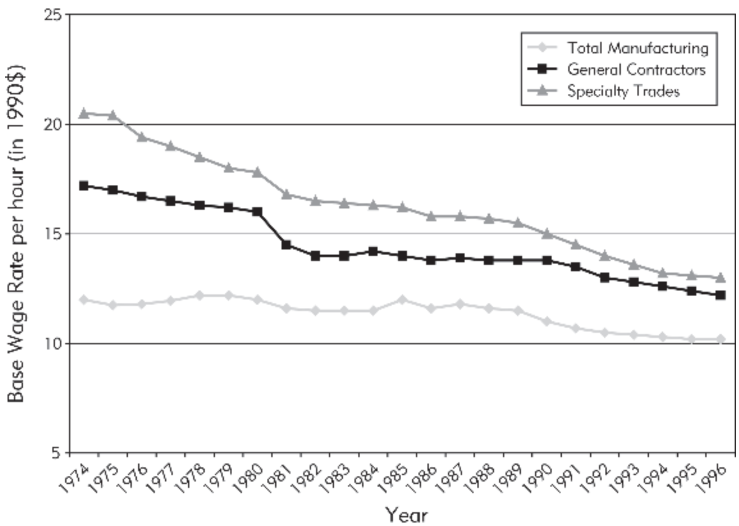

FIGURE 1-4 Trends in real wages (1990 $) for manufacturing and construction hourly workers, 1974–1996. BLS, Series ID : EES00500006.

with the increase in use of non-union immigrant workers with little prior training. The lower cost associated with these workers has discouraged efforts to replace field labor with automated (or offsite) solutions.

Existing problems within the construction industry also involve issues unrelated to the use of advanced technologies. These business practices (described above) limit how quickly new and innovative tools can be adopted. Pushing in the other direction is the growing competitive pressure of globalization which allows overseas firms to provide services and/or materials used in local projects. To cope with this added pressure, leading U.S. firms will need to implement changes that allow them to work faster and more efficiently than they otherwise would.

1.3.2 NIST Study of Cost of Construction Industry Inefficiency

The National Institute of Standards and Technology (NIST) performed a study of the additional cost incurred by building owners as a result of inadequate interoperability (Gallaher et al. 2004). The study involved both the exchange and management of information, in which individual systems were unable to access and use information imported from other systems. In the construction industry, incompatibility between systems often prevents members of the project team from sharing information rapidly and accurately; it is the cause of numerous problems, including added costs, etc. The NIST study included commercial, industrial and institutional buildings and focused on new and "set in place" construction taking place in 2002. The results showed that inefficient interoperability accounted for an increase in construction costs by $6.12 per sf for new construction and an increase in $0.23 per sf for operations and maintenance (O & M), resulting in a total added cost of $15.8 billion. Table 1-1 shows the breakdown of these costs and to which stakeholder they were applied.

In the NIST study, the cost of inadequate interoperability was calculated by comparing current business activities and costs with hypothetical scenarios in which there was seamless information flow and no redundant data entry. NIST determined that the following costs resulted from inadequate interoperability:

- Avoidance (redundant computer systems, inefficient business process management, redundant IT support staffing)
- Mitigation (manual reentry of data, request for information management)
- Delay (costs for idle employees and other resources)

Of these costs, roughly 68% ($10.6 billion) were incurred by building owners and operators. These estimates are speculative, due to the impossibility of providing accurate data. They are, however, significant and worthy of serious consideration and effort to reduce or avoid them as much as possible.

Table 1-1 Additional costs of inadequate interoperability in the construction industry, 2002 (in $millions).

Stakeholder Group	Planning, Engineering, Design Phase	Construction Phase	O&M Phase	Total Added Cost
Architects and Engineers	$1,007.2	$147.0	$15.7	$1,169.8
General Contractors	$485.9	$1,265.3	$50.4	$1,801.6
Special Contractors and Suppliers	$442.4	$1,762.2		$2,204.6
Owners and Operators	$722.8	$898.0	$9,027.2	$1,0648.0
Total	**$2,658.3**	**$4,072.4**	**$9,093.3**	**$15,824.0**
Applicable sf in 2002	1.1 billion	1.1 billion	39 billion	n/a
Added cost/sf	**$2.42/sf**	**$3.70/sf**	**$0.23/sf**	**n/a**

Source: Table 6-1 NIST study (Gallaher et al. 2004).

Widespread adoption of BIM and the use of a comprehensive digital model throughout the lifecycle of a building would be a step in the right direction to eliminate such costs resulting from the inadequate interoperability of data.

1.4 BIM: NEW TOOLS AND NEW PROCESSES

This section gives an overall description of BIM-related terminology, concepts, and functional capabilities; and it addresses how these tools can improve business processes. Specific topics are discussed in further detail in the chapters indicated in parenthesis.

1.4.1 BIM Model Creation Tools (Chapter 2)

All CAD systems generate digital files. Older CAD systems produce plotted drawings. They generate files that consist primarily of vectors, associated line-types, and layer identifications. As these systems were further developed, additional information was added to these files to allow for blocks of data and associated text. With the introduction of 3D modeling, advanced definition and complex surfacing tools were added.

As CAD systems became more intelligent and more users wanted to share data associated with a given design, the focus shifted from drawings and 3D images to the data itself. A building model produced by a BIM tool can support multiple different views of the data contained within a drawing set, including 2D and 3D. A building model can be described by its content (what objects it describes) or its capabilities (what kinds of information requirements it can support). The latter approach is preferable, because it defines what you can do with the model rather than how the database is constructed (which will vary with each implementation).

For the purpose of this book, we define BIM as a modeling technology and associated set of processes to produce, communicate, and analyze *building models.* Building models are characterized by:

- **Building components** that are represented with intelligent digital representations (objects) that 'know' what they are, and can be associated with computable graphic and data attributes and parametric rules.
- **Components that include data that describe how they behave,** as needed for analyses and work processes, e.g., takeoff, specification, and energy analysis.
- **Consistent and non-redundant data** such that changes to component data are represented in all views of the component.
- **Coordinated data** such that all views of a model are represented in a coordinated way.

The following is a definition of BIM technology provided by the M.A. Mortenson Company, a construction contracting firm that has used BIM tools extensively within their practice (Campbell 2006).

Mortenson's Definition of BIM Technology

BIM has its roots in computer-aided design research from decades ago, yet it still has no single, widely-accepted definition. We at the M.A. Mortenson Company think of it as "an intelligent simulation of architecture." To enable us to achieve integrated delivery, this simulation must exhibit six key characteristics. It must be:

- Digital,
- Spatial (3D),
- Measurable (quantifiable, dimension-able, and query-able),
- Comprehensive (encapsulating and communicating design intent, building performance, constructability, and include sequential and financial aspects of means and methods),
- Accessible (to the entire AEC/ owner team through an interoperable and intuitive interface), and
- Durable (usable through all phases of a facility's life).

In light of these definitions, one might argue that few design or construction teams are truly using BIM today. In fact, we may not achieve this high standard for several years. But we believe these characteristics are all essential for reaching the goal of integrated practice.

Furthermore, there are no current implementations of BIM software that meet all of the BIM technology criteria. Over time, the capabilities will grow as will the ability to support better and more extensive practices. The list in the following section is intended to provide a starting point for evaluating specific BIM software tools. See Chapter 2 for more detailed information about BIM technology and an analysis of current BIM tools.

1.4.2 Definition of Parametric Objects (Chapter 2)

The concept of parametric objects is central to understanding BIM and its differentiation from traditional 2D objects. Parametric BIM objects are defined as follows:

- consist of geometric definitions and **associated data and rules**.
- geometry is integrated **non-redundantly**, and allows for no inconsistencies. When an object is shown in 3D, the shape cannot be represented internally redundantly, for example as multiple 2D views. A plan and elevation of a given object must always be consistent. Dimensions cannot be 'fudged'.
- Parametric rules for objects **automatically modify associated geometries** when inserted into a building model or when changes are made to associated objects. For example, a door will fit automatically into a wall, a light switch will automatically locate next to the proper side of the door, a wall will automatically resize itself to automatically butt to a ceiling or roof, etc.
- Objects can be defined at **different levels of aggregation**, so we can define a wall as well as its related components. Objects can be defined and managed at any number of hierarchy levels. For example, if the weight of a wall subcomponent changes, the weight of the wall should also change.
- Objects rules can identify when a particular change violates **object feasibility** regarding size, manufacturability, etc.
- objects have the ability to **link to or receive, broadcast or export sets of attributes**, e.g., structural materials, acoustic data, energy data, etc. to other applications and models.

Technologies that allow users to produce building models that consist of parametric objects are considered BIM authoring tools. In Chapter 2 we elaborate the discussion of parametric technologies and discuss common capabilities in BIM tools including features to automatically extract consistent drawings and to extract reports of geometric parameters. In Chapters 4–7 we discuss these capabilities and others and their potential benefits to various AEC practitioners and building owners.

1.4.3 Support for Project Team Collaboration (Chapter 3)

Open interfaces should allow for the import of relevant data (for creating and editing a design) and export of data in various formats (to support integration with other applications and workflows). There are two primary approaches for such integration: (1) to stay within one software vendor's products or (2) to use software from various vendors that can exchange data using industry supported standards. The first approach allows for tighter integration among products in multiple directions. For example, changes to the architectural model will generate changes to the structural model, and vice versa. This requires, however, that all members of a design team use software provided from the same vendor.

The second approach uses either proprietary or open-source, publicly available, and supported standards created to define building objects (Industry Foundation Classes or IFCs). These standards may provide a mechanism for interoperability among applications with different internal formats. This approach provides more flexibility at the expense of reduced interoperability, especially if the various software programs in-use for a given project do not support the same exchange standards. This allows objects from one BIM application to be exported from or imported into another (see Chapter 3 for an extensive discussion of collaboration technology).

1.5 WHAT IS NOT BIM TECHNOLOGY

The term BIM is a popular buzz word used by software developers to describe the capabilities that their products offer. As such, the definition of what constitutes BIM technology is subject to variation and confusion. To deal with this confusion, it is useful to describe modeling solutions that DO NOT utilize BIM technology. These include tools that create the following kinds of models:

Models that contain 3D data only and no object attributes. These are models that can only be used for graphic visualizations and have no intelligence at the object level. They are fine for visualization but provide no support for data integration and design analysis.

Models with no support of behavior. These are models that define objects but cannot adjust their positioning or proportions because they do not utilize parametric intelligence. This makes changes extremely labor intensive and provides no protection against creating inconsistent or inaccurate views of the model.

Models that are composed of multiple 2D CAD reference files that must be combined to define the building. It is impossible to ensure that the resulting 3D model will be feasible, consistent, countable, and display intelligence with respect to the objects contained within it.

Models that allow changes to dimensions in one view that are not automatically reflected in other views. This allows for errors in the model that are very difficult to detect (similar to overriding a formula with a manual entry in a spreadsheet).

1.6 WHAT ARE THE BENEFITS OF BIM? WHAT PROBLEMS DOES IT ADDRESS?

BIM technology can support and improve many business practices. Although the AEC/FM (Facility Management) industry is in the early days of BIM use, significant improvements have already been realized (compared to traditional 2D CAD or paper-based practices). Though it is unlikely that all of the advantages discussed below are currently in use, we have listed them to show the entire scope of changes that can be expected as BIM technology develops.

1.6.1 Pre-Construction Benefits to Owner (Chapters 4 and 5)

Concept, Feasibility and Design Benefits

Before owners engage an architect, it is necessary to determine whether a building of a given size, quality level, and desired program requirements can be built within a given cost and time budget, i.e. can a given building meet the financial requirements of an owner. If these questions can be answered with relative certainty, owners can then proceed with the expectation that their goals are achievable. Finding out that a particular design is significantly over budget after a considerable amount of time and effort has been expended is wasteful. An approximate (or macro) building model built into and linked to a cost database can be of tremendous value and assistance to an owner. This is described in further detail in Chapter 4 and illustrated in the Hillwood Commercial Project case study in Chapter 9.

Increased Building Performance and Quality

Developing a *schematic model* prior to generating a *detailed building model* allows for a more careful evaluation of the proposed scheme to determine whether it meets the building's functional and sustainable requirements. Early evaluation of design alternatives using analysis/simulation tools increases the overall quality of the building.

1.6.2 Design Benefits (Chapter 5)

Earlier and More Accurate Visualizations of a Design

The 3D model generated by the BIM software is designed directly rather than being generated from multiple 2D views. It can be used to visualize the design at any stage of the process with the expectation that it will be dimensionally consistent in every view.

Automatic Low-Level Corrections When Changes Are Made to Design

If the objects used in the design are controlled by parametric rules that ensure proper alignment, then the 3D model will be constructible. This reduces the user's need to manage design changes (see Chapter 2 for further discussion of parametric rules).

Generate Accurate and Consistent 2D Drawings at Any Stage of the Design

Accurate and consistent drawings can be extracted for any set of objects or specified view of the project. This significantly reduces the amount of time and number of errors associated with generating construction drawings for all design disciplines. When changes to the design are required, fully consistent drawings can be generated as soon as the design modifications are entered.

Earlier Collaboration of Multiple Design Disciplines

BIM technology facilitates simultaneous work by multiple design disciplines. While collaboration with drawings is also possible, it is inherently more difficult and time consuming than working with one or more coordinated 3D models[†] in which change-control can be well managed. This shortens the design time and significantly reduces design errors and omissions. It also gives earlier insight into design problems and presents opportunities for a design to be continuously improved. This is much more cost effective than waiting until a

[†]If a BIM system does not use a single database, which can create problems for very large and/or finely detailed projects, alternative approaches involving automatic coordination of multiple files can also be used. This is an important implementation issue for software vendors. (See Chapter 2 for more discussion of model size issues).

design is nearly complete and then applying value engineering only after the major design decisions have been made.

Easily Check against the Design Intent

BIM provides earlier 3D visualizations and quantifies the area of spaces and other material quantities, allowing for earlier and more accurate cost estimates. For technical buildings (labs, hospitals, etc.), the design intent is often defined quantitatively, and this allows a building model to be used to check for these requirements. For qualitative requirements (this space should be near another, etc.), the 3D model can support automatic evaluations.

Extract Cost Estimates during the Design Stage

At any stage of the design, BIM technology can extract an accurate bill of quantities and spaces that can be used for cost estimation. In the early stages of a design, cost estimates are based primarily on the unit cost per square foot. As the design progresses, more detailed quantities are available and can be used for more accurate and detailed cost estimates. It is possible to keep all parties aware of the cost implications associated with a given design before it progresses to the level of detailing required of construction bids. At the final stage of design, an estimate based on the quantities for all the objects contained within the model allows for the preparation of a more accurate final cost estimate. As a result, it is possible to make better informed design decisions regarding costs using BIM rather than a paper-based system.

Improve Energy Efficiency and Sustainability

Linking the building model to energy analysis tools allows evaluation of energy use during the early design phases. This is not possible using traditional 2D tools which require that a separate energy analysis be performed at the end of the design process thus reducing the opportunities for modifications that could improve the building's energy performance. The capability to link the building model to various types of analysis tools provides many opportunities to improve building quality.

1.6.3 Construction and Fabrication Benefits (Chapters 6 & 7)

Synchronize Design and Construction Planning

Construction planning using 4D CAD requires linking a construction plan to the 3D objects in a design, so that it is possible to simulate the construction process and show what the building and site would look like at any point in time. This graphic simulation provides considerable insight into how the building will be constructed day-by-day and reveals sources of potential problems and opportunities for possible improvements (site, crew and equipment, space conflicts, safety problems, etc.). This type of analysis is not available from paper bid documents. It does, however, provide added benefit if the model includes temporary construction objects such as shoring, scaffolding, cranes, and other major equipment so that these objects can be linked to schedule activities and reflected in the desired construction plan.

Discover Design Errors and Omissions before Construction (Clash Detection)

Because the virtual 3D building model is the source for all 2D and 3D drawings, design errors caused by inconsistent 2D drawings are eliminated. In addition, because systems from all disciplines can be brought together and compared, multi-system interfaces are easily checked both systematically (for hard and soft clashes) and visually (for other kinds of errors). Conflicts are identified before they are detected in the field. Coordination among participating designers and contractors is enhanced and errors of omission are significantly reduced. This speeds the construction process, reduces costs, minimizes the likelihood of legal disputes, and provides a smoother process for the entire project team.

React Quickly to Design or Site Problems

The impact of a suggested design change can be entered into the building model and changes to the other objects in the design will automatically update. Some updates will be made automatically based on the established parametric rules. Additional cross system updates can be checked and updated visually. The consequences of a change can be accurately reflected in the model and all subsequent views of it. In addition, design changes can be resolved more quickly in a BIM system because modifications can be shared, visualized, estimated, and resolved without the use of time-consuming paper transactions. Updating in this manner is extremely error-prone in paper-based systems.

Use Design Model as Basis for Fabricated Components

If the design model is transferred to a BIM fabrication tool and detailed to the level of fabrication objects (shop model), it will contain an accurate representation of the building objects for fabrication and construction. Because components are already defined in 3D, their automated fabrication using numerical control machinery is facilitated. Such automation is standard practice today in steel fabrication and some sheet metal work. It has been used successfully in precast components, fenestration and glass fabrication. This allows vendors world-wide to elaborate on the model, to develop details needed for fabrication and to maintain links that reflect the design intent. This facilitates offsite fabrication and reduces cost and construction time. The accuracy of BIM also allows larger components of the design to be fabricated offsite than would normally be attempted using 2D drawings, due to the likely need for onsite changes (rework) and the inability to predict exact dimensions until other items are constructed in the field.

Better Implementation and Lean Construction Techniques

Lean construction techniques require careful coordination between the general contractor and subs to ensure that work can be performed when the appropriate resources are available onsite. This minimizes wasted effort and reduces the need for onsite material inventories. Because BIM provides an accurate model of the design and the material resources required for each segment of the work, it provides the basis for improved planning and scheduling of subcontractors and helps to ensure just-in-time arrival of people, equipment, and materials. This reduces cost and allows for better collaboration at the job site.

Synchronize Procurement with Design and Construction

The complete building model provides accurate quantities for all (or most, depending upon level of 3D modeling) of the materials and objects contained within a design. These quantities, specifications, and properties can be used to procure materials from product vendors and subcontractors (such as precast concrete subs). At the present time (2007), the object definitions for many manufactured products have not yet been developed to make this capability a complete reality. Where the models have been available (steel members, precast concrete members), however, the results have been very beneficial.

1.6.4 Post Construction Benefits (Chapter 4)

Better Manage and Operate Facilities

The building model provides a source of information (graphics and specifications) for all systems used in a building. Previous analyses used to determine mechanical equipment, control systems, and other purchases can be provided to the owner, as a means for verifying the design decisions once the building is in use. This information can be used to check that all systems work properly after the building is completed.

Integrate with Facility Operation and Management Systems

A building model that has been updated with all changes made during construction provides an accurate source of information about the as-built spaces and systems and provides a useful starting point for managing and operating the building. A building information model supports monitoring of real-time control systems, provides a natural interface for sensors and remote operating management of facilities. Many of these capabilities have not yet been developed, but BIM provides an ideal platform for their deployment. An example of how a building model can serve as a database for facility data is discussed in the Coast Guard Facility Planning case study in Chapter 9.

1.7 WHAT CHALLENGES CAN BE EXPECTED?

Improved processes in each phase of design and construction will reduce the number and severity of problems associated with traditional practices. Intelligent use of BIM, however, will also cause significant changes in the relationships of project participants and the contractual agreements between them. (Traditional contract terms are tailored to paper-based practices.) In addition, earlier collaboration between the architect, contractor, and other design disciplines will be needed, as knowledge provided by specialists is of more use during the design phase. (This is not consistent with the current design-bid-build business model.)

1.7.1 Challenges with Collaboration and Teaming

While BIM offers new methods for collaboration, it introduces other issues with respect to the development of effective teams. Determining the methods that will be used to permit adequate sharing of model information by members of the project team is a significant issue. If the architect uses traditional paper-based drawings, then it will be necessary for the contractor (or a third party) to build the model so that it can be used for construction planning, estimating, and coordination etc. Creating a model after the design is complete adds cost and time to the project, but it may be justified by the advantages of using it for construction planning and detailed design by mechanical, plumbing, other subs and fabricators, design change resolution, procurement, etc. If the members of the project team use different modeling tools, then tools for moving the models from one environment to another or combining these models are needed. This can add complexity and introduce potential errors to the project. Such problems can be reduced by using IFC standards for exchanging data. Another approach is to use a model server that communicates with all BIM applications through IFC or proprietary standards. A number of the case studies presented in Chapter 9 provide background for this issue.

1.7.2 Legal Changes to Documentation Ownership and Production

Legal concerns are presenting challanges, with respect to who owns the multiple design, fabrication, analysis, and construction datasets, who pays for them, and who is responsible for their accuracy. These issues are being addressed by practioners through BIM use on projects. As owners learn more about the advantages of BIM, they will likely require a building model to support operations, maintenance, and subsequent renovations. Professional groups, such as the AIA and AGC, are developing guidelines for contractual language to cover issues raised by the use of BIM technology.

1.7.3 Changes in Practice and Use of Information

The use of BIM will also encourage the integration of construction knowledge earlier in the design process. Integrated design-build firms capable of coordinating all phases of the design and incorporating construction knowledge from the outset will benefit the most. Contracting arrangements that require and facilitate good collaboration will provide greater advantages to owners when BIM is used. The most significant change that companies face when implementing BIM technology is using a shared building model as the basis of all work processes and for collaboration. This transformation will require time and education, as is true of all significant changes in technology and work processes.

1.7.4 Implementation Issues

Replacing a 2D or 3D CAD environment with a BIM system involves far more than acquiring software, training, and upgrading hardware. Effective use of BIM requires that changes be made to almost every aspect of a firm's business (not just doing the same things in a new way). It requires a thorough understanding and a plan for implementation before the conversion can begin. While the specific changes for each firm will depend on their sector(s) of AEC activity, the general steps that need to be considered are similar and include the following:

- Assign top level management responsibility for developing a BIM adoption plan that covers all aspects of the firm's business and how the proposed changes will impact both internal departments and outside partners and clients.
- Create an internal team of key managers responsible for implementing the plan, with cost, time, and performance budgets to guide their performance.

- Start using the BIM system on one or two smaller (perhaps already completed) projects in parallel with existing technology and produce traditional documents from the building model. This will help reveal where there are deficits in the building objects, in output capabilities, in links to analysis programs, etc. It will also provide educational opportunities for leadership staff.
- Use initial results to educate and guide continued adoption of BIM software and additional staff training. Keep senior management apprised of progress, problems, insights, etc.
- Extend the use of BIM to new projects and begin working with outside members of the project teams in new collaborative approaches that allow early integration and sharing of knowledge using the building model.
- Continue to integrate BIM capabilities into all aspects of the firm's functions and reflect these new business processes in contractual documents with clients and business partners.
- Periodically re-plan the BIM implementation process to reflect the benefits and problems observed thus far, and set new goals for performance, time, and cost. Continue to extend BIM-facilitated changes to new locations and functions within the firm.

In Chapters 4 through 7, where specific applications of BIM over the lifecycle of a building are discussed, additional adoption guidelines specific to each party involved in the building process are reviewed.

1.8 FUTURE OF DESIGNING AND BUILDING WITH BIM (CHAPTER 8)

Chapter 8 describes the authors' views of how BIM technology will evolve and what impacts it is likely to have on the future AEC industry and to society at large. There are comments on the near-term future (up to 2012) and the long-term future (up to 2020). We also discuss the kinds of research that will be relevant to support these trends.

It is rather straightforward to anticipate near-term impacts. For the most part, they are extrapolations of current trends. Projections over a longer period are those that to us seem likely, given our knowledge of the AEC industry and BIM technology. Beyond that, it is difficult to make useful projections.

1.9 CASE STUDIES (CHAPTER 9)

Chapter 9 presents ten case studies that illustrate how BIM technology and its associated work processes are being used today. These cover the entire range of the building lifecycle, although most focus on the design and construction phases (with extensive illustration of offsite fabrication building models). For the reader who is anxious to "dive right in" and get a first-hand view of BIM, these case histories are a good place to start.

Chapter One Discussion Questions

1. What is BIM and how does it differ from 3D modeling?
2. What are some of the significant problems associated with the use of 2D CAD, and how do they waste resources and time during both the design and construction phases as compared to BIM-enabled processes?
3. Why has the construction industry not been able to overcome the impact of these problems on field labor productivity, despite the many advances in construction technology?
4. What changes in the design and construction process are needed to enable productive use of BIM technology?
5. How do parametric rules associated with the objects in BIM improve the design and construction process?
6. What are the limitations that can be anticipated with the generic object libraries that come with BIM systems?
7. Why does the design-bid-build business process make it very difficult to achieve the full benefits that BIM provides during design or construction?
8. What kind of legal problems can be anticipated as a result of using BIM with an integrated project team?
9. What techniques are available for integrating design analysis applications with the building model developed by the architect?