

# BIM Handbook

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A Guide to Building Information  
Modeling for Owners, Managers,  
Designers, Engineers, and Contractors

Second Edition

Chuck Eastman  
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# Foreword

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In the seven years since the term “Building Information Modeling” or BIM was first introduced in the AEC industry, it has gone from being a buzzword with a handful of early adopters to the centerpiece of AEC technology, which encompasses all aspects of the design, construction, and operation of a building. Most of the world’s leading architecture, engineering, and construction firms have already left behind their earlier, drawing-based, CAD technologies and are using BIM for nearly all of their projects. The majority of other firms also have their transitions from CAD to BIM well underway. BIM solutions are now the key technology offered by all the established AEC technology vendors that were earlier providing CAD solutions. In addition, the number of new technology providers that are developing add-on solutions to extend the capabilities of the main BIM applications in various ways is growing at an exponential pace. In short, BIM has not only arrived in the AEC industry but has literally taken it over, which is particularly remarkable in an industry that has historically been notoriously resistant to change.

It is important to keep in mind that BIM is not just a technology change, but also a process change. By enabling a building to be represented by intelligent objects that carry detailed information about themselves and also understand their relationship with other objects in the building model, BIM not only changes how building drawings and visualizations are created, but also dramatically alters all of the key processes involved in putting a building together: how the client’s programmatic requirements are captured and used to develop space plans and early-stage concepts; how design alternatives are analyzed for aspects such as energy, structure, spatial configuration, way-finding, cost, constructability, and so on; how multiple team members collaborate on a design, within a single discipline as well as across multiple disciplines; how the building is actually constructed, including the fabrication of different components by sub-contractors; and how, after construction, the building facility is operated and maintained. BIM impacts each of these processes by bringing in more intelligence and greater efficiency. It also goes over and beyond improving existing processes by enabling entirely new capabilities, such as checking a multi-disciplinary model for conflicts prior to construction, automatically checking a

design for satisfaction of building codes, enabling a distributed team to work simultaneously on a project in real time, and constructing a building directly from a model, thereby passing 2D drawings altogether. It is hardly surprising, then, to find that BIM has also become the catalyst for significant process and contractual changes in the AEC industry such as the growing move towards IPD or “Integrated Project Delivery.”

Given how vast BIM is, both as a multi-disciplinary design, analysis, construction, and facilities management technology, as well as the harbinger of dramatic process changes, it would seem almost impossible to distill the essence of it in a book. Yet this is precisely what *The BIM Handbook* has been able to do. It provides an in-depth understanding of the technology and processes behind building information modeling, the business and organizational issues associated with its implementation, and the advantages that the effective use of BIM can provide to all members of a project team, including architects, engineers, contractors and sub-contractors, facility owners and operators, as well as building product suppliers who need to model their products so that they can be incorporated into the building model. The book is targeted towards both practitioners in the industry as well as students and researchers in academia. For practitioners, it provides not just a deeper understanding of BIM but practical information including the software applications that are available, their relative strengths and limitations, costs and needed infrastructure, case studies, and guidance for successful implementation. For students and researchers, it provides extensive information on the theoretical aspects of BIM that will be critical to further study and research in the field.

First published in 2008, *The BIM Handbook* is authored by a team of leading academics and researchers including Chuck Eastman, Paul Teicholz, Rafael Sacks, and Kathleen Liston. It would be difficult to find a team more suited to crafting the ultimate book on BIM. Chuck Eastman, in particular, can be regarded as the world’s leading authority on building modeling, a field he has been working in since the 1970s at universities including UCLA and Carnegie-Mellon. I referred to his papers and books extensively during the course of my own Ph.D. work in building modeling while I was at UC Berkeley. In 1999, he published the book *Building Product Models: Computer Environments Supporting Design and Construction*, which was the first and only book to extensively compile and discuss the concepts, technologies, standards, and projects that had been developed in defining computational data models for supporting varied aspects of building design, engineering, and construction. He continues to lead research in the area of building product models and IT in building construction in his current role as Professor in the Colleges of Architecture and Computing at Georgia Institute of Technology, Atlanta,

and Director of Georgia Tech's Digital Building Laboratory. In addition to his research and teaching work, Chuck is very active in industry associations such as the AISC, NIBS, FIATECH, and AIA TAP, and is a frequent speaker at industry conferences.

Given his credentials and those of his co-authors including Paul Teicholz, who founded the Center for Integrated Facility Engineering (CIFE) at Stanford University and directed that program for 10 years; Rafael Sacks, Associate Professor in Construction Management at the Technion (Israel Institute of Technology); and Kathleen Liston, also from Stanford University and an industry practitioner, it is hardly surprising that *The BIM Handbook* continues to be one of the most comprehensive and authoritative published resources on BIM. This new second edition, coming three years after the publication of the first edition, keeps up with all of the rapid advances in BIM technology and associated processes, including new BIM tools and updates to the existing tools, the growing availability of model servers for BIM-based collaboration, the increasing focus on extending BIM technology all the way through to facilities management, the growing use of BIM to support sustainable design and lean construction, the integration of BIM with technologies such as laser-scanning to capture as-built conditions, and the growing momentum of alternate delivery models such as IPD. The new edition also greatly expands upon the case studies section of the first edition, highlighting several new projects that have pushed the boundaries of BIM use to achieve exceptional results, both in signature architecture as well as more common building designs.

The book is well organized with an executive summary at the beginning of each chapter providing a synopsis of its content and a list of relevant discussion questions at the conclusion of each chapter targeted towards students and professors. In addition to a bibliography, it includes a very useful Company and Software Index towards the end of the book that lists all the different software applications that were discussed in the book and the corresponding page numbers, not only making it easy to find the sections where a particular software is discussed, but also to get an at-a-glance overview of the extensive range of BIM and related applications that are currently available.

It is not often that practitioners in a field can get the benefits of an extensively researched and meticulously written book, showing evidence of years of work rather than something that has been quickly put together in the course of a few months, as most industry-focused books tend to be. The AEC industry has been fortunate to have this distinguished team of authors put their efforts into creating *The BIM Handbook*. Thanks to them, anyone in the AEC industry looking for a deeper understanding of BIM now knows exactly where to look for it. It brings together most of the current information about BIM, its

history, as well as its potential future in one convenient place. It is, of course, the must-have text book on BIM for all academic institutions who would like to teach or research this subject, given the academic and research credentials of its authors. There were many sections of the book that were illuminating and insightful even to someone like me, who has been analyzing and writing about AEC technology for close to ten years now. This helps to gauge how much value the book would bring to an AEC practitioner whose prime focus would be on the actual process of design, construction, or operation of a building rather than a full-time study of the technologies supporting it. True to its title, *The BIM Handbook* indeed serves as a handy reference book on BIM for anyone working in the AEC industry who needs to understand its current and future technological state of the art, as BIM is not only what is “in” today but is also the foundation on which smarter and better solutions will be built going forward.

Lachmi Khemlani, Ph.D.  
Founder and Editor, AECbytes

# Preface

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This book is about a new approach to design, construction, and facility management called *building information modeling* (BIM). It provides an in-depth understanding of BIM technologies, the business and organizational issues associated with its implementation, and the profound impacts that effective use of BIM can provide to all parties involved in a facility over its lifetime. The book explains how designing, constructing, and operating buildings with BIM differs from pursuing the same activities in the traditional way using drawings, whether paper or electronic.

BIM is beginning to change the way buildings look, the way they function, and the ways in which they are built. Throughout the book, we have intentionally and consistently used the term “BIM” to describe an activity (meaning *building information modeling*), rather than an object (*building information model*). This reflects our belief that BIM is not a thing or a type of software but a human activity that ultimately involves broad process changes in design, construction and facility management.

Perhaps most important is that BIM creates significant opportunity for society at large to achieve more sustainable building construction processes and higher performance facilities with fewer resources and lower risk than can be achieved using traditional practices.

## **Why a BIM Handbook?**

Our motivation in writing this book was to provide a thorough and consolidated reference to help students and practitioners in the construction industry learn about this exciting new approach, in a format independent of the commercial interests that guide vendors’ literature on the subject. There are many truths and myths in the generally accepted perceptions of the state of the art of BIM. We hope that *The BIM Handbook* will help reinforce the truths, dispel the myths, and guide our readers to successful implementations. Some well-meaning decision-makers and practitioners in the construction industry at-large have had disappointing experiences after attempting to adopt BIM, because their efforts and expectations were based on misconceptions and inadequate planning. If this book can help readers avoid these frustrations and costs, we will have succeeded.

Collectively, the authors have a wealth of experience with BIM, both with the technologies it uses and the processes it supports. We believe that BIM represents a paradigm change that will have far-reaching impacts and

benefits, not only for those in the construction industry but for society at-large, as better buildings are built that consume fewer materials and require less labor and capital resources and that operate more efficiently. We make no claim that the book is objective in terms of our judgment of the necessity for BIM. At the same time, of course, we have made every effort to ensure the accuracy and completeness of the facts and figures presented.

### **Who Is *The BIM Handbook* For, and What Is in It?**

*The BIM Handbook* is addressed to building developers, owners, managers, and inspectors; to architects, engineers of all disciplines, construction contractors, and fabricators; and to students of architecture, civil engineering, and building construction. It reviews Building Information Modeling and its related technologies, its potential benefits, its costs and needed infrastructure. It also discusses the present and future influences of BIM on regulatory agencies; legal practice associated with the building industry; and manufacturers of building products—it is directed at readers in these areas. A rich set of BIM case studies are presented and various BIM tools and technologies are described. Current and future industry and societal impacts are also explored.

The book has four sections:

- I. Chapters 1, 2, and 3 provide an introduction to BIM and the technologies that support it. These chapters describe the current state of the construction industry, the potential benefits of BIM, the technologies underlying BIM including parametric modeling of buildings and interoperability.
- II. Chapters 4, 5, 6, and 7 provide discipline-specific perspectives of BIM. They are aimed at owners (Chapter 4), designers of all kinds (Chapter 5), general contractors (Chapter 6), and subcontractors and fabricators (Chapter 7).
- III. Chapter 8 discusses potential impacts and future trends associated with the advent of BIM-enabled design, construction, and operation of buildings. Current trends are described and extrapolated through the year 2015, as are forecasts of potential long-term developments and the research needed to support them through 2020.
- IV. Chapter 9 provides ten detailed cases studies of BIM in the design and construction industry that demonstrate its use for feasibility studies, conceptual design, detail design, estimating, detailing, coordination, construction planning, logistics, operations and many other common construction activities. The case studies include buildings with signature architectural and structural designs (such as the Aviva Stadium in Dublin, the 100 11th Avenue apartment building facade in New York City, and the environmentally friendly Music Hall in Helsinki) as well as a wide range of fairly common buildings (a Marriott Hotel renovation, a hospital, a high-rise office building, and a mixed commercial and retail

development, and a coast-guard training facility). There is also a study of a single tower cable-stayed bridge in Finland.

### **What's New in This Edition?**

BIM is developing rapidly, and it is difficult to keep up with the advances in both technology and practice. Integrated Project Delivery (IPD) is a collaborative contracting paradigm that has been developed and adopted within the three years since we completed the first edition. BIM tools are increasingly used to support sustainable design, construction, and operation. There has been increasing support by BIM for lean design and construction methods which are highlighted throughout the book. Some innovations we predicted would become commercial by 2012, such as tracking of building components using BIM and radio-frequency ID tagging, have already been used in practice.

This edition not only addresses these themes and updates the material related to the BIM applications; it also introduces sections on new technologies, such as laser scanning and BIM servers. It also includes six new case studies.

### **How to use *The BIM Handbook***

Many readers will find the *Handbook* a useful resource whenever they are confronted with new terms and ideas related to BIM in the course of their work or study. A thorough first-reading, while not essential, is of course the best way to gain a deeper understanding of the significant changes that BIM is bringing to the AEC/FM industry.

The first section (Chapters 1–3) is recommended for all readers. It gives a background to the commercial context and the technologies for BIM. Chapter 1 lists many of the potential benefits that can be expected. It first describes the difficulties inherent in current practice within the U.S. construction industry and its associated poor productivity and higher costs. It then describes various approaches to procuring construction, such as traditional design-bid-build, design-build, and others, describing the pros and cons for each in terms of realizing benefits from the use of BIM. It describes newer integrated project delivery (IPD) approaches that are particularly useful when supported by BIM. Chapter 2 details the technological foundations of BIM, in particular parametric and object-oriented modeling. The history of these technologies and their current state of the art are described. The chapter then reviews the leading commercial application platforms for generating building information models. Chapter 3 deals with the intricacies of interoperability, including how building information can be communicated and shared from profession to profession and from application to application. The relevant standards, such as IFC (Industry Foundation Classes) and the U.S. National BIM Standards are covered in detail. Chapters 2 and 3 can also be used as a reference for the technical aspects of parametric modeling and interoperability.

Readers who desire specific information on how they can adopt and implement BIM in their companies can find the details they need in the

relevant chapter for their profession within Chapters 4–7. You may wish to read the chapter closest to your area of interest and then only the executive summaries of each of the other chapters. There is some overlap within these chapters, where issues are relevant to multiple professions (for example, subcontractors will find relevant information in Chapters 6 and 7). These chapters make frequent reference to the set of detailed case studies provided in Chapter 9.

Those who wish to learn about the long-term technological, economic, organizational, societal, and professional implications of BIM and how they may impact your educational or professional life will find an extensive discussion of these issues in Chapter 8.

The case studies in Chapter 9 each tell a story about different professionals' experiences using BIM on their projects. No one case study represents a "complete" implementation or covers the entire building lifecycle. In most cases, the building was not complete when the study was written. But taken together, they paint a picture of the variety of uses and the benefits and problems that these pioneering firms have already experienced. They illustrate what could be achieved with existing BIM technology at the start of the 21st century. There are many lessons learned that can provide assistance to our readers and guide practices in future efforts.

Finally, students and professors are encouraged to make use of the study questions and exercises provided at the conclusion of each chapter.

## **Acknowledgments**

Naturally, we are indebted first and foremost to our families, who have all borne the brunt of the extensive time we have invested in this book. Our thanks and appreciation for the highly professional work of Lauren Poplawski, Editorial Program Coordinator, and to Kathryn Bourgoine, Acquisitions Editor, both at John Wiley and Sons.

Our research for the book was greatly facilitated by numerous builders, designers, and owners, representatives of software companies and government agencies; we thank them all sincerely. Five of the case studies were originally prepared by graduate students in the College of Architecture at Georgia Tech, and others were initially drafted by students at the School of the Built Environment at the University of Salford, and at the Tallinn University of Applied Sciences; we thank them, and their efforts are acknowledged personally at the end of each relevant case study. The case studies were made possible through the very generous contributions of the project participants who corresponded with us extensively and shared their understanding and insights.

Finally, we are grateful to Lachmi Khemlani for her enlightening foreword to this second edition and for her significant contributions to BIM, reflected in her publication of AECbytes. Finally, we are grateful to Jerry Laiserin for his enlightening foreword in the first edition and for helping to initiate the original idea for *The BIM Handbook*.

# CHAPTER 1

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## BIM Handbook Introduction

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### 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, one or more accurate virtual models of a building are constructed digitally. They support design through its phases, allowing better analysis and control than manual processes. When completed, these computer-generated models contain precise geometry and data needed to support the construction, fabrication, and procurement activities through which the building is realized.

BIM also accommodates many of the functions needed to model the lifecycle of a building, providing the basis for new design and construction capabilities and changes in the roles and relationships among a project team. When adopted well, 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.

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## 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 early phase of development and use.

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## 1.2 THE CURRENT AEC BUSINESS MODEL

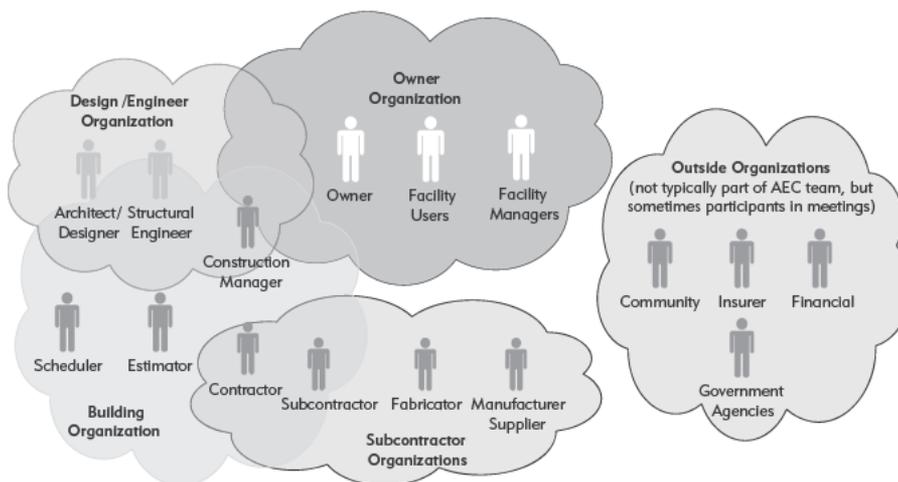
Currently, the facility delivery process remains fragmented, and it depends on paper-based modes of communication. Errors and omissions in paper documents often cause unanticipated field costs, delays, and eventual lawsuits between the various parties in a project team. These problems cause friction, financial expense, and delays. 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 or their electronic equivalents.

One of the most common problems associated with 2D-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, and so forth. 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.



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

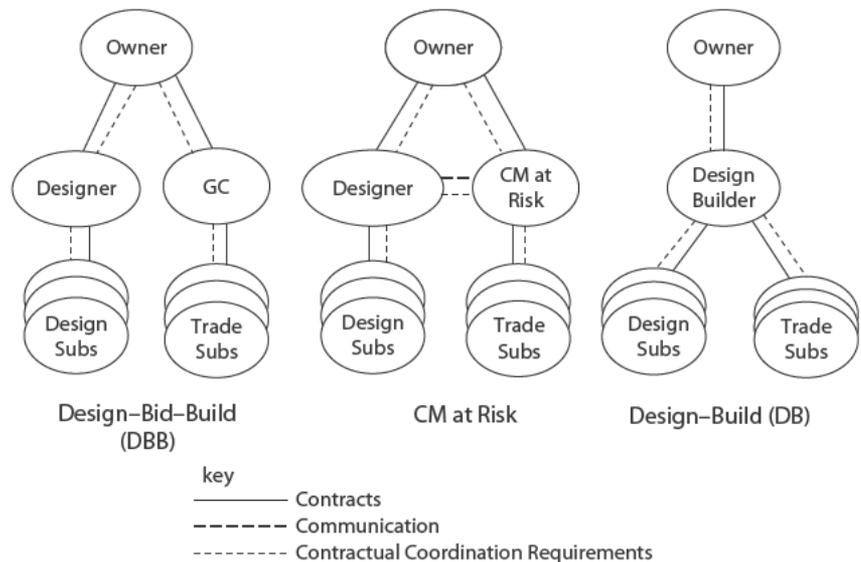
There are three dominant contract methods in the United States: Design-Bid-Build, Design-Build, and Construction Management at Risk. There are also many variations of these (Sanvido and Konchar 1999; Warne and Beard 2005). A fourth method, quite different from the first three, called “Integrated Project Delivery” is becoming increasingly popular with sophisticated building owners. These four approaches are now described in greater detail.

### 1.2.1 Design-Bid-Build

A significant percentage of buildings are built using the Design-Bid-Build (DBB) approach (almost 90 percent of public buildings and about 40 percent 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 schematically illustrates the typical DBB procurement process as compared to the typical Construction Management at Risk (CM at Risk) and Design-Build (DB) processes (see Section 1.2.2)

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

**FIGURE 1–2**  
Schematic diagram of Design-Bid-Build, CM at Risk, and Design-Build processes.



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 percent of their estimated costs in compiling bids.<sup>1</sup> 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 percent 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, and the like.

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.

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<sup>1</sup> This is based on two of the authors' personal experience in working with the construction industry. This cost includes the expense of obtaining bid documents, performing quantity takeoff, coordinating with suppliers and subcontractors, and the cost estimating processes.

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 after exact conditions are established. Onsite construction work 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 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 also arise whenever a contractor bids below the estimated cost in order to win the job. Contractors often 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 may extend the project 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, and so forth) to make sure they work properly. Depending on contract requirements, final 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.

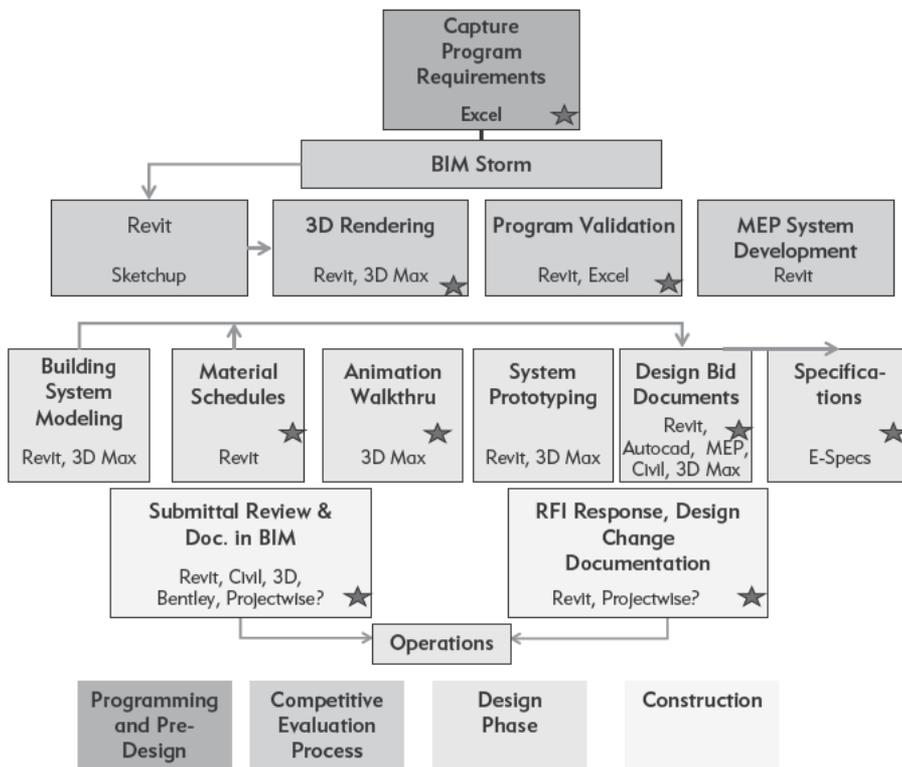
Because all of the information provided to the owner is conveyed in 2D (on paper or equivalent electronic files), the owner must put in a considerable amount of effort to relay all relevant information to the facility management team charged with maintaining and operating the building. The process is 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

The design-build (DB) 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 1–3 illustrates this process.

In this model, the owner contracts directly with the design-build team (normally a contractor with a design capability or working with an architect) to develop a well-defined building program and a schematic design that meets the owner's needs. The DB contractor then estimates the total cost and time needed to design and construct the building. After all modifications requested by the owner are implemented, the plan is approved and the final budget for the project is established. It is important to note that because the DB model



**FIGURE 1-3**

Adapted from workflow and deliverables for LACCD BIM standard on design-build projects (only the BIM-related workflows are shown).

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. These are usually based on a fixed price, lowest bid basis. 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 and early building elements. 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 little 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 United States 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 percent of construction projects in the United States relied on a variation of the DB procurement approach. Higher percentages (50 to 70 percent) were measured for some government organizations (Navy, Army, Air Force, and GSA).

The use of BIM within a DB model is clearly advisable. The Los Angeles Community College District (LACCD) has established a clear set of guidelines for this use of BIM for its design-build projects (see <http://standards.build-laccd.org/projects/dcs/pub/BIM%20Standards/released/PV-001.pdf>). Figure 1–3 is adapted from this paper and shows the BIM-related workflow and deliverables for this standard.

### **1.2.3 Construction Management at Risk**

Construction management at risk (CM@R) project delivery is a method in which an owner retains a designer to furnish design services and also retains a construction manager to provide construction management services for a project throughout the preconstruction and construction phases. These services may include preparation and coordination of bid packages, scheduling, cost control, value engineering, and construction administration. The construction manager is usually a licensed general contractor and guarantees the cost of the project (guaranteed maximum price, or GMP). The owner is responsible for the design before a GMP can be set. Unlike DBB, CM@R brings the constructor into the design process at a stage where they can have definitive input. The value of the delivery method stems from the early involvement of the contractor and the reduced liability of the owner for cost overruns.

### 1.2.4 Integrated Project Delivery

Integrated project delivery (IPD) is a relatively new procurement process that is gaining popularity as the use of BIM expands and the AEC facility management (AEC/FM) industry learns how to use this technology to support integrated teams. There are multiple approaches to IPD as the industry experiments with this approach. The American Institute of Architecture (AIA) has prepared sample contract forms for a family of IPD versions (AIA 2010). They have also published a useful Guide to IPD (AIA 2010). In all cases, integrated projects are distinguished by effective collaboration among the owner, the prime (and possibly sub-) designers, the prime (and possibly key sub-) contractor(s). This collaboration takes place from early design and continues through project handover. The key concept is that this project team works together using the best collaborative tools at their disposal to ensure that the project will meet owner requirements at significantly reduced time and cost. Either the owner needs to be part of this team to help manage the process or a consultant must be hired to represent the owner's interests, or both may participate. The tradeoffs that are always a part of the design process can best be evaluated using BIM—cost, energy, functionality, esthetics, and constructability. Thus, BIM and IPD go together and represent a clear break with current linear processes that are based on paper representation exchange of information. Clearly the owner is the primary beneficiary of IPD, but it does require that they understand enough to participate and specify in the contracts what they want from the participants and how it will be achieved. The legal issues of IPD are very important and are discussed in Chapters 4 and 6. There are several case studies of IPD projects presented in Chapter 9.

### 1.2.5 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, and so forth. It is beyond the scope of this book to outline each of these and the benefits and problems associated with them (but 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 one or more digital models. The DBB approach presents the greatest challenge to the use of BIM because the contractor does not participate in the design process and thus must

build a new building model after design is completed. The DB approach may provide an excellent opportunity to exploit BIM technology, because a single entity is responsible for design and construction. The CM@R approach allows early involvement of the constructor in the design process which increases the benefit of using BIM and other collaboration tools. Various forms of integrated project delivery are being used to maximize the benefits of BIM and “Lean” (less wasteful) processes. Other procurement approaches can also benefit from the use of BIM but may achieve only partial benefits, particularly if 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 1–4, developed by

**FIGURE 1–4**  
Indexes of labor productivity for construction and nonfarm industries, 1964–2009.

Adapted from research by Paul Teicholz at CIFE.



one of the authors, illustrates productivity within the U.S. field construction industry relative to all nonfarm industries over a period of 45 years, from 1964 through 2009. The data was calculated by dividing constant contract dollars (from the Department of Commerce) by field worker-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, and the like, are not included. The amount of worker-hours required for labor excludes offsite work, such as steel fabrication, precast concrete, and so forth, but does include the installation labor for these materials. During this 44-year-long period, the productivity of nonfarm industries (including construction) has more than doubled. Meanwhile, labor productivity within the construction industry is relatively unchanged and is now estimated to be about 10 percent less than what it was in 1964. Labor represents about 40 to 60 percent of construction's estimated costs (depending on the type of structure). Owners were actually paying approximately 5 percent more in 2009 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 and offsite prefabrication is becoming a bigger factor. 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 considering the industry as a whole.

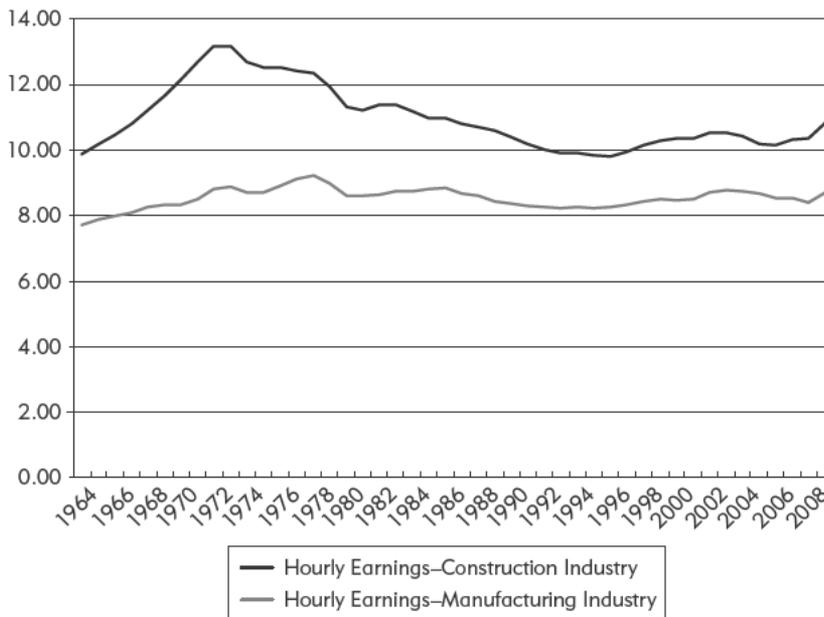
Contractors have made greater use of offsite components which take advantage of factory conditions and specialized equipment. Clearly this has allowed for higher quality and lower cost production of components, as compared to onsite work (Eastman and Sacks 2008). Although the cost of these components 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 is not well-documented over the total period covered by these statistics.<sup>2</sup>

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<sup>2</sup>From 1997–2008 the cost of prefabricated wood and steel components represented about 3.3 percent of total construction value put in place or about 9.7 percent of the value of the material, supplies, and fuel used for construction (from Economic Census data).

While the reasons for the apparent decrease in construction productivity are not completely understood, the statistics are dramatic and point at significant structural 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 fewer than five people, making it difficult for them to invest in new technology; even the largest firms account for less than 0.5 percent 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.
- Additions, alterations, or reconstruction work represents about 23 percent and maintenance and repair represents about 10 to 12 percent of construction volume. It is more difficult to use capital-intensive methods for these kinds of work. It is labor intensive and likely to remain so. New work represents only about 64 percent of total construction volume.
- The adoption of new and improved business practices within both design and construction has been noticeably slow and limited primarily to larger firms. In addition, the introduction of new technologies has been fragmented. Often, 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. Municipal governments almost all require paper submittals for construction permit reviews. For these reasons, paper use maintains a strong grip on the industry.
- 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

**FIGURE 1-5**

Trends in real wages (1990 U.S. \$) for manufacturing and construction hourly workers, 1974–2008.

BLS, Series ID: EES00500006.

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 1-5 shows that, since 1974, compensation for hourly workers has steadily declined with the increase in use of nonunion immigrant workers with little prior training. The lower cost associated with these workers may have discouraged efforts to replace field labor with automated (or offsite) solutions. The fact that average hourly wages for manufacturing are lower than those in construction may indicate that automation in both industries is less dependent on the cost of labor than on whether the basic processes are able to be automated (factory versus field work environments and the like).

### 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, and so forth. 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 square foot for new construction and an increase in \$0.23 per square foot 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)

**Table 1–1** Additional Costs of Inadequate Interoperability in the Construction Industry, 2002 (In \$M)

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
<b>Total</b>	<b>\$2,658.3</b>	<b>\$4,072.4</b>	<b>\$9,093.3</b>	<b>\$15,824.0</b>
Applicable sf in 2002	1.1 billion	1.1 billion	39 billion	n/a
<b>Added cost/sf</b>	<b>\$2.42/sf</b>	<b>\$3.70/sf</b>	<b>\$0.23</b>	<b>n/a</b>

Source: Table 6.1 NIST study (Gallaher et al. 2004).

Of these costs, roughly 68 percent (\$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. 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.

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## 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).

The following is both the vision for and a definition of BIM technology provided by the National Building Information Modeling Standard (NBIMS) Committee of the National Institute of Building Sciences (NIBS) Facility Information Council (FIC). The NBIMS vision for BIM is “an improved

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 digital representations (objects) that carry computable graphic and data attributes that identify them to software applications, as well as parametric rules that allow them to be manipulated in an intelligent fashion.
- Components that include data that describe how they behave, as needed for analyses and work processes, for example, takeoff, specification, and energy analysis.
- Consistent and nonredundant data such that changes to component data are represented in all views of the component and the assemblies of which it is a part.
- Coordinated data such that all views of a model are represented in a coordinated way.

planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle.” (NIBS 2008).

The scope of BIM directly or indirectly affects all stakeholders supporting the capital facilities industry. BIM is a fundamentally different way of creating, using, and sharing building lifecycle data. The terms *Building Information Model* and *Building Information Modeling* are often used interchangeably, reflecting the term’s growth to manage the expanding needs of the constituency.

The NBIMS Initiative categorizes the Building Information Model (BIM) three ways:

1. As a product
2. As an IT-enabled, open standards–based deliverable, and a collaborative process
3. As a facility lifecycle management requirement.

These categories support the creation of the industry information value chain, which is the ultimate evolution of BIM. This enterprise-level (industry-wide) scope of BIM is the area of focus for NBIMS, bringing together the various BIM implementation activities within stakeholder communities.

The methodologies used by NBIMS are rooted in the activities of the International Alliance for Interoperability (IAI), the Information Delivery Manuals (IDM) and Model View Definitions (MVDs), Industry Foundation Dictionaries (IFD), and the development of North American (NA) Information Exchanges that define user requirements and localized content supporting the NA approach to the various building lifecycle processes.

BIM supports a reevaluation of IT use in the creation and management of the facility's lifecycle. The stakeholders include real estate; ownership; finance; all areas of architecture, engineering, and construction (AEC); manufacturing and fabrication; facility maintenance, operations, and planning; regulatory compliance; management; sustainment; and disposal within the facility lifecycle. With society's growing environmental, sustainment, and security mandates, the need for open and reusable critical infrastructure data has grown beyond the needs of those currently supplying services and products to the industry. First-responders, government agencies, and other organizations also need this data.

BIM moves the industry forward from current task automation of project and paper-centric processes (3D CAD, animation, linked databases, spreadsheets, and 2D CAD drawings) toward an integrated and interoperable workflow where these tasks are collapsed into a coordinated and collaborative process that maximizes computing capabilities, Web communication, and data aggregation into information and knowledge capture. All of this is used to simulate and manipulate reality-based models to manage the built environment within a fact-based, repeatable and verifiable decision process that reduces risk and enhances the quality of actions and product industry-wide.

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 3D objects. Parametric BIM objects are defined as follows:

- Consist of geometric definitions and **associated data and rules**.
- Geometry is integrated **nonredundantly**, 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 butt to a ceiling or roof, and so forth.

- 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, and so forth.
- Objects have the ability to **link to or receive, broadcast, or export sets of attributes**, for example, structural materials, acoustic data, energy data, and the like, 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 reports of geometric parameters. In Chapters 4 through 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 may allow for tighter and easier integration among products in multiple directions. For example, changes to the architectural model will generate changes to the mechanical systems 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) 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 possibly reduced interoperability, especially if the various software programs in use for a given project do not support, or only partially support with some data loss, 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).

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## 1.5 WHAT IS NOT BIM TECHNOLOGY?

The term *BIM* is a popular buzzword 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 design technology. These include tools that create the following kinds of models:

**Models that contain 3D data only and no (or few) 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 little or no support for data integration and design analysis. An example is Google's SketchUp application which is excellent for rapid development of building schematic designs, but limited use for any other type of analysis because it has no knowledge of the objects in the design other than their geometry and appearance for visualization.

**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).

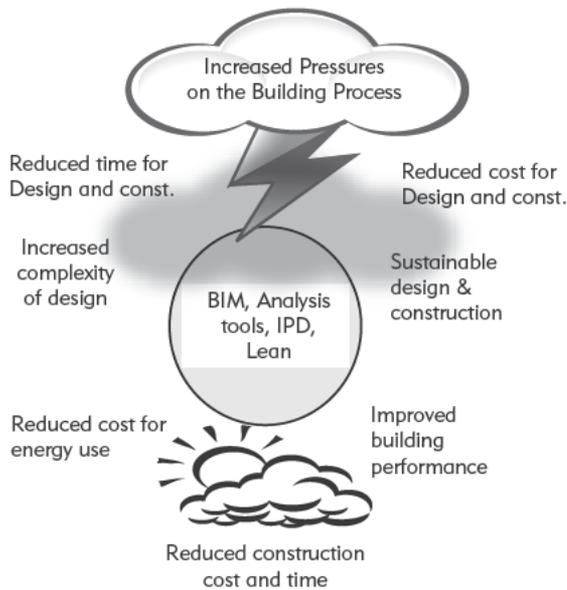
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## 1.6 WHAT ARE THE BENEFITS OF BIM? WHAT PROBLEMS DOES IT ADDRESS?

BIM technology can support and improve many business practices. Although the AEC/FM (facility management) industry is in the early days of BIM use,

**FIGURE 1-6**

BIM technology and associated processes can help to respond to the increasing pressures on a building over its lifecycle.



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. Figure 1-6 illustrates how BIM technology and associated processes are at the heart of how the building design and construction process can respond to the increasing pressures of greater complexity, faster development, improved sustainability while reducing the cost of the building and its subsequent use. Traditional practice is not able to respond to these pressures. The subsequent sections briefly describe how this improved performance can be achieved. The goal of this book is to provide the necessary knowledge to allow a reader to understand both the technology and business processes that underlie BIM.

### 1.6.1 Preconstruction 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. In other words, 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.

### ***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. These capabilities are reviewed in Chapter 5.

### ***Improved Collaboration Using Integrated Project Delivery***

When the owner uses Integrated Project Delivery (IPD) for project procurement, BIM can be used by the project team from the beginning of the design to improve their understanding of project requirements and to extract cost estimates as the design is developed. This allows design and cost to be better understood and also avoids the use of paper exchange and its associated delays. This is described further in Chapters 4 through 7 and is illustrated in the Sutter Medical Center Castro Valley case study in Chapter 9.

## **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 free of geometry, alignment, and spatial coordination errors. This reduces the user’s need to manage design changes (see Chapter 2 for further discussion of parametric rules).

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

### ***Easy Verification of Consistency to 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, and the like), 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), the 3D model also can support automatic evaluations.

### ***Extraction of 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 either on formulas that are keyed to significant project quantities, for example, number of parking spaces, square feet of office areas of various types, or unit costs 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. When using BIM for cost estimates, it is clearly desirable to have the general contractor and possibly key trade contractors who will be responsible for building the structure, as part of the project

team. Their knowledge is required for accurate cost estimates and constructability insights during the design process. The use of BIM for cost estimating is a complex one and is discussed in Chapters 4 through 7 and in a number of the case studies presented in Chapter 9.

### ***Improvement of 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 practical using traditional 2D tools because of the time required to prepare the relevant input. If applied at all, energy analysis is performed at the end of the 2D design process as a check or a regulatory requirement, 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 and 7)**

### ***Use of 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 worldwide 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. It also allows smaller installation crews, faster installation time, and less onsite storage space.

### ***Quick Reaction to Design Changes***

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 or

through clash detection. 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.

### ***Discovery of Design Errors and Omissions before Construction***

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 models from all disciplines can be brought together and compared, multisystem interfaces are easily checked both systematically (for hard and clearance clashes) and visually (for other kinds of errors). Conflicts and constructability problems 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.

### ***Synchronization of 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, and so forth). 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.

### ***Better Implementation of Lean Construction Techniques***

Lean construction techniques require careful coordination between the general contractor and all 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 jobsite. The model can also be used with wireless hand-held computers to facilitate material tracking, installation progress, and automated positioning in the field. These benefits are illustrated in the Maryland General Hospital and Crusell Bridge case studies presented in Chapter 9.

### ***Synchronization of Procurement with Design and Construction***

The complete building model provides accurate quantities for all (or most, depending upon the 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 (2010), the object definitions for many manufactured products have not yet been developed to make this capability a complete reality. However, when the models have been available (steel members, precast concrete members, some mechanical components, some windows and doors), the results have been very beneficial.

## **1.6.4 Post Construction Benefits (Chapter 4)**

### ***Improved Commissioning and Handover of Facility Information***

During the construction process the general contractor and MEP contractors collect information about installed materials and maintenance information for the systems in the building. This information can be linked to the object in the building model and thus be available for handover to the owner for use in their facility management systems. It also can be used to check that all the systems are working as designed before the building is accepted by the owner. This is illustrated in the Maryland General Hospital case study discussed in Chapter 9.

### ***Better Management and Operation of 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.

### ***Integration 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. This is discussed in Chapter 8.

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## 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. The growing use of IPD project delivery for buildings and other types of structures reflects the strong benefits of integrated teams using BIM and lean construction techniques to manage the design and construction process.

### 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. If the architect does create their design using BIM, the model may not have sufficient detail for use for construction or may have object definitions that are inadequate for extracting necessary construction quantities. This may require creating a new model for construction use. If the architectural model is provided, cost and time may be added to the project, but the cost of a model is usually justified by the advantages of using it for construction planning and detailed design by mechanical, plumbing, other subs and fabricators, design change resolution, procurement, and so forth. 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 and time to the project. Such problems may 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. These capabilities and issues are reviewed in Chapter 3. 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 challenges, 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 practitioners 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. These are discussed in Chapter 4.

### **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. IPD 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 intensively using a shared building model during design phases and a coordinated set of building models during construction and fabrication, 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 building model 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 some understanding of BIM technology and related processes and a plan for

implementation before the conversion can begin. A consultant can be very helpful to plan, monitor, and assist in this process. 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, and so forth. It will also allow the firm to develop modeling standards and determine the quality of models and level of detail needed for different uses. 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, and so forth.
- 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 additional 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 life-cycle of a building are discussed, additional adoption guidelines specific to each party involved in the building process are reviewed.

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## 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 of the AEC/FM industry and to society at large. There are comments on the near-term future (up to 2015) and the long-term future (up to 2025). 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/FM industry and BIM technology. Beyond that, it is difficult to make useful projections.

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## 1.9 CASE STUDIES (CHAPTER 9)

Chapter 9 presents 10 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 studies are a good place to start.

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## Chapter 1 Discussion Questions

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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 can provide during design or construction?
8. How does integrated project delivery differ from the design-build and construction management at risk project procurement methods?
9. What kind of legal problems can be anticipated as a result of using BIM with an integrated project team?
10. What techniques are available for integrating design analysis applications with the building model developed by the architect?
11. How does the use of BIM allow a more sustainable building design?