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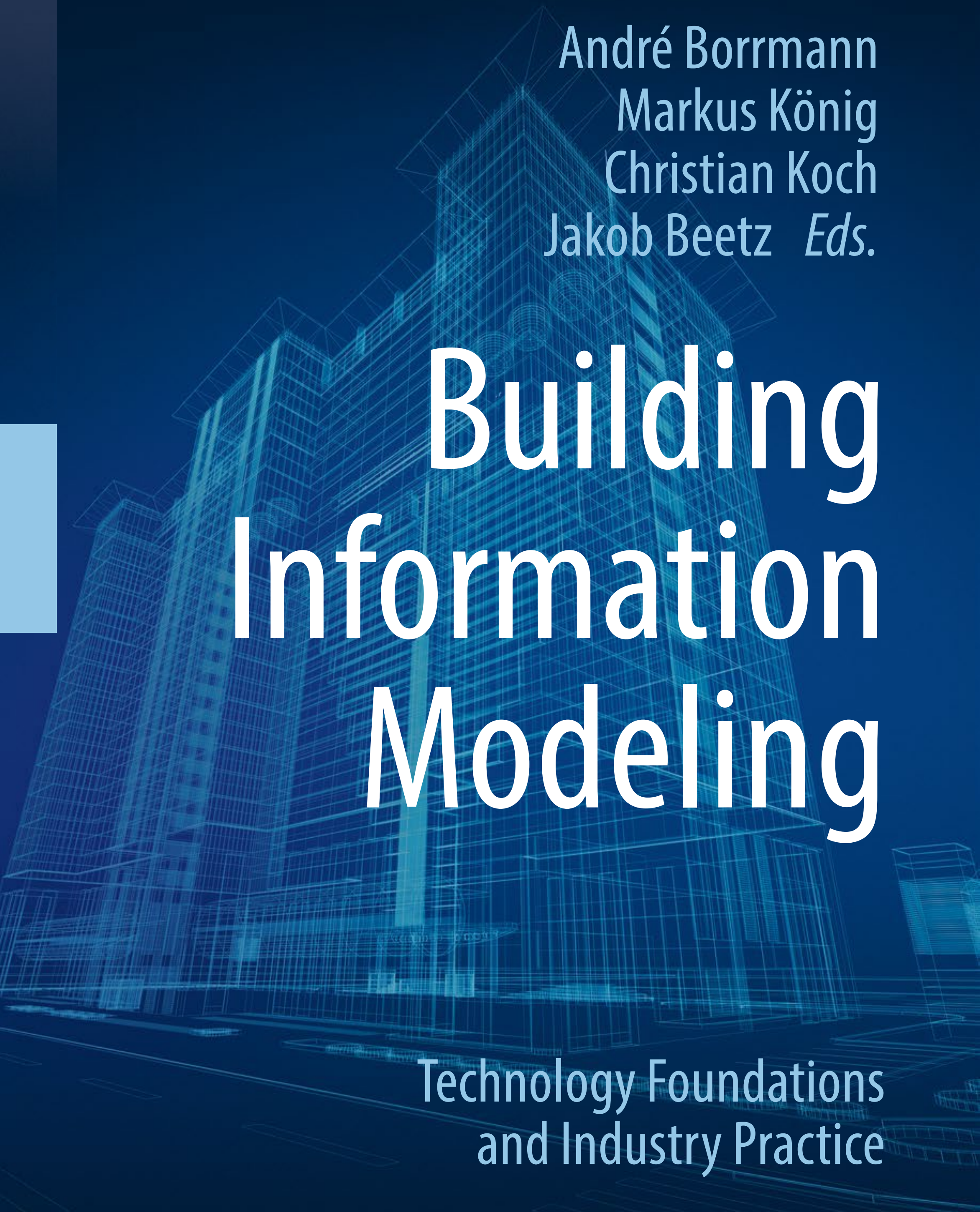
Building Information Modeling

Technology Foundations and Industry Practice



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Preface

Building Information Modeling (BIM) represents the consistent and continuous use of digital information across the entire lifecycle of a built facility, including its design, construction and operation. This idea was originally proposed by researchers in the 1980s, but has only reached technical maturity in recent years and is now being successively adopted by the industry across the globe. The implementation of BIM technology profoundly changes the way architects and engineers work and drives the digital evolution of the AEC industry.

BIM is based on the consistent use and re-use of digital data and helps to raise productivity while lowering error rates as mistakes can be detected and resolved before they become serious problems. Important benefits lie in the direct use of the models for different analysis and simulation tools and the seamless handover of data for the operation phase. Today, powerful and sophisticated software products are available that provide the technical foundation for realizing BIM-based construction projects. The real challenge, however, lies in creating the right models and applying the right tools in the most beneficial way, as well as in developing and establishing the corresponding workflows and processes. In addition, BIM adoption requires changes in legal practices and remuneration. These are currently the main hurdles that hinder its broader uptake.

If we look at the degree of BIM adoption in practice, we can see that in the USA, BIM was already introduced in the mid-2000s and since then has been consistently intensified. Accordingly, large parts of the American AEC industry already use BIM methods in daily practice. In Asia, Singapore and South Korea are among the most advanced countries worldwide with a long history in establishing BIM working methods and corresponding governmental BIM roadmaps and BIM guidelines. Europe's forerunners are the Scandinavian countries: Finland began conducting a number of BIM pilot projects as early as 2001. Based on the success of these projects, the Finnish Senate decided in 2007 to make BIM mandatory for all its projects. BIM is accordingly widespread in the Finnish industry today. Norway and Sweden have taken similar steps and have reached a correspondingly high degree of BIM adoption. Another very influential development is the UK BIM initiative started by the British government in 2011, which has resulted in BIM becoming mandatory for all centrally procured Government projects from 2016 onward. The degree of BIM penetration reached in all the above countries shows the success of the top-down impulses given by the respective governments and the public authorities.

In many other European countries, the introduction of BIM methods is advancing. The Netherlands, Germany, France, and Spain, among others, have established governmental BIM roadmaps. These go hand in hand with activities by the European Union including an update of the Public Procurement Directive which now allows public clients to stipulate digital working practices. Another important EU initiative is the EU BIM Task Force which aims to establish a common European network for aligning the use of Building Information Modeling in public construction works. At the same time, efforts to establish BIM standards have been significantly intensified at international, European and national levels.

In short, the shift towards model-based working practices has gained huge momentum around the world in recent years and the AEC industry across the globe is undergoing a fundamental transition from conventional paper-based workflows to digitized ones. Directing and implementing this transition requires sound knowledge of both the capabilities of BIM as well as its limitations.

It is the editors' strong conviction that in order to properly understand and apply BIM methods to beneficial effect, fundamental knowledge of its key principles is paramount. The book complements the discussion of theoretical foundations with reports from the industry on currently applied best practices. The book is written both for experts in the construction industry as well as students of Architecture and Construction Engineering programs.

The content is organized in six parts:

- Part I discusses the technological basics of BIM and addresses computational methods for the geometric and semantic modeling of buildings as well as methods for process modeling.
- Part II covers the important aspect of the interoperability of BIM software products and describes in detail the standardized data format Industry Foundation Classes. It sheds light on the different classification systems, discusses the data format CityGML for describing 3D city models and COBie for handing over data to clients. It also gives an overview of BIM programming tools and interfaces.
- Part III is dedicated to the philosophy, the organization and the technical implementation of BIM-based collaboration, and discusses the impact on legal issues including construction contracts.
- Part IV covers a wide range of BIM use cases in the different life-cycle phases of a built facility, including the use of BIM for design coordination, structural analysis, energy analysis, code compliance checking, quantity take-off, prefabrication, progress monitoring and operation.
- Part V, a number of design and construction companies report on the current state of BIM adoption by means of practical BIM projects, and discuss the approach taken for the shift towards BIM including the hurdles taken.
- Finally, Part VI summarizes the book's content and provides an outlook on future developments.

We thank all the authors for their valuable contributions. Without them, this book would not have been possible. We would particularly like to thank Simon Vilgertshofer and Martin Slepicka for their extraordinary application in the technical coordination of the book and the careful typesetting of the chapters. We also thank our proofreaders Julian Reisenberger and Robert Kurth for their excellent service.

We wish our readers an insightful journey through the world of BIM.

München, Germany — André Borrmann
Bochum, Germany — Markus König
Weimar, Germany — Christian Koch
Aachen, Germany — Jakob Beetz
May 2018

Contents

Acronyms

ADE	Application Domain Extension
AEC	Architecture Engineering Construction
AIA	American Institute of Architects
AP	Application Protocol
API	Application Programming Interface
BC	British Code
BCF	BIM Collaboration Format
BEP	BIM Execution Plan
BIM	Building Information Modeling
BOM	Bill of Materials
BPMN	Business Process Model and Notation
BREEAM	Building Research Establishment Environmental Assessment Methodology
bS	buildingSMART
bSDD	buildingSMART Data Dictionary
CAD	Computer-Aided Design
CAFM	Computer-Aided Facility Management
CAM	Computer-Aided Manufacturing
CAQM	Computer-Aided Quality Management
CDE	Common Data Environment
CIC	Construction Industry Council
CIM	Computer Integrated Manufacturing
CIS	CIMSteel Integration Standards
COBie	Construction-Operations Building Information Exchange
COINS	Construction Objects and INtegration of Processes and Systems
CSCW	Computer-supported collaborative work
DMS	Document Management System
DXF	Drawing Interchange Format
EBOM	Engineering Bill Of Materials
EIR	Employer’s Information Requirements or Exchange Information Requirements (Chap. 13)

ER	Exchange Requirement
ERP	Enterprise Resource Planning
EU	European Union
FM	Facility Management
gbXML	Green Building XML
GIS	Geographic Information System
GML	Geography Markup Language
GTDS	Global Testing and Documentation Server
GUID	Globally Unique Identifier
HVAC	Heating Ventilation Air Conditioning
IAI	International Alliance for Interoperability
ICAM	Integrated Computer Aided Manufacturing
IDEF	Icam DEFinition for Function Modeling
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
IFD	International Framework for Dictionaries
IGES	Initial Graphics Exchange Specification
INSPIRE	Infrastructure for Spatial Information in the European Community
IPD	Integrated Project Delivery
ISO	International Organization for Standardization
KML	Keyhole Markup Language
LD	Linked Data
LEED	Leadership in Energy and Environmental Design
LoD	Level of Detail
LOD	Level of Development
LOG	Level of Geometry
LOI	Level of Information
LOMD	Level of Model Definition
MBOM	Manufacturing Bill Of Materials
MVD	Model View Definition
NBS	National Building Specification
OOM	Object-Orientated Modeling
OWL	Web Ontology Language
PDM	Product Data Management
PLM	Product Lifecycle Management
PM	Process Management
PPP	Public Private Partnership
PSet	PropertySet
QTO	Quantity Take-Off
RDF	Ressource Description Framework
RFC	Request for Change
RFI	Request for Information
RFID	Radio Frequency Identification
SB	Space Boundary
SDAI	Standard Data Access Interface

SIG	Special Interest Group
SPARQL	Simple Protocol and RDF Query Language
STEP	Standard for the Exchange of Product Model Data
UML	Unified Modeling Language
URL	Uniform Resource Locator
VDC	Virtual Design and Construction
W3C	World Wide Web Consortium
WBS	Work Breakdown Structure
XDR	XML Data Reduced
XML	Extensible Markup Language
XSD	XML Schema Definition

Chapter 1
Building Information Modeling: Why? What? How?

André Borrmann, Markus König, Christian Koch, and Jakob Beetz

Abstract Building Information Modeling is based on the idea of the continuous use of digital building models throughout the entire lifecycle of a built facility, starting from the early conceptual design and detailed design phases, to the construction phase, and the long phase of operation. BIM significantly improves information flow between stakeholders involved at all stages, resulting in an increase in efficiency by reducing the laborious and error-prone manual re-entering of information that dominates conventional paper-based workflows. Thanks to its many advantages, BIM is already practiced in many construction projects throughout the entire world. However, the fragmented nature of the construction industry still impedes its more widespread use. Government initiatives around the world play an important role in increasing BIM adoption: as the largest client of the construction industry in many countries, the state has the power to significantly change its work practices. This chapter discusses the motivation for applying BIM, offers a detailed definition of BIM along with an overview of typical use cases, describes the common BIM maturity grades and reports on BIM adoption levels in various countries around the globe.

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1.1 Building Information Modeling: Why?

In the last decade, digitalization has transformed a wide range of industrial sectors, resulting in a tremendous increase in productivity, product quality and product variety. In the Architecture, Engineering, Construction (AEC) industry, digital tools are increasingly adopted for designing, constructing and operating buildings and infrastructure assets. However, the continuous use of digital information along the entire process chain falls significantly behind other industry domains. All too often, valuable information is lost because information is still predominantly handed over in the form of drawings, either as physical printed plots on paper or in a digital but limited format. Such disruptions in the information flow occur across the entire lifecycle of a built facility: in its design, construction and operation phases as well as in the very important handovers between these phases.

The planning and realization of built facilities is a complex undertaking involving a wide range of stakeholders from different fields of expertise. For a successful construction project, a continuous reconciliation and intense exchange of information among these stakeholders is necessary. Currently, this typically involves the handover of technical drawings of the construction project in graphical manner in the form of horizontal and vertical sections, views and detail drawings. The software used to create these drawings imitate the centuries-old way of working using a drawing board.

However, line drawings cannot be comprehensively understood by computers. The information they contain can only be partially interpreted and processed by computational methods. Basing the information flow on drawings alone therefore fails to harness the great potential of information technology for supporting project management and building operation. A key problem is that the consistency of the diverse technical drawings can only be checked manually. This is a potentially massive source of errors, particularly if we take into account that the drawings are typically created by experts from different design disciplines and across multiple companies. Design changes are particularly challenging: if they are not continuously tracked and relayed to all related plans, inconsistencies can easily arise and often remain undiscovered until the actual construction – where they then incur significant extra costs for ad-hoc solutions on site. In conventional practice, design changes are marked only by means of revision clouds in the drawings, which can be hard to detect and ambiguous.

The limited information depth of technical drawings also has a significant drawback in that information on the building design cannot be directly used by downstream applications for any kind of analysis, calculation and simulation, but must be re-entered manually which again requires unnecessary additional work and is a further source of errors. The same holds true for the information handover to the building owner after the construction is finished. He must invest considerable effort into extracting the required information for operating the building from the drawings and documents and enter it into a facility management system. At each of

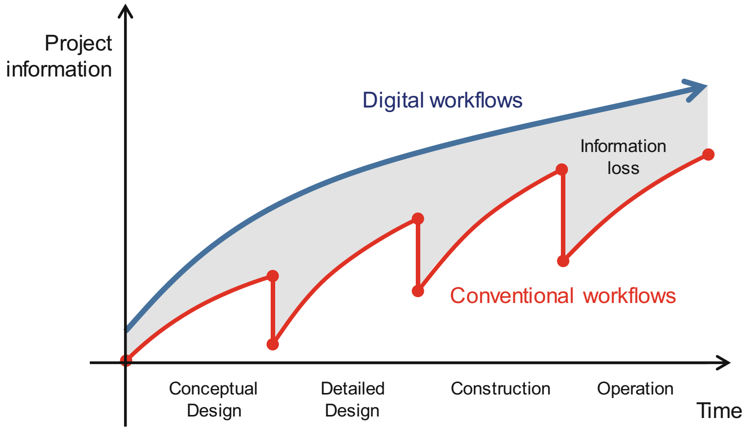

Fig. 1.1 Loss of information caused by disruptions in the digital information flow. (Based on Eastman et al. 2008)

these information exchange points, data that was once available in digital form is lost and has to be laboriously re-created (Fig. 1.1).

This is where Building Information Modeling comes into play. By applying the BIM method, a much more profound use of computer technology in the design, engineering, construction and operation of built facilities is realized. Instead of recording information in drawings, BIM stores, maintains and exchanges information using comprehensive digital representations: the building information models. This approach dramatically improves the coordination of the design activities, the integration of simulations, the setup and control of the construction process, as well as the handover of building information to the operator. By reducing the manual re-entering of data to a minimum and enabling the consequent re-use of digital information, laborious and error-prone work is avoided, which in turn results in an increase in productivity and quality in construction projects.

Other industry sectors, such as the automotive industry, have already undergone the transition to digitized, model-based product development and manufacturing which allowed them to achieve significant efficiency gains (Kagermann 2015). The Architecture Engineering and Construction (AEC) industry, however, has its own particularly challenging boundary conditions: first and foremost, the process and value creation chain is not controlled by one company, but is dispersed across a large number of enterprises including architectural offices, engineering consultancies, and construction firms. These typically cooperate only for the duration of an individual construction project and not for a longer period of time. Consequently, there are a large number of interfaces in the ad-hoc network of companies where digital information has to be handed over. As these information flows must be supervised and controlled by a central instance, the onus is on the building owner to specify and enforce the use of Building Information Modeling.

1.2 Building Information Modeling: What?

A Building Information Model is a comprehensive digital representation of a built facility with great information depth. It typically includes the three-dimensional geometry of the building components at a defined level of detail. In addition, it also comprises non-physical objects, such as spaces and zones, a hierarchical project structure, or schedules. Objects are typically associated with a well-defined set of semantic information, such as the component type, materials, technical properties, or costs, as well as the relationships between the components and other physical or logical entities (Fig. 1.2). The term Building Information Modeling (BIM) consequently describes both the process of creating such digital building models as well as the process of maintaining, using and exchanging them throughout the entire lifetime of the built facility (Fig. 1.3).

The US National Building Information Modeling Standard defines BIM as follows (NIBS 2012):

> Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder.

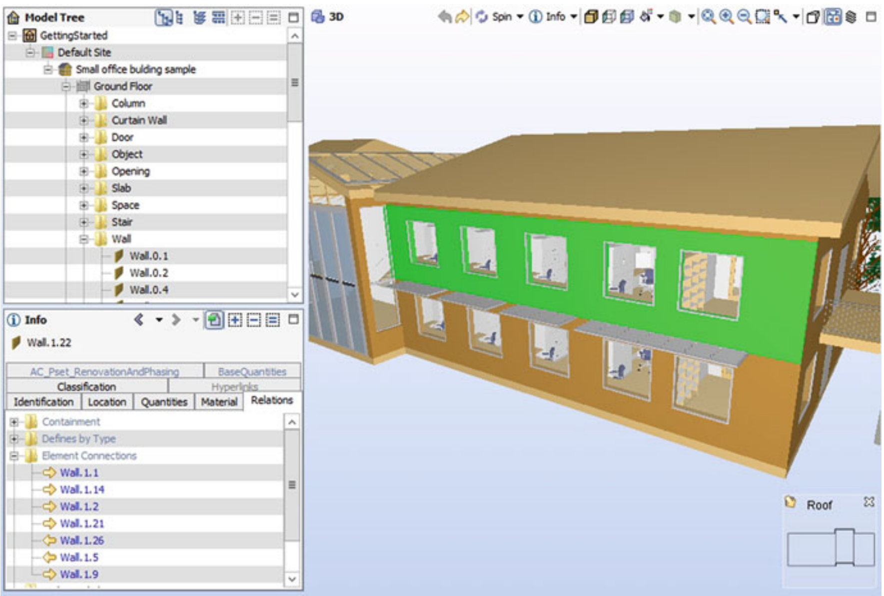

Fig. 1.2 A BIM model comprises both the 3D geometry of each building element as well as a rich set of semantic information provided by attributes and relationships

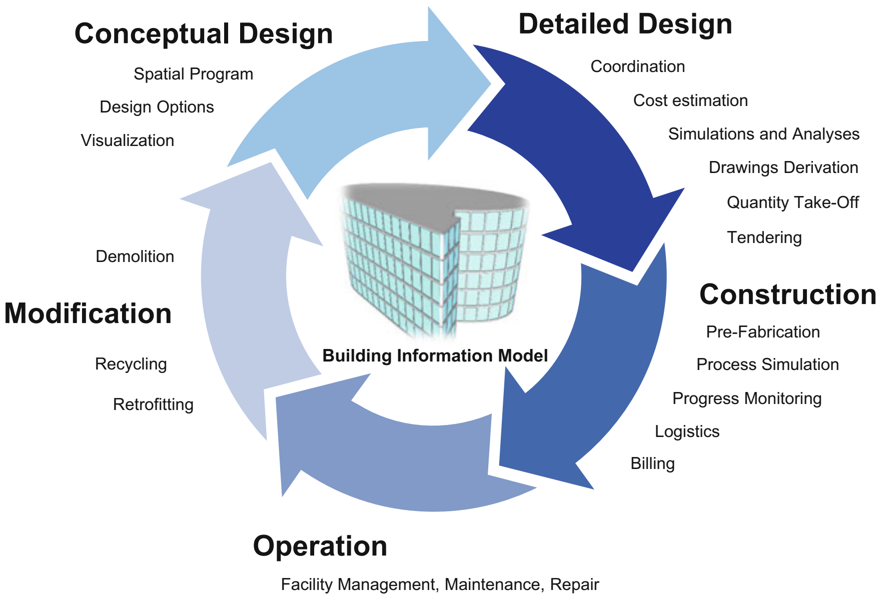

Fig. 1.3 The concept of Building Information Modeling relies on the continuous use and low-loss handover of digital information across the entire lifecycle of a built facility. (© A. Borrmann, reprinted with permission)

The BIM concept is not new. Indeed, research papers about the creation and employment of virtual building models were first published in the 1970s (Eastman et al. 1974). The term Building Information Modeling was used for the first time in 1992 by the researchers van Nederveen and Tolman (1992). However, the widespread dissemination of the term was initiated by the software company Autodesk which used it the first time in a White Paper published in 2003 (Autodesk 2003). In recent years, a large range of software products with powerful BIM functionalities have been published by many different vendors, and the concept which originated in academic research has now become established industry practice.

The most obvious feature of a Building Information Model is the three-dimensional geometry of the facility under design or construction, which provides the basis for performing clash detection and for deriving consistent horizontal and vertical sections (Fig. 1.2). It is important to note, however, that 3D geometry on its own is not sufficient to provide a really capable digital representation. One of the major characteristics of a Building Information Model is its capability to convey semantics. This means that all its objects possess a meaning, i.e. they are instances of object types such as a Wall, Column, Window, Door and so on. These objects combine a parametrized 3D geometry representation with additional descriptive properties and their relationships to other elements in the model. Working with objects is a prerequisite for using the model for any kind of analysis, including quantity take-off, structural analysis or building performance simulations. In addition, object-based modeling is also required for deriving drawings that are compliant with norms and regulations for technical drawings which often employ abstract or symbolized representations which cannot be produced from the 3D geometry alone.

There is no universally applicable definition of what information a Building Information Model must provide. Instead, the concrete information content depends heavily on the purpose of the model, i.e. the use cases it is created to support (Kreider et al. 2010). Indeed, the intended BIM use cases provide a very important point of departure for the BIM project execution and must be defined at the beginning of the project. Table 1.1 lists some of the most common uses cases (the list is by no means exhaustive). For example, PennState has developed a comprehensive use case scheme which comprises 32 detailed uses cases across the four phases Plan, Design, Construct and Operate (PennState 2013).

In typical BIM projects, multiple BIM models are used across the project phases, each of which tailored to the specific phase and use cases to be implemented. Figure 1.4 shows a typical example of the BIM information flow.

The following sections give an overview on the typical BIM applications in the different phases of a construction project. Part IV of this book is entirely dedicated to BIM use cases: each of its chapters addresses a different use case in great detail.

1.2.1 BIM in the Design Development Phase

BIM provides a large number of advantages for the design and engineering process. Compared to conventional 2D processes, one of the most significant advantages of using BIM is that most of the technical drawings, such as horizontal and vertical sections, are derived directly from the model and are thus automatically consistent with each other. Clash detection between the different partial models makes it possible to identify and resolve conflicts between the design disciplines at an early stage. BIM also facilitates the integration of computations and simulations in a seamless way, as a lot of input information about the building's geometry and material parameters can be taken directly from the model. A wide range of simulations, including structural analysis, building performance simulation, evacuation simulation, or lightning analysis, are then usable in the design process. In addition, the model can be checked for compliance with codes and regulations; currently mostly semi-automated, but in future with a higher degree of automation. Finally, the model data can be used to compute a very precise quantity take-off, providing the basis for reliable cost estimations and improving accuracy in the tendering and bidding process.

Applying BIM in the planning process results in shifting the design effort to earlier phases, as illustrated in Fig. 1.5. In conventional planning processes, the main design and engineering effort occurs in the later detailed design phases, sometimes even during the actual construction phase. As a result, the detailed coordination of

Table 1.1 A selection of the most widespread BIM use cases

Use case	Description
Technical visualization	Visualization of the 3D model as basis for project meetings and for public relations
Coordination of the specialist disciplines	Merging of discipline models into a coordination model at regular intervals, collision detection and systematic conflict resolution
Derivation of technical drawings	Derivation of the major parts of the design and construction drawings
BIM-based simulations and analyses	Use of the BIM model as input for various simulation and analysis tools, including structural analysis, energy performance simulation, daylight analysis, computational fluid dynamics, etc.
Cost estimation	BIM-based quantity take-off as basis for cost estimation
Tendering	BIM-based quantity take-off for creating the Bill of Quantities required for tendering construction works
Construction process modeling (4D modeling)	Linkage of individual components of the BIM model with the corresponding processes of the construction schedule
Simulation of the cost progress (5D modeling)	Linkage of the 4D model with costs for fabricating and/or purchasing the corresponding building components
Progress monitoring	Creation and update of a 4D model for reflecting and monitoring the construction progress
Billing and controlling	Billing and controlling based on the progress monitoring BIM model
Issue and defects management	Use of the BIM model for documenting construction defects and tracking their removal
Building operation and maintenance	Handover of BIM data to the client and subsequent take-over into facility management systems for operation and management

design disciplines, the integration of analysis and simulation tools and consequently a comprehensive assessment of the building design only occurs at a relatively late point in the overall process. At this point, however, the possibilities for design changes are more limited and also more costly to implement.