BIM Handbook

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

Chuck Eastman
Paul Teicholz
Rafael Sacks
Kathleen Liston

John Wiley & Sons, Inc.

BIM Handbook: A Guide to Building InformationModeling for Owners, Managers,Designers, Engineers, and Contractors.
Chuck Eastman, Paul Teicholz, Rafael Sacks and Kathleen Liston Copyright © 2008 John Wiley & Sons, Inc.

This book is printed on acid-free paper. ♾

Copyright © 2008 by John Wiley & Sons, Inc. All rights reserved

Published by John Wiley & Sons, Inc., Hoboken, New Jersey
Published simultaneously in Canada

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 646-8600, or on the web at www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at www.wiley.com/go/permissions.

Limit of Liability/Disclaimer of Warranty: While the publisher and the author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor the author shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

For general information about our other products and services, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books. For more information about Wiley products, visit our web site at www.wiley.com.

Library of Congress Cataloging-in-Publication Data:
BIM handbook : a guide to building information modeling for owners, managers, designers, engineers, and contractors / Chuck Eastman . . . [et al.].
p. cm.
Includes bibliographical references and index.
ISBN: 978-0-470-18528-5 (cloth)
1. Building—Data processing—Handbooks, manuals, etc. 2. Building management—Data processing—Handbooks, manuals, etc. 3. Communication in the building trades—Handbooks, manuals, etc. 4. Architectural practice—Handbooks, manuals, etc. 5. Architects and builders—Handbooks, manuals, etc. I. Eastman, Charles M.
TH437.B53 2008
690.0285—dc22

2007029306

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Contents

	Preface	vii
	Foreword	xi
CHAPTER 1	BIM Handbook Introduction	1
	1.0 Executive Summary	1
	1.1 Introduction	1
	1.2 The Current AEC Business Model	2
	1.3 Documented Inefficiencies of Traditional Approaches	8
	1.4 BIM: New Tools and New Processes	12
	1.5 What Is Not BIM Technology	15
	1.6 What Are the Benefits of BIM? What Problems Does It Address?	16
	1.7 What Challenges Can Be Expected?	21
	1.8 Future of Designing and Building with BIM (Chapter 8)	23
	1.9 Case Studies (Chapter 9)	24
CHAPTER 2	BIM Tools and Parametric Modeling	25
	2.0 Executive Summary	25
	2.1 History of Building Modeling Technology	26
	2.2 Varied Capabilities of Parametric Modelers	44
	2.3 Overview of the Major BIM Model Generating Systems	54
	2.4 Conclusion	63
CHAPTER 3	Interoperability	65
	3.0 Executive Summary	65
	3.1 Introduction	66
	3.2 Different Kinds of Exchange Formats	67
	3.3 Background of Product Data Models	70
	3.4 XML Schemas	84

3.5 Portable, Web-Based Formats: DWF and PDF 86
3.6 File Exchange Versus Building Model Repositories 87
3.7 Summary 90

CHAPTER 4 BIM for Owners and Facility Managers 93
4.0 Executive Summary 93
4.1 Introduction: Why Owners Should Care About BIM 94
4.2 BIM Application Areas for Owners 96
4.3 Types of Owners: Why, How Often, and Where They Build 111
4.4 How Owners Build 115
4.5 BIM Tool Guide for Owners 120
4.6 An Owner and Facility Manager's Building Model 130
4.7 Leading the BIM Implementation on a Project 133
4.8 Barriers to Implementing BIM: Risks and Common Myths 141
4.9 Guidelines and Issues for Owners to Consider When Adopting BIM 145

CHAPTER 5 BIM for Architects and Engineers 149
5.0 Executive summary 149
5.1 Introduction 150
5.2 Scope of Design Services 152
5.3 BIM Use in Design Processes 156
5.4 Building Element Models and Libraries 190
5.5 Considerations in Adoption for Design Practice 196
5.6 New and Changed Staffing within Design Firms 202
5.7 New Contractual Opportunities in Design 204

CHAPTER 6 BIM for the Construction Industry 207
6.0 Executive Summary 207
6.1 Introduction 208
6.2 Types of Construction Firms 209
6.3 Information Contractors Want from BIM 212
6.4 Processes to Develop a Contractor Building Information Model 213

6.5 Reduction of Design Errors Using Clash Detection 216
6.6 Quantity Takeoff and Cost Estimating 218
6.7 Construction Analysis and Planning 224
6.8 Integration with Cost and Schedule Control and Other Management Functions 233
6.9 Use for Offsite Fabrication 235
6.10 Use of BIM Onsite: Verification, Guidance, and Tracking of Construction Activities 236
6.11 Implications for Contract and Organizational Changes 238
6.12 BIM Implementation 240

CHAPTER 7 BIM for Subcontractors and Fabricators 243
7.0 Executive Summary 243
7.1 Introduction 244
7.2 Types of Subcontractors and Fabricators 246
7.3 The Benefits of a BIM Process for Subcontractor Fabricators 248
7.4 BIM-Enabled Process Change 260
7.5 Generic BIM System Requirements for Fabricators 264
7.6 Major Classes of Fabricators and Their Specific Needs 268
7.7 Adopting BIM in a Fabrication Operation 276
7.8 Conclusions 282

CHAPTER 8 The Future: Building with BIM 285
8.0 Executive Summary 285
8.1 Introduction 286
8.2 The Development of BIM Up To 2007 287
8.3 Current Trends 288
8.4 Vision 2012 292
8.5 Drivers of Change and BIM Impacts up to 2020 308

CHAPTER 9 BIM Case Studies 319
9.0 Introduction to BIM Case Studies 319
9.1 Flint Global V6 Engine Plant Expansion 324
9.2 United States Coast Guard BIM Implementation 339

9.3 Camino Medical Group Mountain View Medical Office Building Complex 358
9.4 Beijing National Aquatics Center 375
9.5 San Francisco Federal Building 388
9.6 100 11th Avenue, New York City 405
9.7 One Island East Project 418
9.8 Penn National Parking Structure 432
9.9 Hillwood Commercial Project 441
9.10 U. S. Courthouse, Jackson, Mississippi 450

Glossary 467
Bibliography 469
Index 485

Preface

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 members of a project team. 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 construction.

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 building 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. Many well-meaning decision-makers and practitioners in the building 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. We believe that BIM represents a paradigm change that will have far-reaching benefits, not

only for those in the building industry but for society at-large, as better buildings are built that consume less energy and require less labor and capital resources. 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. 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 building industry, the potential benefits of BIM, parametric modeling of buildings, and interoperability issues.

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 2012 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 construction industry that demonstrate its use for feasibility studies, conceptual 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 Beijing National Aquatics Center, the 100 11th Avenue apartment building facade in New York City, and the environmentally friendly Federal Building in San Francisco) as well as a wide range of fairly common buildings (a GM production plant, a federal courthouse, a medical office building, a parking structure, a high-rise office building, a mixed commercial and retail development, and a coast-guard training facility).

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 building 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. building 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. 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. 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 a small degree of overlap within these chapters, where issues are relevant to multiple professions. 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 economic, organizational, social, 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 exsiting 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 highly professional work are due to Laurie Manfra, who copyedited the book, and to Jim Harper, our publisher representative 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. Six of the case studies were originally prepared by graduate students in the College of Architecture at Georgia Tech; 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 Jerry Laiserin, not only for his enlightening foreword, but also for helping to initiate the idea for the BIM Handbook.

Foreword

In recent years, both the concept and nomenclature we now know as BIM— or Building Information Models and Building Information Modeling—have engaged professional and industry awareness sufficiently to justify treatment in handbook format. The result is this book, which amply fulfills the requirements anyone would expect of a handbook, with respect to both breadth of coverage and depth of exposition.

However, neither the concept nor nomenclature of BIM is new—not as of 2007, not as of 2002, nor even 1997. The concepts, approaches and methodologies that we now identify as BIM can be dated back nearly thirty years, while the terminology of the "Building Information Model" has been in circulation for at least fifteen years. Note that my gloss on the history of BIM, below, is necessarily condensed to isolated highlights; my apologies in advance to those whose contributions I may unintentionally have slighted.

The earliest documented example I have found for the concept we know today as BIM was a working prototype "Building Description System" published in the now-defunct *AIA Journal* by Charles M. "Chuck" Eastman, then at Carnegie-Mellon University, in 1975. Chuck's work included such now-routine BIM notions as:

> [designing by] ". . . interactively defining elements . . . deriv[ing] sections, plans, isometrics or perspectives from the same description of elements . . . Any change of arrangement would have to be made only once for all future drawings to be updated. All drawings derived from the same arrangement of elements would automatically be consistent . . . any type of quantitative analysis could be coupled directly to the description . . . cost estimating or material quantities could be easily generated . . . providing a single integrated database for visual and quantitative analyses . . . automated building code checking in city hall or the architect's office. Contractors of large projects may find this representation advantageous for scheduling and materials ordering." (Eastman 1975)

Comparable research and development work was conducted throughout the late 1970s and early 1980s in Europe—especially in the UK—in parallel with early efforts at commercialization of this technology (see below). During the early 1980s this method or approach was most commonly described in the USA as "Building Product Models" and in Europe—especially in Finland—as "Product Information Models" (in both phrases, "product" was used to distinguish this approach from "process" models). The next logical step in this nomenclature evolution was to verbally factor out, so to speak, the duplicated "product" term, so that "Building Product Model" + "Product Information Model" would merge into "Building Information Model." Although the German *BauInformatik* may be translated this way, its usual meaning more closely conforms to the general application of information and computer technology (ICT) to construction. However, the Dutch *Gebouwmodel* was occasionally used in the mid-to-late 1980s in contexts that arguably could be translated to English as "Building Information Model" rather than the literal rendition of "Building Model."

The first documented use of the term "Building Modeling" in English—in the sense that "Building Information Modeling" is used today—appeared in the title of a 1986 paper by Robert Aish, then with GMW Computers Ltd., makers of the legendary RUCAPS software system. Aish, who is today with Bentley Systems, set out in this paper all the arguments for what we now know as BIM and the technology to implement it, including: 3D modeling; automatic drawing extraction; intelligent parametric components; relational databases; temporal phasing of construction processes; and so forth (Aish 1986). Aish illustrated these concepts with a case study applying the RUCAPS building modeling system to the phased refurbishment of Terminal 3 at Heathrow Airport, London (there is, in my opinion, a bit of historical irony in the fact that some twenty years later, the construction of Terminal 5 at Heathrow often is cited as one of the "pioneering" case examples of this technology).

From "Building Model" it was but a short leap to "Building Information Model," for which the first documented use in English appeared in a paper by G.A. van Nederveen and F. Tolman in the December 1992 *Automation in Construction*. (van Nederveen & Tolman 1992).

In parallel with the evolving nomenclature and the R&D efforts centered in academia, commercial products implementing the BIM approach (under whatever commercial moniker at the time) also have a long history. Many of the software functions and behaviors ascribed to today's generation of model-authoring tools, such as AllPlan, ArchiCAD, Autodesk Revit, Bentley Building, DigitalProject or VectorWorks, were also the design goals of earlier commercial software efforts such as: the UK lineage from RUCAPS (cited above) to Sonata and Reflex; another UK lineage from Oxsys to BDS and GDS (the latter still available as MicroGDS); a French lineage that included Cheops and Architrion (the spirit of which lives on in BOA); Brics (a Belgian system that provided the technology core for Bentley's Triforma); the US-based Bausch & Lomb modeling system of 1984; Intergraph's efforts with Master Architect; plus many others, now but dimly remembered (at least, within my recollection).

Thus, by the time of my first attempt to popularize the term (Laiserin, 2002) and craft a multi-vendor consensus around it (Laiserin, 2003) the core nomenclature of Building Information Modeling had been coined at least ten years earlier, and the concept or approach had been established more than a further fifteen years before that (with numerous practical demonstrations along the way, most notably in the Finnish efforts that culminated in the Vera Project by Tekes, the National Technology Agency of Finland).

The present book, as might be expected of any work crafted by multiple authors, contains more than one definition of BIM—from process-oriented to product-oriented and from constructor-practical to defining BIM by what it is not. Allow me to add yet two more of my own: one, broader and more analytic than the subject as covered in this Handbook; the other, more simplistic and functional than the Handbook treatment.

Because my broader definition of BIM-as-process is wholly independent of software for implementation, and therefore outside the scope of this book, I offer only the citations here (Laiserin 2005, 2007). However, the arena of "BIM-ready" or "BIM-worthy" commercial software for design and analysis has so expanded and matured in the decade immediately preceding this writing, that I believe it is now both possible and worthwhile to propose instead some quick and practical principles for qualifying BIM applications. For this purpose, I suggest the following: that IFC certification (per the International Alliance for Interoperability, IAI, and/or the buildingSMART initiative) be deemed a sufficient, but not necessary condition of "BIM-ness" for any design, analysis or collaborative software. IFC certification may be supplemented as needed by local requirements, such as support for the GSA Space Object or conformity with the National BIM Standard in the

USA, or the IFC Code Checking View in Singapore. My point is that while there may be numerous paths to BIM-ness, many of which need not lead through IFC certification, surely it is the case that any design or analysis application that is IFC-certified has thereby attained the requisite BIM-ness to be deemed BIM-ready, BIM-worthy, or indeed just plain BIM.

Notwithstanding the semantic distinctions among various BIM definitions, some people labor under the impression that I—or one or another of the design-software vendors—"coined" the term and/or "originated" or "developed" or "introduced" the concept or approach circa 2002. I have never claimed such distinction for myself, and it is my opinion that the historical record outlined above shows that Building Information Modeling was not an innovation attributable solely to any individual or entity.

Rather than "father of BIM"—as a few well-meaning but over-enthusiastic peers have labeled me—I prefer the unattributed epithet "godfather of BIM," in the sense that a godfather is an adult sponsor of a child not his own. If anyone deserves the title "father of BIM," surely it is Chuck Eastman. From his 1975 pioneering prototype system cited above to his 1999 text, *Building Product Models* (Eastman, 1999—the most authoritative treatment of the subject prior to the present volume), Chuck devoted a quarter century to defining the problems and advancing the solutions, plus a further decade continuing to push forward the frontiers of Building, Information, and Modeling.

In 2005, I had the honor and privilege of co-producing and co-hosting with Chuck (and the PhD program at the College of Architecture, Georgia Institute of Technology) the first industry-academic Conference on BIM (Laiserin, 2005). This venue featured a broad cross-section of design-software and analysis vendors, as well as leading practitioners such as Vladimir Bazjanac of Lawrence Berkeley National Laboratories and Godfried Augenbroe of Georgia Tech. To complement our own opening keynotes, Chuck and I were fortunate to engage for the conference's closing keynote Paul Teicholz, now emeritus at Stanford and the founder of Stanford's Center for Integrated Facility Engineering (CIFE—which has become the leading proponent of Virtual Design and Construction, an approach I see as the ultimate state or end-game of BIM automation). Post-conference correspondence among Paul, Chuck and myself provided the impetus for this Handbook.

In the course of producing the Handbook, Chuck and Paul engaged an additional two formidable collaborators, Rafael Sacks and Kathleen Liston. Rafael's doctoral work at Israel's Technion addressed Computer Integrated Construction and Project Data Models, areas in which he subsequently collaborated with Chuck Eastman (especially regarding structural engineering of steel and precast concrete systems). While pursuing her doctorate at Stanford/CIFE, Kathleen co-authored seminal papers on construction schedule simulation or 4D-CAD, and went on to commercialize that BIM-related technology in the successful software startup company, Common Point, Inc.

All of which brings us back to the present work. It would be difficult to imagine a more accomplished quartet of authors in this field, or any team better suited to undertake a task such as The BIM Handbook. What they have accomplished will stand as the most definitive and authoritative treatment of the subject for many years to come. I now place the reader in the capable hands of my friends and colleagues—Chuck, Paul, Rafael and Kathleen—and their chef d'ouvre—The BIM Handbook.

JERRY LAISERIN
WOODBURY, NEW YORK
NOVEMBER 2007

ACKNOWLEDGMENTS

I wish to thank the following individuals for their generous assistance in documenting the early history of the BIM concept and terminology: Bo-Christer Björk, Hanken University, Finland; Arto Kiviniemi, VTT, Finland; Heikki Kulusjarvi, Solibri, Inc., Finland; Ghang Lee, Yonsei University, Korea; Robert Lipman, National Institute of Standards and Technology, USA; Hannu Penttila, Mittaviiva Öy, Finland.

REFERENCES

Aish, R., 1986, "Building Modelling: The Key to Integrated Construction CAD," CIB 5th International Symposium on the Use of Computers for Environmental Engineering Related to Buildings, 7–9 July.

Eastman, C., 1975, "The Use of Computers Instead of Drawings," *AIA Journal,* March, Volume 63, Number 3, pp 46–50.

Eastman, C., 1999, *Building Product Models: Computer Environments, Supporting Design and Construction,* CRC

Laiserin, J, 2002, "Comparing Pommes and Naranjas," *The LaiserinLetter*™, December 16, Issue 16, http://www.laiserin.com/features/issue15/feature01.php

Laiserin, J, 2003, "The BIM Page," *The LaiserinLetter*™, http://www.laiserin.com/features/bim/index.php

Laiserin, J, 2005, "Conference on Building Information Modeling: Opportunities, Challenges, Processes, Deployment," April 19–20, http://www.laiserin.com/laiserinlive/index.php

Laiserin, J., 2007, "To BIMfinity and Beyond!" *Cadalyst,* November, Volume 24, Number 11, pp 46–48.

van Nederveen, G.A. & Tolman, F., 1992, "Modelling Multiple Views on Buildings," *Automation in Construction,* December, Volume 1, Number 3, pp 215–224.