In: Borrmann, A.; König, M.; Koch, C.; Beetz, J. (Eds): Building Information Modeling - Technology Foundations
and Industry Practice, Springer, 2018, DOI: 10.1007/978-3-319-92862-3

# Chapter 1

# Building Information Modeling – Why? What? How?

André Borrmann, Markus König, Christian Koch, 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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André Borrmann
Technical University of Munich, Chair of Computational Modeling and Simulation, Arcisstr. 21, 80333 Munich, Germany
e-mail: andre.borrmann@tum.de

Markus König
Ruhr University Bochum, Chair of Computing in Engineering, Universitätsstraße 150, 44780 Bochum, Germany
e-mail: koenig@inf.bi.rub.de

Christian Koch
Bauhaus University Weimar, Chair of Intelligent Technical Design, Marienstr. 13a, 99423 Weimar, Germany
e-mail: c.koch@uni-weimar.de

Jakob Beetz
CAAD – Design Computation, RWTH Aachen University, Schinkelstr. 1, 52062 Aachen, Germany
e-mail: j.beetz@caad.arch.rwth-aachen.de

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

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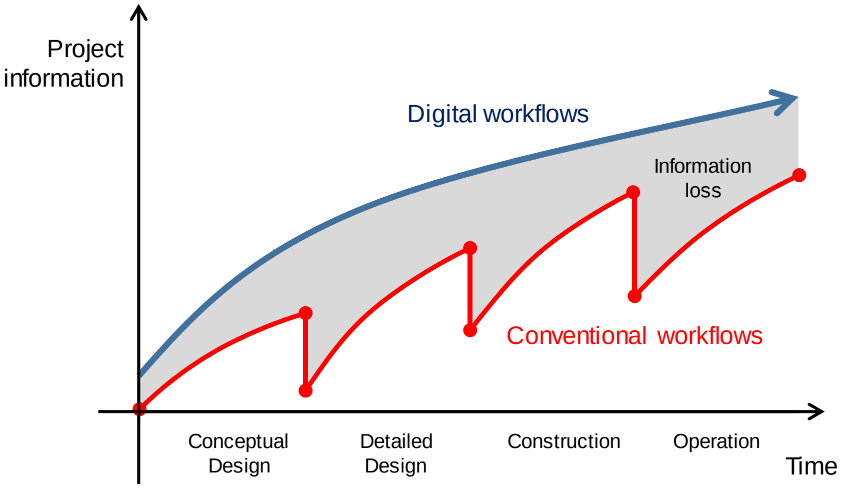

**Fig. 1.1** Loss of information caused by disruptions in the digital information flow (based on Eastman et al., 2008)

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.

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## 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 dif-*

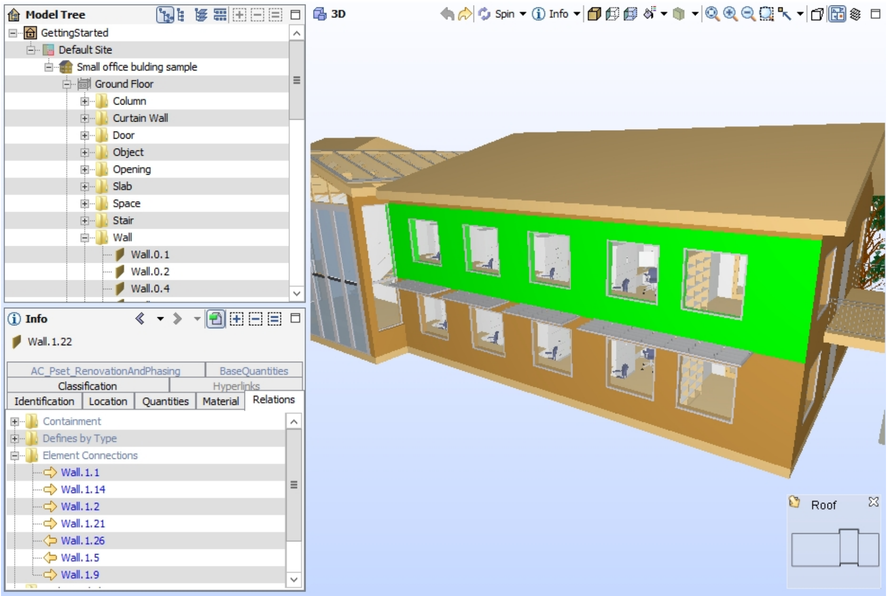

**Fig. 1.2** A BIM model comprises both the 3D geometry of each building element as well as a rich set of semantic information provided by attributes and relationships.

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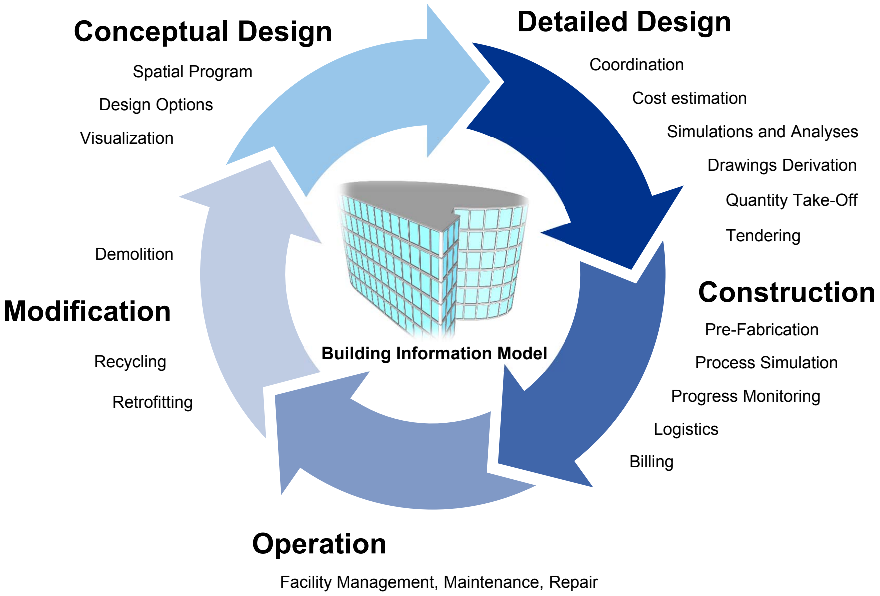

**Fig. 1.3** The concept of Building Information Modeling relies on the continuous use and low-loss handover of digital information across the entire lifecycle of a built facility. © A. Borrmann, reprinted with permission

> *ferent 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.”*

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

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**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 |

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

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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.

### 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 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.

In a BIM-based planning process, by contrast, much of this planning effort can be brought forward to the early design phases by building up a comprehensive digital building model. The ability to plan coordination requirements in detail and to employ computational analyses in the early design phases makes it possible to evaluate the impact of design decisions more comprehensively and to identify and resolve possible conflicts early on, significantly decreasing the effort required at later phases and improving the overall design quality.

### BIM in the construction phase

The application of BIM offers significant advantages not only for the design of a built facility, but also for preparing and executing its actual construction. Providing the digital building model as part of the tendering process makes it possible to deter-

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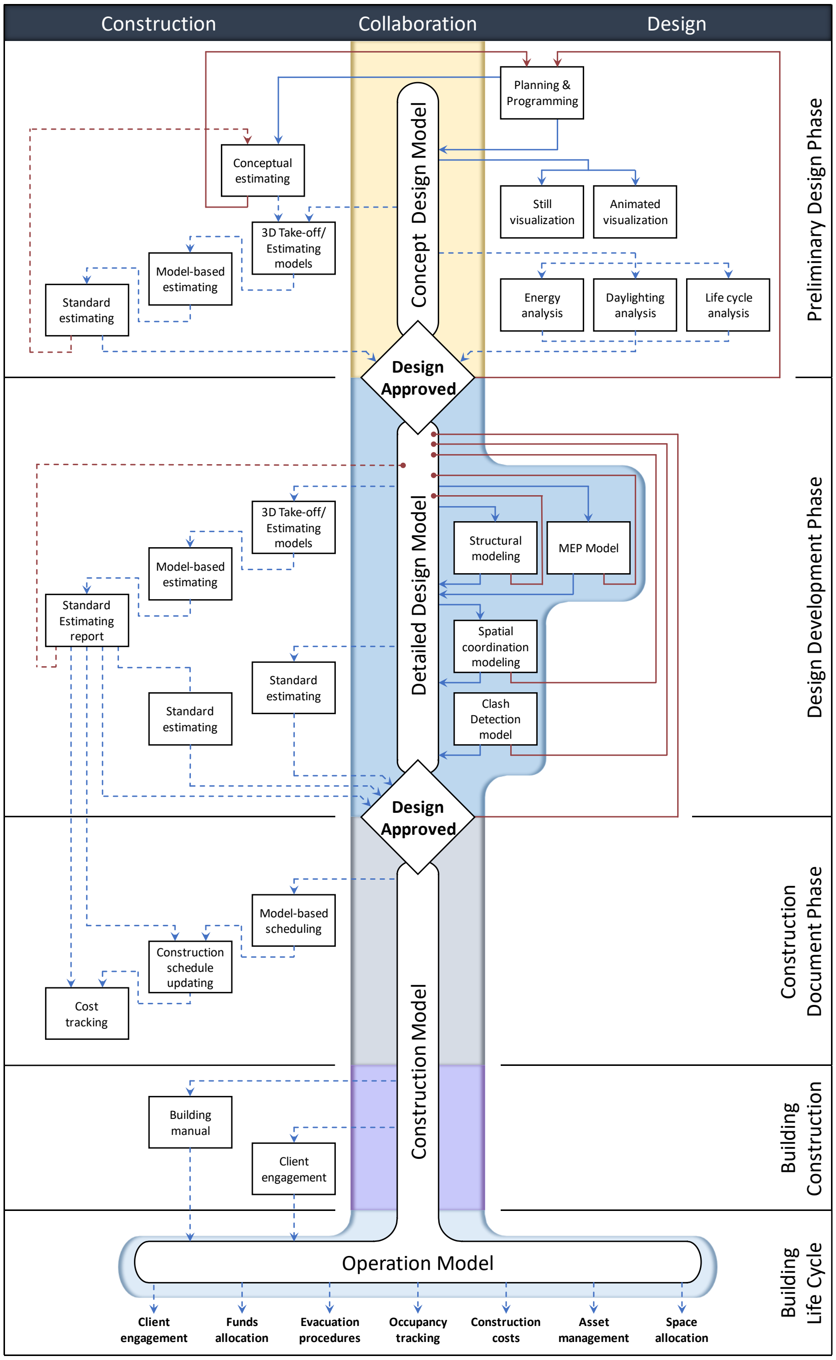

**Fig. 1.4** BIM use cases and their mutual dependencies across the different phases of a construction project (based on Joseph Joseph, 2011)

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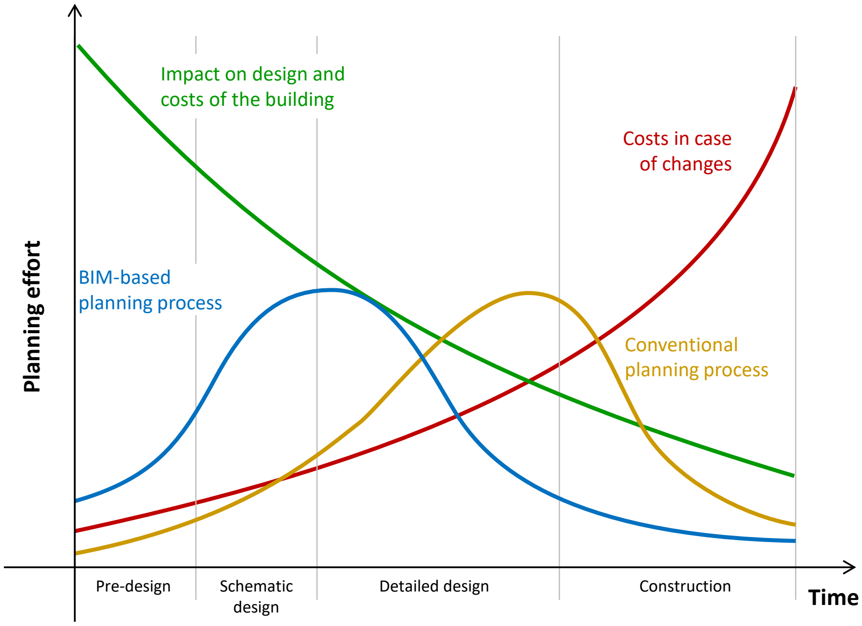

**Fig. 1.5** Building Information Modeling shifts planning effort and design decisions to earlier phases. This makes it possible to influence the design, performance and costs of the resulting facility before design changes start to become costly to implement (based on MacLeamy, 2004)

mine the services required and costs for the contractors when preparing the bid and also facilitates precise billing at a later stage. By means of a 4D Building Information Model, which associates the individual building components with the scheduled construction times, the construction sequence can be validated, spatial collisions can be detected and the site logistics can be organized. A 5D model additionally integrates cost information and can be used to simulate the cost development over time. Finally, the invoicing of construction work, as well as issue management can also be supported using BIM methods.

### BIM in the operation phase

Further advantages of the BIM method result from using the digital building model across the comparatively long operation phase of a built facility. A critical prerequisite is the well-organized handover of BIM information from the design team to the owner, including all relevant information from the construction phase. If the owner receives high-value digital information instead of 'dead' drawings, he can feed them directly into his facility or asset management systems. In the case of buildings, this means that information about room sizes, HVAC, electricity and telecommunication is directly accessible and does not need to be entered manually. For the operation of a building, information about the installed devices including maintenance cycles and warranty conditions are particular valuable. An important aspect is the con-

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stant upkeep of the digital building model; all changes in the real facility must be recorded in its digital twin. When larger renovations or modifications are required at a later date, the building model provides an excellent basis for the necessary design activities. When the built facility reaches the end of its life cycle and is going to be demolished, the digital twin provides detailed information about the materials used in its construction, in order to plan their environmentally-sound recycling or disposal.

**Level of Development**

Building design is a process of continuous development, elaboration and refinement. In conventional planning processes, the drawing scale provides a well-established means for describing the geometric resolution required for a certain project stage which implicitly defines the degree of elaboration, maturity and reliability of the design information to be delivered. As there is no scale in the world of digital models, an analogy had to be found for reflecting the concept of geometric resolution and degree of elaboration.

After the initially used term "Level of Detail" (as used in neighboring domains) was deemed misleading as it puts too much emphasis on the geometric appearance, the term "Level of Development" (LOD) was coined and is now in widespread use. An LOD defines both the required geometric detail (also denoted as Level of Geometry – LOG) as well as the required alphanumeric information (also denoted as Level of Information – LOI). An LOD defines the extent of information provided but also gives an indication of its maturity and reliability. In most cases, an LOD can be associated with a specific design phase.

The US-American BIMForum has defined six standardized LODs (100, 200, 300, 350, 400, 500) and published an extensive catalog depicting the geometric part of the LODs for typical building components (BIMForum, 2017). This document, however, provides only minimal specifications regarding the LOI, as the required alphanumeric information depends heavily on the type of construction project and the respective BIM use cases. A more detailed description of the LOD concept is provided in Chap. 7.

LOD requirements typically form part of the Employer's Information Requirements (EIR) defined by the client at the beginning of the project (see Sect. 1.3.3 and Chap. 14).

## 1.3 Building Information Modeling – How?

### *1.3.1 little bim vs. BIG BIM, Closed BIM vs. Open BIM*

The shift from conventional drawing-based workflows to model-based ones requires significant changes in both internal company workflows as well as cross-company processes. To avoid unduly unsettling the basic functioning of established work-

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flows, a stepwise transition is recommended. Accordingly, different technological levels of BIM implementation are distinguished.

The simplest differentiation is expressed by the terms “BIG BIM” and “little bim” (Jernigan, 2008). Here, little bim describes the application of a specific BIM software by an individual stakeholder to realize a discipline-specific design task. Typically, software is used to create a building model and derive the drawings which are then fed into the conventional process. The building model is not used across different software packages and is not handed over to other stakeholders. This BIM implementation is, therefore, an insular solution within one design discipline, with all external communications taking place using drawings. Although, implementing “little bim” can offer efficiency gains, the big potential of comprehensively using digital building information remains untapped.

By contrast, BIG BIM involves consistently model-based communications between all stakeholders and across the entire lifecycle of a facility (Fig. 1.3). For the data exchange and the coordination of the model-based workflows, digital technologies such as model servers, databases or project platforms are employed in a comprehensive manner.

Alongside the extent of BIM usage is the question of whether software products from just one vendor are employed (“Closed BIM”) or whether open vendor-neutral data formats are utilized to allow data to be exchanged between products by different software vendors (“Open BIM”), see Fig. 1.6. Although some software companies on the market provide a large range of software products required for the design, construction and operation of built facilities, there will always be a need to exchange data with other products that either serve a specific purpose or are used by other stakeholders in the overall process. The variety of software systems in use is usually a product of the many disciplines involved and the distribution of tasks across different companies.

Although achieving high-quality data exchange using neutral formats is a challenge, there is no alternative. In 2004, the US National Institute of Standards and Technology published a study which quantified the costs caused by poor software interoperability in the capital sector at 15.8 billion US$ per year (Gallagher et al., 2004).

To overcome this enormous economic waste and significantly improve data exchange between software products in the AEC industry, the *International Alliance for Interoperability* was founded in 1994 by a number of software vendors, users and public authorities across the world. In 2003, it was renamed *buildingSMART* for marketing reasons. The international non-profit organization succeeded in defining a vendor-independent data format for exchanging comprehensive digital building models. The resulting object-oriented data model named *Industry Foundation Classes (IFC)* provides very rich data structures covering almost all aspects of built facilities. In 2013, the data format was adopted as an ISO standard (ISO, 2013) and it now forms the basis for many national guidelines that stipulate the implementation of Open BIM. Chapter 6 provides detailed information about this format.

Despite much progress in recent years, BIM data exchange using the IFC format still does not work perfectly, i.e. data loss and misinterpretation still occurs from

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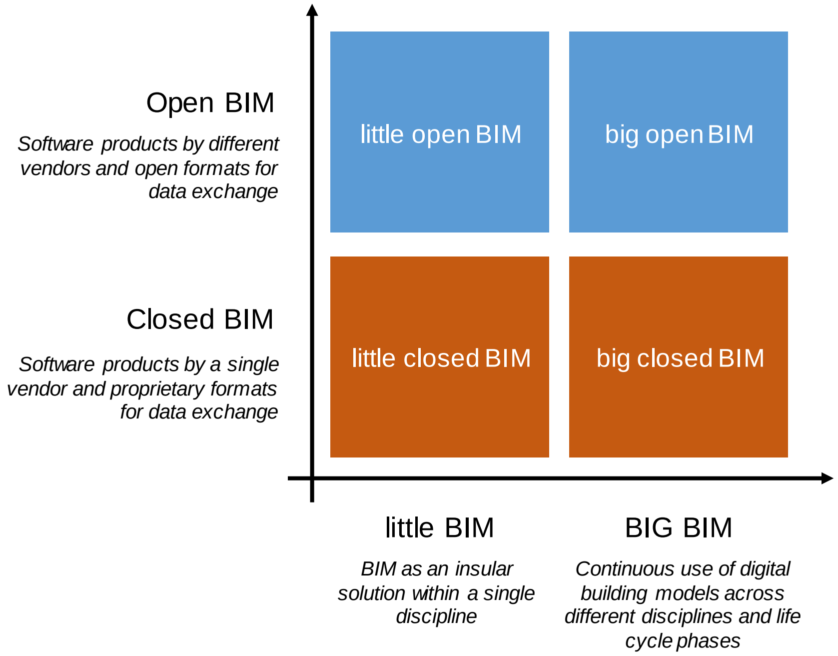

**Fig. 1.6** The terms "little BIM" and "BIG BIM" describe the extent of BIM usage. The terms "Closed BIM" and "Open BIM" distinguish between the exclusive use of software products from a single vendor and the use of open, vendor-neutral data exchange formats (based on Liebich et al., 2011).

time to time. Both the definition of neutral formats as well as their correct implementation is a technically challenging task but there are promising signs that the remaining problems will be solved very soon if the software vendors are serious about pursuing this goal. This depends to a large degree on how much market demand (e.g. from public owners) there is for the implementation of Open BIM. If we consider the negative effects of an overwhelming dominance of a single software vendor, realizing Open BIM is definitely worth the effort.

### *1.3.2 BIM Maturity Levels*

The construction industry cannot realize the big transition to fully-digitized model-based working procedures – i.e. BIG Open BIM – in one go. Instead, a more appropriate approach is to introduce the new technology and the accompanying changes in processes step by step. To illustrate this, the UK BIM Task Group developed the BIM Maturity Model which defines four discrete levels of BIM implementation (Fig. 1.7).

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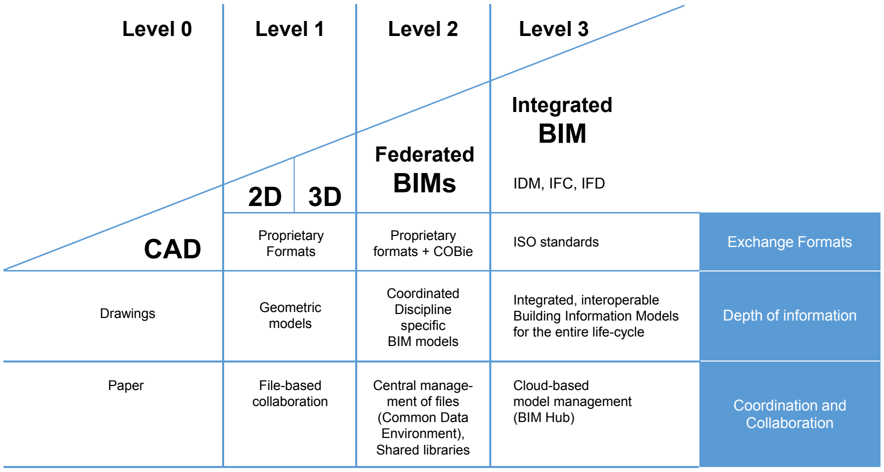

| | Level 0 | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Exchange Formats | CAD | Proprietary Formats | Proprietary formats + COBie | ISO standards |
| Depth of information | Drawings | Geometric models | Coordinated Discipline specific BIM models | Integrated, interoperable Building Information Models for the entire life-cycle |
| Coordination and Collaboration | Paper | File-based collaboration | Central management of files (Common Data Environment), Shared libraries | Cloud-based model management (BIM Hub) |

**Fig. 1.7** The BIM Maturity Ramp of the UK BIM Task Group (Bew and Richards, 2008) defines four discrete levels of BIM maturity. Since April 2016, the British Government is mandating Level 2 for all public construction projects. © A. Borrmann, reprinted with permission

Level 0 describes conventional working practice based on 2D CAD and the exchange of paper-based drawings. Level 1 comprises the partial 3D modeling of the facility (mostly for complex geometries) while most of the design is still realized by means of 2D drawings. Here, data exchange is realized through sending and receiving individual files, and a central project platform is not employed.

Level 2 is defined by the use of BIM software products for authoring digital building models, however, each of the various disciplines involved develops its own model. Their mutual consistency is ensured by periodic coordination sessions, where the individual sub-models are brought together and checked for clashes or other discrepancies. This approach is known as the federated models approach since the sub-models are only loosely coupled (Fig. 1.8). 2D drawings are mostly derived from BIM models. Data exchange is still realized on the basis of files (in native formats), however, all files are managed on a central platform called a Common Data Environment (CDE) (Chap. 16). A CDE records the status of each file which describes the maturity of the contained information as well as the level of access provided for other parties. A CDE also enforces formal procedures for changing the status of a file. A particular role has the COBie standard for handing over data about a building to the client at regular intervals. COBie does not support geometry, but facilitates the transmission of purely alphanumeric information relevant for the operation phase (Chap. 10). For handing over BIM models comprising both 3D geometry and semantics, open standards are not demanded on BIM Level 2. Instead, proprietary formats may be used.

From April 2016, the British Government began mandating Level 2 for all public construction projects (Cabinet Office, 2011). To this end, detailed specifications have been published, most importantly PAS1192-2:2013 “Specification for infor-

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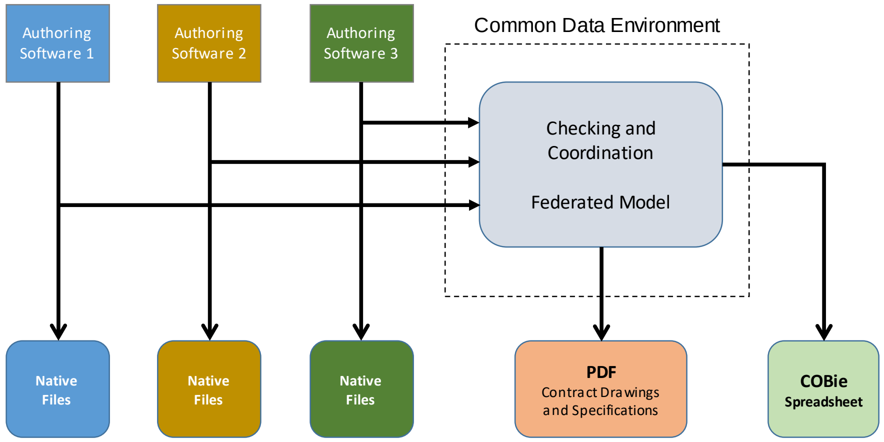

**Fig. 1.8** In BIM Level 2, the workflow uses native files from the individual specialist planners that are regularly integrated into a common data model for verifying and coordinating the different trades. From this model, a contractually agreed set of 2D plans and specifications are derived and saved as PDF files. An important role is played by COBie spreadsheets that contain information on a building and its technical installations in a structured form for transferring to the client. © A. Borrmann, reprinted with permission

mation management for the capital/delivery phase of construction projects using building information modeling" and PAS1192-3:2014 "Specification for information management for the operational phase of assets using building information modeling" as well as the BIM protocol to be used as an appendix of legal contracts and the Digital Plan of Work which defines what information is required at which project stage (PAS 1192-2, 2013).

Level 3, which is targeted for the future, is based on the concept of a fully integrated BIM. It is based on the implementation of BIG Open BIM, i.e. ISO standards are employed for data exchange and process descriptions, and deeply integrated digital models are used throughout the entire lifecycle. Cloud services are used for managing project data so that data is continuously and consistently maintained over the building's life cycle.

### *1.3.3 BIM project execution*

An important prerequisite for the successful realization of BIM projects are legally binding agreements addressing model contents, model qualities and workflows, in particular for the handover of building models to the owner. General contractual specifications are typically provided by a contract appendix that defines the applied terminology as well as global responsibilities. The British Construction Industry

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Council (CIC) has published a template called the BIM protocol that serves this purpose (CIC, 2013).

In this context, the Employer's Information Requirements (EIR) and the BIM Execution Plan (BEP) play a very important role. Both documents are developed specifically for the respective construction project and form part of the contractual agreements. In the EIR, which forms part of the tendering documents, the client declares the objectives of applying BIM in the project and how the digital processes shall be executed.It contains detailed specifications on responsibilities, handover dates and procedures, as well as data exchange formats. The content of the models to be delivered is specified through well-defined LODs for each element type including detailed lists of attributes.

In the Pre-Award BEP, bidders (potential contractors) describe how they plan to meet the requirements of the EIR. The BEP is refined into a more detailed document after the contract is awarded. A number of templates have been published for both the EIR and BEP by different institutions (AEC UK, 2012a,b; Richards et al., 2013; CIC, 2013; PennState, 2011).

General specifications for BIM project execution have been provided by the British PAS 1192-2:2013 as part of the UK BIM mandate. It forms the basis for ISO 19650 which is currently in development. More details about BIM project execution and management are provided in Chap. 14.

### 1.3.4 BIM roles and professions

The introduction of BIM brings with it numerous new tasks and responsibilities for the management and coordination of digital building models. This means not only that there are new roles in the project team, but also new professions. The most important roles are that of the BIM Manager, the BIM Coordinator and the BIM Modeler. Currently, there are no broadly agreed descriptions of these roles.

Most guidelines accord the BIM Manager a strategic role in the company, responsible for guiding the transition towards digital practices and for developing guidelines regarding workflows, model contents and best practices. The BIM Coordinator, by contrast, is a role assigned on a per-project basis, and is responsible for coordinating the specialist disciplines, merging sub-models, checking model contents and applying quality control in order to meet the client's demands. The BIM modeler is an engineer or architect responsible for developing the model.

Figure 1.9 shows the responsibilities of the BIM Manager, the BIM Coordinator and the BIM Modeler, as defined by the UK AEC BIM Protocol (AEC UK, 2012a).

The guidelines of the British Construction Industry Council (CIC), however, define the role of the Information Manager as a person with similar responsibilities to the aforementioned BIM Coordinator (CIC, 2013), but with a slightly higher-level perspective. According to the guidelines, this role is not responsible for coordinating the discipline-specific partial models, but for defining and monitoring data exchange processes as well as performing quality control regarding the model delivery, i.e.

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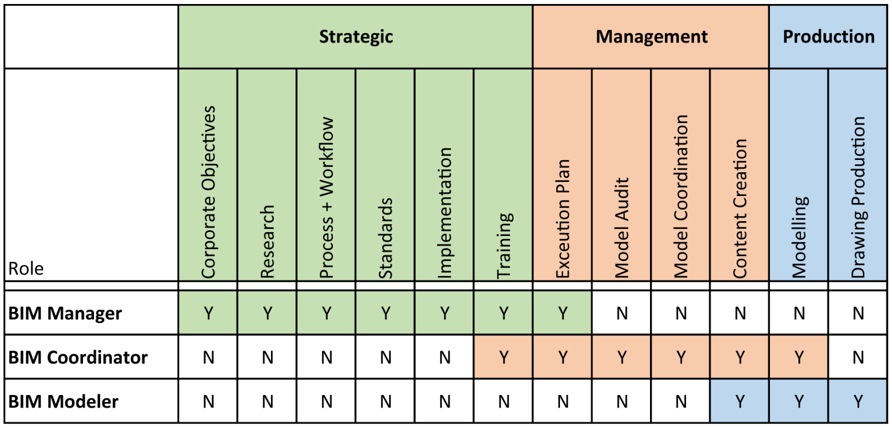

| | Strategic | | | | | | Management | | | | Production | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Role | Corporate Objectives | Research | Process + Workflow | Standards | Implementation | Training | Exceution Plan | Model Audit | Model Coordination | Content Creation | Modelling | Drawing Production |
| **BIM Manager** | Y | Y | Y | Y | Y | Y | Y | N | N | N | N | N |
| **BIM Coordinator** | N | N | N | N | N | Y | Y | Y | Y | Y | Y | N |
| **BIM Modeler** | N | N | N | N | N | N | N | N | N | Y | Y | Y |

**Fig. 1.9** Responsibilities of the BIM Manager, BIM Coordinator and BIM Modeler (based on AEC UK, 2012a)

checking model contents and enforcing their handover in time. The British Building Research Establishment (BRE) accordingly defines the Information Manager as an “organizational representative appointed by the employer or asset owner, who is responsible for establishing governance and assuring data and information flow to and from the common data environment (CDE) during the design, construction, operation and maintenance, and disposal or decommissioning of a built asset.” (BRE, 2017).

## 1.4 State of BIM adoption

The degree of BIM adoption and BIM maturity varies across the world. In some countries, the introduction of the BIM methods is already quite advanced. Singapore, Finland, Korea, the USA, UK and Australia are among the pioneers. In all these countries, the government and its subsidiary authorities play a key role in demanding and fostering the introduction of BIM.

As far back as 2004, Singapore already made it obligatory to submit construction documents for public construction projects via an internet platform (Khemlani, 2005). This included the submission of Building Information Models in the vendor-neutral IFC format. The digital building models are subsequently checked for conformance with codes and guidelines, e.g. regarding fire safety. BIM penetration in the Singaporean construction sector is accordingly very advanced. The BIM guidelines of the Building and Construction Authority (BCA) were already published in a second edition in 2013 (BCA Singapore, 2013).

Since 2007, public authorities in Finland have required the use of digital building models for all public projects with projected costs in excess of 1 million Euros. Since then, comprehensive experience in the execution of BIM projects has been

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gathered which has been anchored in the “Common BIM requirements”, a set of guidelines that were published in 2012. In general, Finnish BIM requirements for data handover to the public client require the use of the vendor-neutral IFC format.

In the US, major governmental building owners, such as the General Service Administration (GSA) and the US Army Corps of Engineers (USACE) have required the use of BIM methods for project execution for many years (GSA, 2007). USACE has published a comprehensive BIM roadmap and provides templates for BIM authoring tools as well as contract requirements on their website (USACE, 2012). Also large private owners are increasingly demanding BIM in their construction projects. The National Institute of Building Sciences (NIBS) has published the National BIM standard (NIBS, 2012) which basically bundles a set of standards defined elsewhere, including the international data exchange standards IFC and COBie, the BIMforum LOD specifications, the US CAD standards, and the PennState BIM use cases, among others. The first version of NBIMS-US came out as far back as 2007, the most recent version 3 was published in 2015.

An important role for the practical implementation of BIM is played by the American Institute of Architects (AIA). For example, it provides a set of templates for contractual agreements in BIM projects. Together with the Associated General Contractors (AGC), AIA supports the BIMForum, the US chapter of BuildingSMART International. As its most important activity, BIMForum publishes a comprehensive Level of Developments specification in a yearly update cycle (BIMForum, 2017). The specification, which was provided for the first time in 2013, has been used as a basis for many BIM projects across the entire world.

Apart from these US-wide efforts, there are a wide range of BIM standards and guidelines at different governmental and administrative levels, e.g. from the state level down to the local level of individual cities. One example is the BIM guidelines of New York City (NYC DDC, 2012).

A particularly remarkable example is the construction strategy of the British government which was initiated in 2011 with the declared objective of reducing costs and lowering the carbon footprint of construction projects through the consequent use of BIM methods and technologies. The UK government also aims to put the British construction industry “at the vanguard of a new digital construction era and position the UK to become the world leaders in BIM”, in order to acquire a significant competitive advantage on the international market. The key aspect of the 2011 UK construction strategy was to demand “fully collaborative 3D-BIM” for all centrally procured construction projects from 2016 onwards, which corresponds to BIM Level 2 as defined in Sect. 1.3.2. At the time of writing, the goal has been mostly met. This is supported by an annual BIM survey which reported a significant increase in the adoption of BIM methods by the UK construction industry over the past few years.

To achieve this, a BIM Task Group was appointed to coordinate the creation of necessary standards and guidelines. One of the most important standards developed is the aforementioned Publicly Available Specification PAS 1192-2 “Specification for information management for the capital/delivery phase of construction projects using building information modeling”. The document describes the general execu-

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tion of BIM projects including the purposes and required contents of both the Employer's Information Requirements (EIR) and the BIM Execution Plan (BEP), and introduces the concept of Data Drops where at defined project stages information is handed over to the client (see Chap. 19). Currently, however, the PAS requires only the handover of alphanumeric information using the vendor-neutral format COBie (see Chap. 10). The use of IFC for implementing full Open BIM, i.e. including 3D building geometry, is not yet obligatory, i.e. proprietary formats can also be applied.

The PAS makes stipulations at a mostly generic level and leaves details such as the model contents and required LOG/LOI to the arrangements of the individual construction project. This includes the Digital Plan of Work (DPoW) that defines the deliverables required at each stage of a construction project including the levels of geometry, data and documentation. To support clients in the definition of the deliverables, an online toolkit has been developed (NBS, 2015). The consistent use of the British classification system Uniclass is an important aspect in this regard (see Chap. 9). Another important component of the UK BIM initiative is the National BIM Library which provides a large number of BIM objects of products from different manufacturers with pre-defined property sets, for direct use in diverse BIM authoring tools (NBS, 2014). Templates for contractual agreements have also been developed by the Construction Industry Council (CIC) as well as the AEC UK Consortium and are provided online free of charge (CIC, 2013; AEC UK, 2012a,b).

Many other European countries have started initiatives for implementing BIM in the public construction sector. Some of them already require the use of BIM, others plan to do so very soon. Among the most advanced countries are Finland, Sweden (BIM Alliance, 2015), Norway (Staatsbyg, 2013) and the Netherlands (Rijksgebouwendients, 2013).

France initiated its "Plan de transition numérique du bâtiment" (PTNB) in 2014 (Delcambre, 2014) with significant investments to support the transition towards digital technologies. The PTNB published a roadmap in 2015 (PTNB, 2015), a BIM guide specifically addressing the needs of the building owners in 2016 (PTNB, 2016), and a standardization strategy in 2017 (PTNB, 2017). Meanwhile, the French chapter of bSI called "MediaConstruct" has published a comprehensive BIM guide describing BIM processes, BIM use cases and BIM contents (Mediaconstruct, 2016). The French region of Burgundy had deployed BIM models for managing building operations across 135 sites consisting majorly of high schools way back in 2004. Today, the regional council works exclusively within a BIM-based process for construction, maintenance and building operations.

In Germany, the Ministry of Transport published a BIM Roadmap in 2015 which defines the mandatory use of BIM methods for all federal infrastructure projects from 2020 onwards (BMVI, 2015). In this context, significant standardization work is being carried out (VDI, 2014), guidelines and templates for EIR and BEP are being developed, and a number of BIM pilot projects are being conducted. The German approach is remarkable in that BIM is first becoming mandatory for the infrastructure sector before being adopted for public house building. The Deutsche Bahn, as one of the largest infrastructure construction clients, plays a particularly important role and has published detailed BIM guidelines (Deutsche Bahn, 2017)

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and achieved a significant level of BIM adoption in its projects. The European railway companies are currently establishing alliances for collaborating in the field of BIM for railways.

In Spain, a steering committee was established in 2015 and a provisional timetable has been set, with recommended use of BIM in public sector projects by March 2018, mandatory use in public construction projects by December 2018 and mandatory use in infrastructure projects by July 2019.

In the European Union, an important prerequisite for the introduction of national BIM mandates is their compliance with EU legislation. In this regard, the EU Public Procurement Directive was updated in 2014 to allow public clients to stipulate digital working practices (European Parliament, 2014): "For public works contracts and design contests, Member States may require the use of specific electronic tools, such as building information, electronic modeling tools or similar". At the same time, European standardization work has begun and Technical Committee 442 "Building Information Modeling" has been established in the Centre Européen de Normalisation (CEN). As one of its first steps, the committee adopted the international standards ISO 16739 (Industry Foundation Classes) and ISO 29481 (Information Delivery Manual) as European standards. All CEN standards must be implemented by the EU member states as national standards. Another important initiative on the EU level is the EU BIM Task Force which aims to establish a common European network for aligning the use of Building Information Modeling in public works. One of the first outcomes of the task force is the publishing of the "BIM Handbook for Owners" in 2017 (EU BIM Task Force, 2017).

In Asia, besides Singapore, South Korea and China are the most advanced countries with respect to BIM adoption. Korea has a long tradition of using BIM and already published its first BIM roadmap in 2010. The first BIM guidelines were published in 2011 and have been frequently updated since then. They included details on how BIM models should be developed incrementally throughout the design and construction phases and define the minimum requirements for various use cases, such as design review, 3D coordination, and cost estimation. Since 2016, the Korean government is mandating BIM for all public construction projects over 50 billion Won. Currently, they are focusing on including the infrastructure sector in the BIM mandate.

China started to develop BIM guidelines and standards in 2001 (Liu et al., 2017). In 2011, the Ministry of Housing and Urban-Rural Development (MOHURD) released the "Outline of Development of Construction Industry Informatization (2011-2015)", which emphasized BIM as a core technology to support and improve the construction industry. In 2016, MOHURD issued an updated version of their "Outline of Development of Construction Industry Informatization (2016-2020)" that proposes enhancing the integrative applications of information technologies like BIM, big data, etc. However, according to Liu et al. (2017) and Jin (2015), the main barriers to the successful adoption of BIM in China are cultural resistance; the low cost of manpower; the lack of domestic BIM data exchange standards, evaluation criteria and BIM project implementation standards; along with the lack of qualified BIM professionals.

In: Borrmann, A.; König, M.; Koch, C.; Beetz, J. (Eds): Building Information Modeling - Technology Foundations
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The BIM implementation strategy of Australia is mainly influenced and driven by the pioneering UK efforts. In 2012, “The National Building Information Modeling Initiative (NBI)” report was published as a strategy for the “the focused adoption of BIM and related digital technologies and process for the Australian built environment sector” (Australian Parliament, 2016). With regard to BIM in infrastructure, in 2016, the Standing Committee on Infrastructure, Transport and City of the Commonwealth of Australia released the “Report on the inquiry into the role of smart ICT in the design and planning of infrastructure” (buildingSMART Australasia, 2012). In this report the committee recommends the Government to “[. . . ] require BIM to LOD500 on all major infrastructure projects exceeding 50 AUS$ million in cost and receiving government funding [. . . ]”.

## 1.5 Summary

Building Information Modeling is an information management method for construction projects based on the consequent use of digital models across the entire lifecycle of a built facility. The models comprise both the 3D geometry of the building components as well as a comprehensive set of semantic information, including function, materials and relationships between the objects. A BIM model provides a high-level digital representation of the real building and forms an optimal basis for computational applications. The actual content of a BIM model depends on the BIM use case and the project phase it is applied in. Typical BIM use cases include visualization, design coordination, drawing generation, quantity take-off, progress monitoring and facility management. The application of BIM methods provides significant benefits when compared with conventional drawing-based processes resulting in more efficient processes, reduced errors in the building design and construction, and improved transparency of the construction process, which ultimately helps to reduce costs and risks with respect to time and budget overruns.

Each BIM use case implies different demands regarding the level of geometric detail and the level of information provided by the model, often subsumed under term Level of Development which has become an important concept when defining BIM requirements. The actual creation of BIM content and its processing for implementing the uses cases is achieved using a variety of different software applications. It is important to note that BIM is an information management method and not a single software product. Accordingly, data exchange between the involved BIM systems is of utmost importance. Here, we can distinguish between the Closed BIM approach, where products by only one vendor or its proprietary interfaces are applied, and the Open BIM approach, which is based on vendor-neutral, standardized data formats such as the Industry Foundation Classes. Both approaches have their own advantages and challenges.

Thanks to the availability of modern software applications, technological barriers for introducing BIM hardly exist. At the same time, however, the use of BIM requires significant changes to working processes and procedures. Due to the strong

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and Industry Practice, Springer, 2018, DOI: 10.1007/978-3-319-92862-3

fragmentation of the construction industry, the impetus for applying BIM must come from the clients who must stipulate and foster the application of BIM methods. The public sector plays a particular role in this regard as, on the one hand, it has sufficient power to change the working practices of the construction sector, and on the other is bound to precise regulations regarding the procurement of design and construction services. The experiences in the countries with the most advanced BIM adoption have shown that a strong political will is required to drive the digitalization of the construction sector.

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# Index