

# Call for a BIM BOK

## CHAPTER SUMMARY

This first chapter aims to provide educators, trainers, employers, and practitioners the background as to why developing building information modeling (BIM) talent is a significant yet unfulfilled undertaking of the journey to implement BIM in the architecture, engineering, construction, and operation (AECO) industry. It discusses several ancillary supporting and related efforts going on in the industry that have a significant impact on the approaches developed and elaborated throughout the book. The expectation is that the industry will continue to evolve and improve, yet the fundamentals presented in this book are foundational and are critical for future advancement. They will continue to be essential to the long-term success of current and future practitioners. This effort is certainly not specific to the United States but applies to a much broader global community of practice that is learning, implementing, and advancing BIM. Practitioners around the world need to share a common understanding not only of their roles but also of the roles of all others involved in the process of delivering the built environment.

### 1.1 THE BIM JOURNEY AHEAD OF US

Historically a building information model used for design has acted primarily as a 3D visualization tool that helps eliminate clashes between design elements such as beams intersecting with ductwork. This activity is possible because a building information model is a mathematical description of a facility or infrastructure asset. In the AECO industry, many stakeholders remain independently focused on BIM uses for project phasing and scheduling. The business processes have been developed in silos over time when individual practitioners focused on their efforts independently of others as much as possible. For example, with the traditional design-bid-build (DBB) project delivery method, contracting for design and contracting for construction are two separate transactions, while the only information passed between the designer and contractor is a set of blueprints and specifications. Although certainly other project procurement and contracting models are in place today, DBB remains the dominant approach, especially in public projects. Even fewer are sharing information across the project life cycle to include facility management (FM) professionals. The consequence of this business paradigm is that BIM has significant yet mostly untapped potential for defining information flows throughout the AECO industry, including the supply chain based on new business process models. To date, individual practitioners independently come to a level of understanding of BIM predicated on their company's level of innovation, experimentation, and risk tolerance.

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Education is the key to creating a shared understanding and expanding the capability of BIM by profoundly changing the workflow and business processes associated with the AECO industry. For example, the retail sales industry has had significant disruption to its business processes from online sales for almost every product – from food to automobiles. This disruption, coupled with the COVID-19 pandemic, quickly transformed how people buy items and how soon people expect them delivered. Even for home renovation projects, when ordering plumbing supplies, they can be delivered the same day at very reasonable prices. The retail sales industry has had to transform quickly or find themselves out of business. Banking is another example. A brick-and-mortar local bank is no longer even needed in many cases unless the customers are depositing cash. To unlock the full potential of BIM, educators must provide emerging practitioners with specific BIM enhanced knowledge, skills, and abilities (KSAs). These KSAs are potentially universal worldwide as virtually every human on the planet seeks cost-effective housing, a place to work, a way to move between locations, receive health care, eat, and play. The KSAs-centric education will not only build a comprehensive foundation for basic BIM job tasks but also allow us to build upon that foundation to achieve even a higher level of collaboration over time. This transfer of expanded knowledge will ensure the AECO workforce can perform more basic tasks and will encourage others to continue to push the industry to higher goals. Hence, this book is needed not only to start the dialogue but also to provide a baseline from which to build in future years. This body of knowledge (BOK) is not the end but only the beginning of a long process to change the facilities and infrastructure industries and more closely link the AECO industry. It will not be a quick process, but if we begin the transformation now society will benefit only that much sooner. This chapter will examine, document, and explain the process proposed to realize that journey.

### 1.1.1 Lack of Standardization

Many aspects of BIM and BIM standards continue to emerge in the United States and the rest of the world. Unfortunately, as an industry, practitioners have not done well at adopting standards even before BIM. As just one example, practitioners cannot agree on the phases of a project. AIA (US), CSI/CSC Omni-Class, International Organization for Standardization (ISO) 12006-2:2015, buildingSMART International (bSI) IDM, HOAI (Germany), and RIBA (UK) all define project phasing differently (Figure 1.1). As time passes, the industry does not seem to blend toward a solution but continues to expand the approaches. While this issue was significant at one point for payments of work in place, the somewhat clear lines between phases have continued to blur. Phasing is but one example of this lack of standardization. While standards for the sake of standards are not helpful, standards for communication and collaboration across the AECO industry are essential, especially as the industry continues to expand the span of practitioners attempting to become interoperable over the entire life cycle of a project.

There are few if any real AECO standards in place and being broadly used at this point. While some are defined at the ISO level and others at the country level, few are commonly used across the AECO industry. The first significant effort to standardize BIM in the United States was the National BIM Standard – United States (NBIMS-US) developed at the National Institute of Building Sciences (NIBS). At the same time it was evolving, the British Standards Institution (BSI) Publicly Available Specification (PAS) 1192 was being developed in the United Kingdom. BSI 1192 has now evolved into ISO 19650 with little US involvement and no visible coordination. This issue is most troubling to multinational design and construction firms now having to deal with many emerging standards in delivering their work. Standardization should have little or no impact on creativity, but the lack of standards does cause additional complexities and slower delivery. It can also add the potential for error. Standards take time to develop and become incorporated into business processes. Very few first- or even second-version standards yield much real standardization because as more people use a standard, it tends to improve with each new update or disappear if no one supports it through a regular review process.

Typically, early versions of standards primarily serve to begin the dialogue between practitioners. Through feedback from practitioners attempting to implement those standards, continuous improvements will yield higher-quality standards over time. Scandinavian countries use another standard called *Cobuilder*.

ISO 22263		ISO 12006-2	HOAI (Germany)	RIBA (UK)	CSI/CSC OmniClass (Canada/USA)	SIA 112 (Switzerland)	Traditional AIA (USA)	AIA IPD (USA)	bSI IDM	bSI UCM - Generic Stages	Simplified bSI Phases
Pre-Life Cycle Stages	Inception	Inception/ Procurement Feasibility	Programming	Strategic Definition	Inception Phase	Strategic Planning	Programming / Pre-design	Conceptualization	Portfolio Requirements Conception of Need	Development	
	Brief	Outline Proposals, Programme Preparation		Preparation & Brief	Conceptualization Phase						
Pre- Construction Stages	Design	Scheme Detail/ Costing	Planning for Preliminary Design	Developed Design	Criteria Definition Phase	Preliminary Studies	Schematic Design	Criteria Design	Outline Conceptual Design	Design	Design
		Detail Design/ Costing	Planning for Conceptual Design	Technical Design	Design Phase						
Construction Stages	Production	Production and Information and Bills of Materials	Planning for Submission and Permission		Coordination Phase	Project Planning			Coordinated Design and procurement		Procure
			Planning for the Execution Documents								
		Tender Action	Prepare Tendering		Construction Phase	Implementation Documents					
		Construction Preparation	Contract Agreement		Construction Phase				Construction Documents		
Post- Construction Stages	Maintenance	Feedback	Construction Supervision - Assembly	Handover & Closeout	Handover Phase	Operations & Maintenance	Construction Bidding	Agent Coordination/ Final Buyout	Construction	Operations & Maintenance	Assemble
			Completion	In Use	Operations Phase						
Dismantling Stages	Demolition		Handover & Documentation		Closure Phase				Disposal	Dismantling	

FIGURE 1.1 Comparison of project phases.

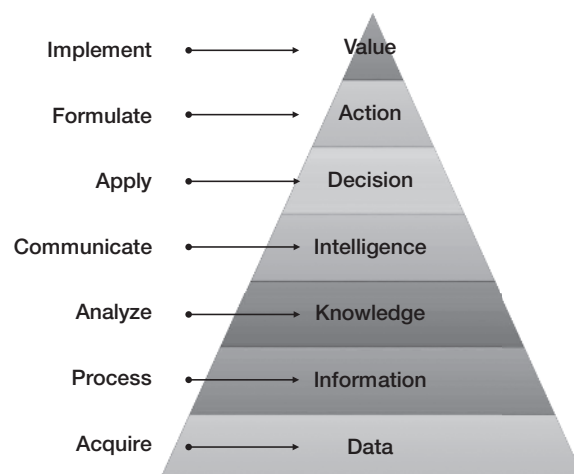
Source: Dana Smith.

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Currently, each of these three standards offers different approaches, including their definitions and organizational structures for BIM, but they all require substantial but similar additional knowledge, skills, and abilities to support practice effectively for the future. In the AECO field, educators are challenged with filling in the gaps between historically good practice in all disciplines, and practitioners are challenged with defining recommended or promoting best practice in the connected or interoperability age practitioners and owners now find themselves. While technology is always changing, BIM seems to be far more disruptive because of its facility or infrastructure life cycle implications. Resolving the deltas between how practitioners did business manually and how practitioners will do business in a connected world creates a significant change in how educators educate since the approach has to fundamentally change to integrate the additional complexity of interoperability and collaboration. The US accreditation and professional licensure bodies, along with their respective counterparts in other countries, should be considered as each may provide constraints to this becoming a reality. This transformation therefore becomes a considerable challenge for educators, students, and practitioners alike, given the limited time students have to accomplish the outcome.

Historically the AECO industry has evolved into silos of thought and expertise. Professionals must now transform into skilled practitioners. They must envision and implement collaboration with other disciplines at multiple levels. Those silos or cylinders of expertise, while vital, need to become more invisible. This transition and transformation will bring a need for an enhanced understanding of information technology as well as knowledge of cybersecurity as the AECO industry begins to collaborate by involving more people between disciplines while building trust in data, information, and experience. Practitioners must be able to share between those silos based on the concepts presented in Figure 1.2 (Frické 2008; Powell 2020). Today the AECO industry is confronted with immense pools of data that can be acquired and digested into information. Then practitioners have to analyze that information to create knowledge and communicate it in such a way as to provide intelligence. BIM is the tool with which practitioners can deliver a facility more effectively and efficiently. Therefore, practitioners have to apply that intelligence to make sensible decisions, which then must be formulated into actions. Without the implementation of those actions, the entire process is of little value.

Additionally, each practitioner must retain control over their intellectual property while allowing others to expand on the information that was created and retaining attribution for the original thoughts and contribution to the project. Many people anticipate that this change will be subject to significant resistance by some current design practitioners who continue to believe the AECO industry is doing just fine using our current pre-Information Age business practices. However, as nearly all information today is available electronically at some point in its life, the AECO industry has to modify and update business processes to take into account the requirement to share, incorporate, and retain the information in a usable and easily sharable format. However, the classroom will not change to support this and other similar needs until the



**FIGURE 1.2** The data, information, knowledge, and wisdom (DIKW) hierarchy.  
*Source: Adapted from Frické (2008) and Powell (2020).*



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use cases introduced by buildingSMART International to yield the 50 BIM use case categories depicted in Figure 1.3. These cover a broad spectrum of practice over the facility life cycle, as we will discuss later in this chapter. As is evident, these are part of a classification of BIM use cases, and additional use cases are being and will continue to be identified over time. The BIM BOK will expand to meet new demands and requirements as they emerge. BIM is all about seamless or interoperable information sharing across all disciplines, from planning to operations and even end-of-life activities related to facilities and infrastructure assets. As new uses are identified, new KSAs will be required but not at the same rate as new use cases emerge.

These 50 use cases are now being identified collectively as BIM use case categories as other specific BIM use cases are being defined. Chuck Eastman developed two of the earliest fully established BIM use cases for precast concrete and architectural pre-cast concrete (Eastman et al. 2010). The two use cases included the information delivery manuals (IDM), which capture the precise information to be exchanged, and detailed process maps, which one would expect in defining a complete BIM use case.

In 2018 and 2019, the bSI award required evidence from submitters as to how people were applying the BIM use cases. This data provided valuable information to practitioners and educators and were being formulated into case studies and implementation guidelines to make them more accessible to practitioners. The bSI award-winning projects and their information are available through the bSI use case management tool (bSI 2019). The materials presented in this tool will be integral to help define the current and future scope of discussion for this book. Having examples of all 50 BIM use cases categories demonstrates just how far BIM has matured, and once case studies are developed others may learn about the reach of BIM today. As new use cases are defined, the need for additional capabilities will create the need to expand the BIM BOK to support that need. However, today practitioners first need to identify the baseline to understand a logical path for future growth.

### 1.1.3 Relationship of Use Cases to KSAs

There are common KSAs that support all these use cases, which are at the heart of the BIM BOK for today and the future. Most of the KSAs will support multiple use case needs, so this one-to-many relationship makes sense to develop and sustain. For example, a BIM execution plan (BXP) relates to business process mapping and information exchange, and those support many if not all use cases. The section about procurement strategies supports only procurement-related use cases.

Some still see BIM as merely a software tool, yet BIM is genuinely a multidimensional interoperability strategy. While 50 use case categories exist today, many more will come as more facets of the AECO industry become aware of the opportunities. For example, there is a significant growth in using BIM for infrastructure projects, and those will need additional use case categories. Working in the current operating environment of data provided by BIM will only serve to expand the complexity and need for broad-thinking practitioners. In the beginning, practitioners started by mapping out optimum business processes to define the needed use cases, as shown in Figure 1.4. This exercise established a method for creating

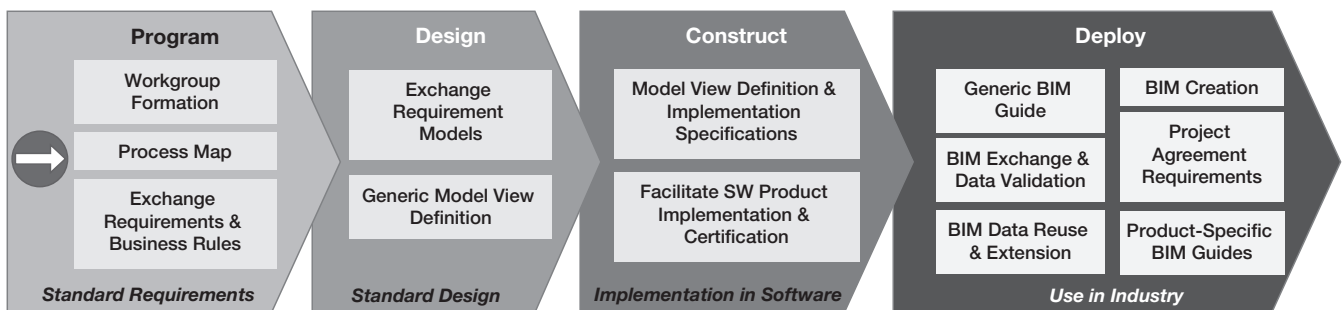


FIGURE 1.4 Process of defining use cases.

Source: Adapted from NIBS (2007).

use cases based on the needs of the practitioner. The precast concrete use case is applicable here, too, as it was identified by the Precast Concrete Institute (PCI) as a needed use case. Originally NIBS had a memorandum of understanding (MOU) in place with some 22 associations with the intent of developing use cases. This strategy was perhaps too advanced in the early days of BIM. The demand was not evident to most organizations to convince them to fund the cost to develop Information Delivery Manuals/Model View Definitions (IDM/MVD) models and turn them into software tools for their practitioner members. Hence, this approach was never fully implemented, although parts of it have proven their validity and are the basis upon which current models are being built. Switzerland, supported by bSI, continues to examine the development of a plan to document use cases using a similar model.

The concept of the model is first to identify a need and form a workgroup to establish the ideal strategy for collecting and sharing information between all parties involved. Eastman, under a grant from the Pankow Foundation and supported by PCI, used this approach for precast concrete with the intent to develop software to assist the business process (Charles Pankow Foundation 2012). While the project was successful, that approach turned out to be far too costly and resource intensive to succeed for all the use cases needed for the entire industry at a time when the value was not yet apparent to those funding the project. The concept remains viable, and as the industry matures and an overall information technology architecture emerges the detailed IDM definitions will be extremely relevant in a future form. As the use cases are developed covering the complete facility life cycle, KSAs will be identified for the use cases, thereby providing continuing enhancements to the value of the BOK. The challenge for education and this book is to keep pace with the profound industry changes occurring and to prepare future practitioners for the new environment of information sharing using BIM while still ensuring that the basics of building design, construction, and facility management are well understood. This book will be the road map as to how the BIM education community transforms from what it has been to what it needs to be.

Historically, information has been gathered anew for each specific aspect of a project and not shared or reused. Recollecting data leads to duplicative data gathering at a minimum and each practitioner working with a different set of facts at worst. Relying on another practitioner's data is now considered a liability since one practitioner is potentially giving up control of the source data for that phase of a project. While the AECO industry is still very early in the transformation process to BIM, it will be through continuing coordinated education with the evolving practice that a new interoperable model will emerge. The truth is that if an organization is allowing the possibility of different information through disconnected data-gathering approaches, it may be opening itself up to even more problems. When project dynamics change more rapidly than data gathering, it will result in different disciplines using different data to make decisions. Therefore, collaboration is more difficult, if not impossible.

While each discipline remains responsible for its expertise and intellectual capital, there must be a constant understanding by the practitioners of the whole project life cycle. Historically, the AECO industry has moved away from that Renaissance Age holistic view and become somewhat myopic. This age of specialization and distrust likely emerged because of the significant complexities and advances in each discipline. There was also the associated fear of accepting the liability of an unvetted methodology. For example, structural engineering now exclusively uses finite element analysis (FEA) to develop a design. FEA examines the entire structure of the building at one time instead of discrete pieces, such as columns and beams, as used to be the norm before computer-aided design. While FEA is now a best practice in structural engineering, others do not want to accept the liability of structural engineering but fully support the outcome in developing their portion of the project.

BIM can provide the same type of holistic approach for a project using information gained during design for construction and later operations and maintenance. This information sharing and information flow are exemplified by the Construction–Operations Building information exchange (COBie) (East 2016). COBie was the first data schema of its kind to capture information about an object during design and further populate it with information during construction with the intent of providing an information-rich object to the operations and maintenance phases of a project. While many see COBie as a spreadsheet, it intends to be a data model integrated with BIM. This concept will grow as the AECO industry injects object models from manufacturers into the information stream. Practitioners must consider all aspects of a facility

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or infrastructure asset and prepare ourselves to be able to deal with big data, whether through human interaction or artificial intelligence.

By adopting the method defined in Figure 1.4, the business process and information flows are identified for a specific detailed BIM use case for architectural precast concrete within the *structural analysis* BIM use case category. This process, as shown in Figure 1.5, defines the multiple roles, for example, architectural designer, precast fabricator, general contractor, and engineer of record (EOR) involved in the sub-use case, along with the specific information exchanged between each party during various phases of a project. This diagram identifies the concepts described previously and also alludes to discussion in the remainder of this book: it articulates the relationships between the BIM use cases and the job tasks that would need to be performed, along with what KSAs the architectural designer needs to successfully transfer information in a usable format to the precast fabricator during the schematic design phase of the project. If the information flow is efficient, it saves time and money. If the data requires significant rework, the process and project are injected with needless waste.

A vital aspect of any life cycle approach is trusting information others enter into the information stream. How do practitioners build trust in other people's data? There is a critical multifaceted answer to the question combining metadata, identifying the authoritative source for the data, and ensuring the data is

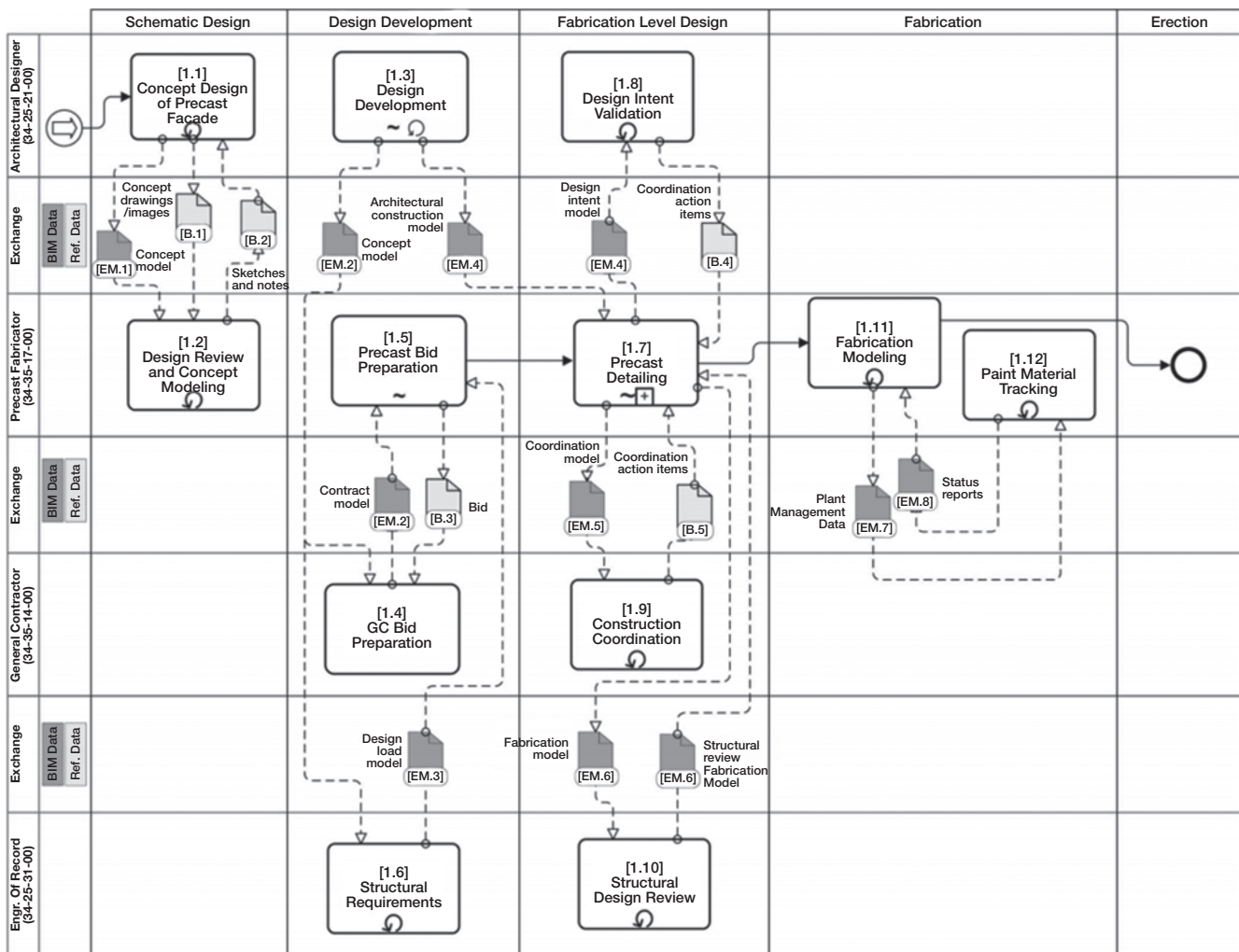


FIGURE 1.5 Process map for architectural precast showing use cases.

Source: Adapted from Eastman et al. (2010).

secure and sustained. The first aspect is to have metadata about every data point. The metadata needs to include the following: (1) who collected the data; (2) when it was collected; (3) for what purpose; (4) the quality; (5) whether it an estimate or a more exact method such as a price quote or the specific results of engineering analysis; and (6) if it was an engineering analysis, its parameters. If changes were made, only the changed information needed to be adjusted.

Entering metadata is not as difficult as it may sound, as a user should be able to rely on computer applications to track most of the information. Once logged on, the computer knows who the user is, what role they play, and therefore the permissions and authority they have. The user will likely need to enter only intent-related information as source information, which should be tracked automatically. Metadata in the AECO industry has been slow to catch on. It is likely because of the disjointed and unconnected approach the industry has taken in the past. There is a lack of information sharing between disciplines. While other sectors with similar issues such as medicine and banking are resolving their data-sharing issues using concepts such as blockchain, the construction industry, for the most part, has not yet understood the significant waste generated in time and materials driving the need to change.

Identifying the single authoritative source of truth for the data is also an essential aspect of building trust. Unfortunately, as data is reentered by someone other than the authoritative source, it has a high risk of being inaccurate. Rule number one in information technology is that if data is stored twice, typically both data sets are incorrect. A goal educators need to instill in everyone in the supply chain is to enter data only one time and then reuse, augment, and repurpose it over the life of the project, always using metadata to track the chain of custody of the data.

The last key element in building trust is identifying everyone involved in the project life cycle uniquely. Each practitioner brings their knowledge, skills, and abilities (KSAs) to the project, and those are their intellectual capital. It is paramount that data is protected and attributable to the individual. The first line of protection is password protection, which includes secure passwords, two-stage authentication, and possibly biometrics such as fingerprint, palm print, or iris recognition. The second element is to encrypt information both at rest and in transmission. While some may feel this is overkill and unnecessary to our BIM BOK, it is at the heart of each job task and any industry transformation. A level of trust must be developed in the information. It is done by knowing that no one has tampered with the information – either unknowingly or with malice. It is nearly impossible to add security to the process later in its development. Information security deserves extra repetition as educators understand the need for it to ensure the BIM BOK is successful. It is also critical to identify and track and attribute any adds, deletions, or changes to the data to create that level of trust. The remaining item – possible only after realizing the first three – is having the business processes in place to ensure data sustainment as information is shared over the life of the project.

Many live by the motto *if it's not broken, don't fix it*. However, for years, we've known that there could be as much as a 33% loss in productivity in the AECO industry, resulting in late delivery and higher project costs (Gallaher et al. 2004). One of BIM's goals is to speed up the process of sharing information and reducing costs. Overall process improvement is a new capability that needs to be introduced to the practitioners through education, embedded into software applications, and implemented organizationally. The BIM BOK identifies business process mapping as just one of the individual job tasks that students who will be future practitioners must understand. However, many see this additional layer of information technology today to be in direct opposition to the more traditional design practices, and it is still looked down upon by some educators. However, information technology in the construction industry has become just as prevalent as the smartphone is to many other aspects of society. As with any new capability, there will be functional as well as harmful elements to which a community must learn to adapt.

Today by necessity, many college curricula provide BIM as a single course or series of individual classes in undergraduate and graduate-level programs. This approach is a consequence of many factors. It is most likely because of limited resources such as BIM knowledgeable professors, time, and other curriculum requirements as only so much content can be delivered in 120 credit hours. BIM strategies ultimately need to be taught across the curriculum, and links should be established with other

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disciplines so that students can understand who the authoritative source of various data points should be. Perhaps universities should create a portfolio of courses that BIM could easily be included at some level – introduce, reinforce, create. They should look at the curriculum and course catalog from design, construction, and FM programs and create a road map to indicate courses and the opportunities for overlap. Then an analysis of who will benefit from the data earlier generated and expanded upon during their phase of the project could also be understood to create trusted information flow.

### 1.1.4 The Academic Interoperability Coalition – Home of the BOK

If practitioners are going to accomplish a substantive change to the AECO industry, they need to start with education. In the early days of BIM, educators were wrestling with the topic just as every practitioner was. The buildingSMART alliance, affiliated with NIBS, facilitated the idea of getting educators together to compare notes concerning what was working and what was not working by inviting them to a one-day BIM academic symposium at the NIBS' annual conference. The Academic Interoperability Coalition (AiC) was created in that context. The AiC's vision (from their website at [www.aicbimed.org/](http://www.aicbimed.org/)) is "Creating a collaborative educational environment that integrates all aspects of the facility life cycle so that graduates have a comprehensive understanding of the facilities industry while still identifying a narrow focus area within which to specialize." Their mission closely follows: "To identify and act upon issues related to transforming facilities education to meet the needs of a collaborative life cycle focused facilities industry for the information age."

For the first several years following AiC's creation in 2005, educators would gather at the NIBS conference in conjunction with AEC Science+Technology (AEC-ST) in Washington and present how they were implementing BIM education. Eastman of Georgia Institute of Technology, John Messner of the Pennsylvania State University, and Arto Kiviniemi of VTT Technical Research Centre of Finland Ltd., among others, indicated that BIM was first introduced on university campuses at the graduate level and very much oriented toward learning the basics of how to apply the tool. AiC, in conjunction with the NIBS event, continued until 2015, and AiC held a symposium at NIBS on a different date. In conjunction with that meeting, AiC attendees participated in a roundtable to identify the KSAs necessary for BIM. AiC began holding independent events organized initially by the University of Florida in 2016.

The AiC BIM BOK endeavor itself began based on concepts related to another project initiated in 2013 via the collaboration between NIBS and the Department of Energy (DOE). DOE came to NIBS with a dilemma. There were over 80 credentials available for five energy positions: energy auditor, commissioning authority, building and stationary engineer, facilities manager, and energy manager. Some credentials were excellent, and some were very inadequate. Organizations were all making money from the credentialing they offered to practitioners. The problem had become that neither the employer nor employee knew which credentialing programs were of value. Therefore, DOE set out to implement an American National Standards Institute (ANSI)-recognized process. The process is based on an ISO and International Electrotechnical Commission (IEC) standard – the ISO/IEC 17024:2012 Conformity Assessment—General Requirements for Bodies Operating Certification of Persons – to ensure only ANSI-credentialed organizations were providing education and testing. As the project manager, Dana K. Smith was trained for the ISO standard and ANSI processes and was responsible for coordinating the entire stringent process that helped the energy community rectify a severe problem. The most important product of the several hundred thousand dollars coordinating effort was a job task analysis (JTA) and definitions of KSAs required for the five energy positions. The process of organizing and holding several required workshops with professional energy experts was contracted to and accomplished by Professional Testing, Inc. in Orlando, Florida. Since they were also involved with developing the ISO standard, they were considered the experts in this process. The outcome was that the associations and other organizations offering credentialing to the energy sector needed to demonstrate how they complied with ANSI-validated methods under ISO/IEC 17024 when offering their credentialing. At last check, there are now eight organizations accredited for the various energy positions identified, a much more manageable number of high-quality programs (DOE 2020).

We anticipated a similar situation would occur with BIM as several institutions and associations now offer various BIM certificates and credentials without a common ground to what is being taught or identified as being needed by the industry. The situation is not yet out of control as with the energy positions. Nevertheless, a similar lack of continuity is beginning to be seen in the BIM community. Therefore, in 2015, as the DOE effort was winding down with very successful results, AiC kicked off a discussion as to how educators could build a foundational JTA that would be available for teaching BIM in higher education as well as providing employers an idea of what to expect from new hires. Practitioners can also use the JTA to identify gaps in employees' KSAs and training of employees. One of several differences that AiC implemented – which DOE wished they had done – was to look at education and training at entry-level, midcareer, and full-performance levels. The NIBS–DOE project looked only at job tasks and associated KSAs at the full performance, that is, expert level. At the 2015 AiC BIM Academic Symposium, a half-day was dedicated to identifying tasks required of BIM practitioners in several categories, which provided the basis for the BIM BOK. This list of task definitions received public comments from a group of designers, contractors, facility managers, and consultants for confirmation and evaluation. Throughout this book, the description and details of these tasks emerge. Following that initial effort, AiC began the Delphi process that Wei Wu led, which is also described in-depth later in this book.

At the time of the Delphi study, the AiC had not fully defined each task identified but left that to the study participants to determine on their own. In 2018, Tamera McCuen led an effort to attach definitions to the job tasks and develop KSAs for each task by the level of performance (LOP) and to validate the KSAs. Many of the job tasks are related to the BIM Project Execution Planning Guide (CICRP 2010). Thus, some of the descriptions have their root in that work. After the Delphi study, AiC did ask for confirmation of the personas of the experts served on the Delphi panel to determine the mind-set used when answering the questions and to validate that AiC indeed had a well-balanced group providing the results presented in the next chapter.

The scope of the Delphi study is developed as an outcome of the various discussions, which is depicted in Figure 1.6. In the context of the next steps, we will again revisit it to put the BIM BOK

Roles of Users (ROU)		Designer		Contractor		Facility Manager/ Operator		Consultant/ Generalist			
		Entry Level	Mid Level	Full Performance	Entry Level	Mid Level	Full Performance	Entry Level	Mid Level	Full Performance	
Levels of Performance (LOP)	Entry Level	Organizational	Project	Organizational	Project	Organizational	Project	Organizational	Project	Organizational	Project
	Mid Level	Organizational	Project	Organizational	Project	Organizational	Project	Organizational	Project	Organizational	Project
Types of Knowledge (TOK)	Organizational	Organizational	Project	Organizational	Project	Organizational	Project	Organizational	Project	Organizational	Project
	Project	Organizational	Project	Organizational	Project	Organizational	Project	Organizational	Project	Organizational	Project
Levels of Implementation (LOI)	Plan It										
	Coordinate It										
	Manage It										
	Do It										

FIGURE 1.6 The BIM BOK matrix.  
Source: Dana Smith.

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in context. The categories have been purposefully simplified somewhat on two levels. Design roles include all planning and design-related disciplines (CSI 2020) to include architecture, interior design, civil engineering, structural engineering, mechanical engineering, electrical engineering, environmental engineering, acoustic engineering, fire protection engineering, and many other specific engineering categories. Design is the phase where decisions are made that affect the entire life of the project. It is critical to understand the total impact of choices on the owner for the life of the facility. According to the BOK and OmniClass Table 34 (however, in this case not according to OmniClass Table 33) (CSI 2020), construction includes construction management and all forms of contracting to encompass general contracting as well as sub-contracting involving earthmoving, concrete, steel, carpentry, roofing, and many more. The facility manager section will include owners, operators, and all types of maintenance disciplines, many of which are similarly trained and have the same skill sets as those who first installed the items. The consultants include those who may have additional experience in specific areas as well as those in support of the AECO disciplines to include accountants, lawyers, specialized BIM consultants, as well as asset managers that all need some understanding of AECO issues. The AECO industry must develop a robust feedback loop so that the designers can be informed of any problems that are found based on their decisions to ensure the same mistakes are not continually repeated. At the same time, any right choices that should be replicated in future projects are also highlighted.

In each of these roles, the industry needs people who can plan BIM activities for a project, coordinate BIM activities, manage BIM activities, as well as create the models themselves. Too often, educators focus only on the training aspect of building models using software applications and not the total management strategy. Many job descriptions will encompass several of the responsibilities defined and therefore involve many of the knowledge, skills, and abilities identified previously. At some point, better-defined job titles will emerge, but since that has not yet occurred, this framework will be used as the starting point to address them. It must be recognized that collaboration between all these facets is necessary to be highly successful. A partnership should not be established for just one project team, as these KSAs must be brought to every level of every project team. All these parts are elements of what is defined as the facilities and infrastructure industry. Therefore, AiC set out to identify the common KSAs that all practitioners need to be successful based on the growth of BIM and the breadth as defined and now being demonstrated by the use cases.

Identifying the job tasks and developing the associated KSAs and ultimately the BIM BOK are but the first steps in transforming the AECO industry. Once facilities and infrastructure education focus on common educational goals based on the BOK with the support of program accreditation boards, then successful testing and credentialing can be developed independently to complete the intended total product of the AiC based on ISO 17024.

### 1.2 THE MANY DIMENSIONS OF BIM: WHY BIM IS REVOLUTIONARY

The idea of BIM has been around since the 1980s, and there are several histories available, as discussed in the *BIM Handbook* by Eastman et al. (2011). While not yet fully realized, BIM has the power to provide the facility owner an information-rich digital twin of their facility. This product will allow an owner to understand the implications of any change in the facility before a planned change on operations or use. Change can be as simple as moving a door or wall or installing a new cable or more significant in use for an entire facility or a portion of the facility. How will access and egress, security, or heating, air-conditioning, and ventilation (HVAC) zones be affected? What building codes or zoning issues must be addressed? Will a building still be net-zero in its energy use? Performing forensics on a facility that is not acting as designed can also be accomplished. Possibly an even more valuable use of this information is in developing and implementing disaster recovery (DR) and continuation of operations plan (COOP) for the organization. Currently, many organizations do not recover after a disaster because of the lack of information at the time of the event to help mitigate further ongoing damage or having an action plan in place to recover

rapidly. To accomplish all of this, not only is a 3D model helpful, but it also needs to be rich in information. Practitioners need to create not only owners who can correctly ask for and apply this information but also practitioners who can deliver.

Before the NBIMS-US Version 1, Part 1, there were as many definitions of BIM as there were practitioners. The industry needed some focus to guide practitioners. The National Building Information Model Standard Project Committee first defined BIM as follows:

*Building Information Modeling (BIM) is a digital representation of the 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 onward.*

*A basic premise of BIM is a 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.*

The NBIMS-US V3 (NIBS 2015) promotes the business requirements that BIM and BIM interchanges are based on (a) a shared digital representation; (b) the fact that the information contained in the model is interoperable (i.e., allow computer-to-computer exchanges); (c) the fact that the exchange is based on open BIM standards; and (d) the fact that the requirements for exchange must be capable of being defined in contract language.

As a practical matter, BIM represents many things depending on one's perspective. When applied to a project, it represents information management, or data contributed to and shared by all project participants – the right information to the right person at the right time. To project participants, it represents an interoperable process for project delivery, defining how individual teams work and how many teams work together to conceive, design, build, and operate a facility. To the design team, it represents integrated design, leveraging technology solutions, encouraging creativity, providing more feedback, and empowering a team.

The NBIMS-US V3 also went on to provide three definitions of various aspects of BIM: (1) *building information model* is the outcome; (2) *building information modeling* is the process; and (3) *building information management* is the administration.

The NBIMS-US was but the first step in helping to align practitioners across the life cycle in the United States. A significant percentage of the population has difficulty reading a set of blueprints and then visualizing the final product. If that is one's primary means of imparting knowledge about the built environment, then practitioners should consider whether perhaps a different medium is needed. Physical models of projects are another way, yet they can be slow and costly to develop and do not convey much more than the form of the resulting project. BIM can provide an easily modified platform to express the structure of the project, which is far more responsive to change and carry a significant amount of information. If well developed, one should be able to delve deep into the model to discover a substantial amount of data to include design calculations and even the design intent of each decision made, again more metadata. This information will inform those today as well as those needing to make future decisions.

Simply designing in 3D is significant in itself, and much of the focus in BIM has been on some independent projects. However, three projects that were recognized and won the 2019 bSI Interoperability Awards are worth taking a more in-depth look at to glimpse into the potential of BIM to revolutionize the facilities and infrastructure industry truly. The first two are megaprojects, one being a facilities project and the other an infrastructure project. The third project is included to demonstrate that not only megaprojects benefit, as it is a retail facility (Big Box store) similar to what can be found in many towns today.

While these are just three examples, they demonstrated 23 of the 50 use case categories; the bSI awards have now provided examples of all 50 use case categories. To accomplish this, a significant amount of on-the-job education and training occurred, which it is hoped, in the future, will be provided through higher-level education so that each project does not have to invent successful business practices with the team assembled for the project.

# CASE STUDY – PROJECT 1

## DBM Vircon (formerly PDC Engineering)

**Project Name:** Queen's Wharf Brisbane

**Objectives:** This \$3.6 billion apartment project aimed to bring together many different organizations and files into a unified methodology with openBIM at the core. An integrated model was developed to ensure that all phases of the project could be managed per the requirements set by the owner (Figure 1.7).



**FIGURE 1.7** Queen's Wharf Brisbane.

**Source:** DBM Vircon.

**Project size:** Covers 10% of Brisbane CBD, 215 models processed weekly, coordinating 25 organizations weekly, 2,000 residential apartments, 1,100 premium hotel rooms, 50 restaurants and bars, 16 different pieces of software in 5 different formats totaling 1000+ models.

### Open BIM Standards Used:

- Industry Foundation Class (IFC2X3)
- BIM Collaboration Format (BCF)
- COBie

### Use Cases Demonstrated:

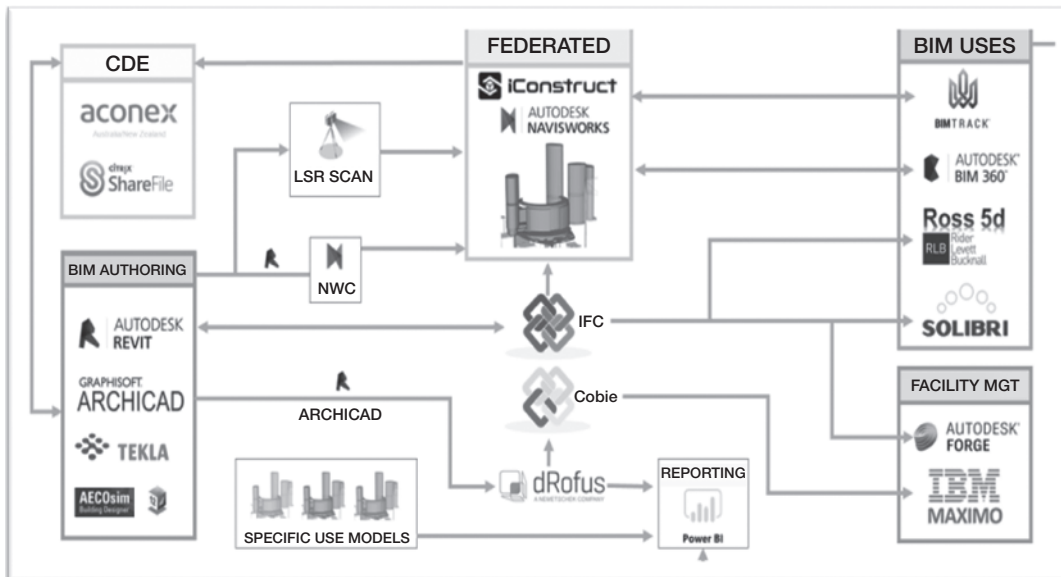
- Design
  - Existing Conditions Modeling (ECM)
  - Site analysis (SAN)
  - Visualization (VIZ)
  - Simulation (SIM)
  - Spatial analysis (SPA)

- Quantity takeoff (QTO)
- Design authoring and briefing (DAB)
- Design reviews (DER)
- Structural analysis (STR)
- 3D coordination (3DC)
- Procure
  - Perform procurement (PEP)
- Assemble
  - QA/QC – Consistency control (QCC)
  - Laser scanning (LAS)
  - Commissioning (COM)
- Operate
  - As constructed modeling (ACM)
  - Asset management (ASM)
  - Disaster planning/emergency preparedness (DRC)
  - Wayfinding (WAF)

**Award Category:** Design

**Year:** 2019

This project demonstrates an extraordinary level of interoperability and open standards-based sharing of information (Figure 1.8). The fact that so many entities and models were involved in such a large project pushed the practitioners to exceptional levels. Business processes had to be developed and followed, and change management strategies were employed. This level of interoperability is currently not taught in any school and can be realized only through on-the-job training. However, to conceive of such a significant project, some very experienced BIM practitioners were involved. With 18 use cases, a large number of KSAs were employed. Many worldwide would claim this level of interoperability and collaboration is not possible, yet here it stands. Practitioners have much to learn and apply from this example.



**FIGURE 1.8** Information flow for Queens Wharf project.

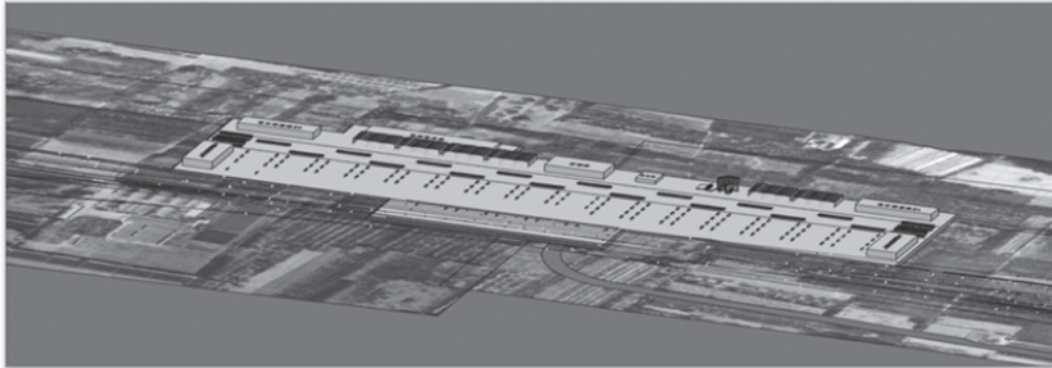
*Source: DBM Vircon.*

# CASE STUDY – PROJECT 2

## China Railway Design Corporation

**Project Name:** Jingxiong High-Speed Railway

**Objectives:** China Railways Design Corporation needed to develop a fully integrated process for the design, construction, and operations and maintenance of this critical Jingxiong High-Speed Railway project that connected some significant areas and buildings along this complex corridor (Figure 1.9).



**FIGURE 1.9 Existing Conditions Model.**

*Source: China Railway Design Corporation (CRDC).*

**Project Value:** undisclosed

**Project size:** This railway project included laying a ballastless track on the whole line. The mainline is 92.8 km, including six bridges with a length of 71.23 km, two tunnels with a length of 12.6 km, subgrade with a length of 8.95 km, and four stations.

### Open BIM Standards Used:

- Industry Foundation Class (IFC2x3 IFC 4 IFC bSI SPEC)

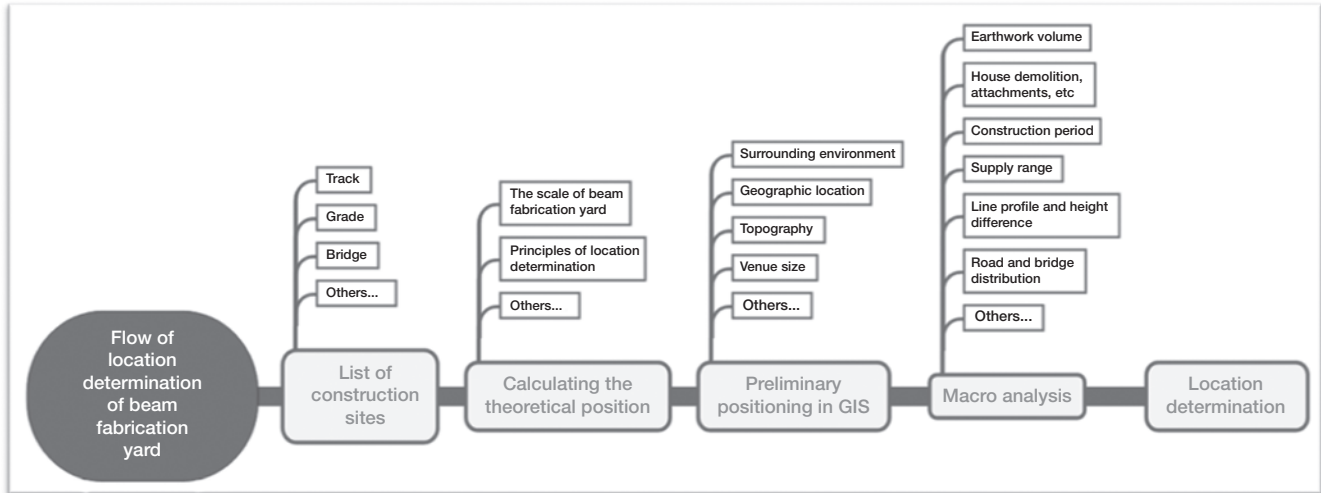
### Use Cases Demonstrated:

- Design
  - ECM
  - Site utilization planning (SUP)
  - VIZ
  - QTO
  - DAB
  - DER
  - Sustainability evaluation (SEV)
  - STR
  - 3DC
- Procure
  - PEP
- Assemble
  - Digital fabrication (DFC)
  - LAS

**Award Category:** Design

**Year:** 2019

An excellent example of a massive infrastructure project demonstrating 12 use cases where a significant amount of collaboration was required, and shared knowledge developed to share information (Figure 1.10). The fact that so many different project types are integrated, as well as multiple phases of the project involved, demonstrated an information flow – the project described in detail how each use case was applied to support the overall outcome.



**FIGURE 1.10** Information Flow Jinxiong High-Speed Railway.

*Source: China Railway Design Corporation (CRDC).*

## CASE STUDY – PROJECT 3

**DEUBIM GmbH**

**Project Name:** FMZ Leinefelde

**Objectives:** This construction project for a retail park aimed to bring together use cases and BIM implementation goals such as optimized comprehension of design, consistent planning, optimization of coordination, quantity and mass reliability, and much more. The result was the creation of BIM models by BIM experts, a coordination model, and authorizing and versioning models (Figure 1.11).



**FIGURE 1.11** Visualization of FMZ Leinefelde.

*Source: DEUBIM GmbH.*

**Project Value:** €9,96 million

**Project size:** 6.400 qm (gla)/sales area 4.550 sqm

**Open BIM Standards Used:**

- Industry foundation class (IFC2x3)
- Model view definition: coordination view (MVD: CV)
- BIM coordination format (BCF)
- Information Delivery Model (IDM)

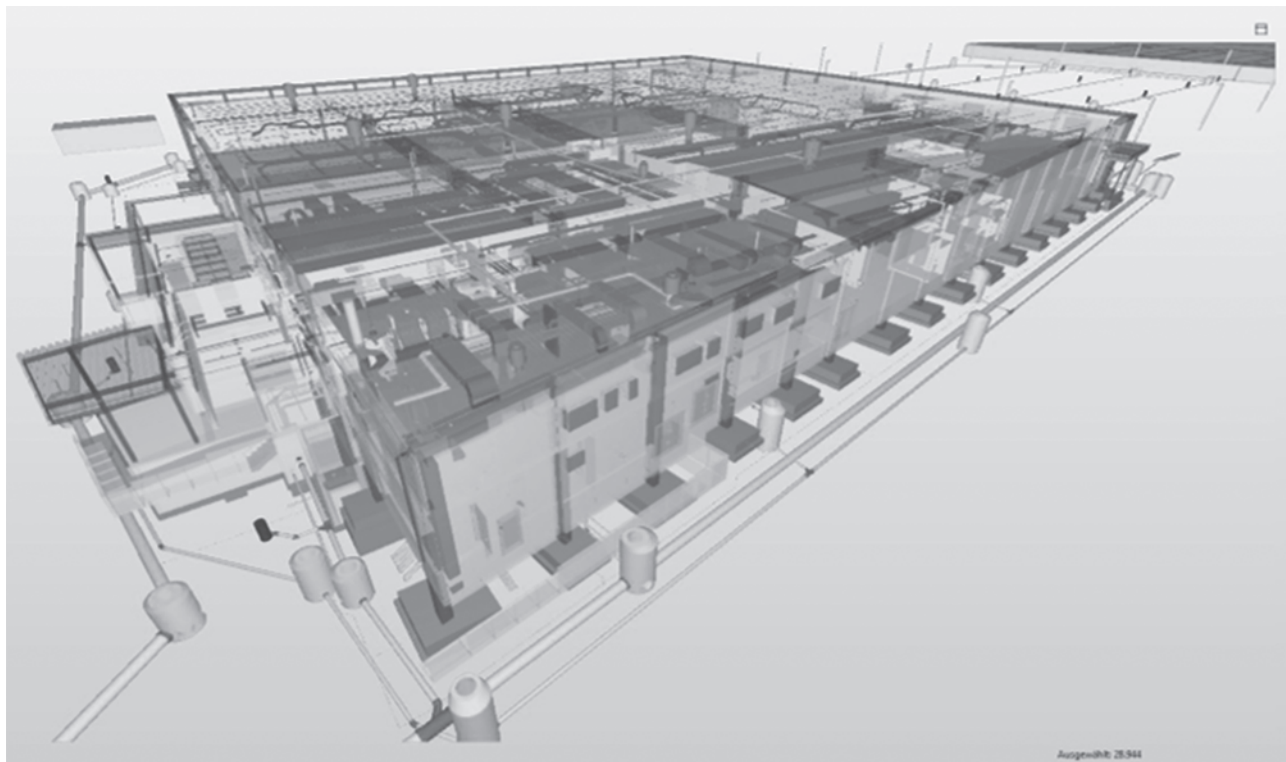
**Use Cases Demonstrated:**

- Design
  - VIZ
  - QTO
  - DER
  - 3DC
- Assemble
  - Construction system design (CSD)
  - Phase planning (PHP)
  - DFC
- Operate
  - ACM
  - ASM

**Award Category:** Design

**Year:** 2019

This case study is included to demonstrate that BIM use is scalable. This project is a relatively small project which can demonstrate multiple use cases spread over three phases of a project while some of the more commonly employed use cases shown here were also some of the less used use cases (Figure 1.12).



**FIGURE 1.12** 3D Coordination of FMZ Leinefelde.

**Source:** DEUBIM GmbH.

Many more project examples are available from past years bSI awards, and many more are emerging each year that demonstrate the potential of BIM far beyond where many still conceive of it being today. Currently, relatively few technically capable practitioners can accomplish openBIM standards-based projects similar to these. How do schools create more such individuals to help take on the ever-expanding challenges humankind will face in the future? During the close-out session at the College of Cinematic Arts at University of Southern California in 2009, a member of the close-out team indicated that they were sad that the project was coming to a close. The group assembled for the project had evolved into a high-performance organization over the life of the project. They were unhappy because they knew that on the next project it would need to start over educating and building a new team; they hoped only that the new group would work as well together. It is expected that this book is the first step in cultivating practitioners who are prepared for these ever-expanding opportunities.

### 1.3 OVERARCHING GOALS OF THE BIM BOK

Before taking on the writing of this book to fully explain the implementation of the BIM BOK, we prepared and published several academic papers to begin informing the education community of the work of the AiC. Those papers identified some overarching goals for the BIM BOK, which include:

- A. To establish contemporary and comprehensive metrics of BIM competency assessment for the workforce across the AECO industry under a wide variety of contexts. Existing literature and metrics developed so far lack the dimensionality to address the integrative performance of individuals, projects, and organizations in BIM implementation under one unified and holistic framework.

This goal is critical for any process: first, a baseline must be established of where the industry is today in this process, and then agreed to metrics must be used to track progress in achieving the identified goals. These goals can be for the education itself as well as higher-level purposes of how the industry is affecting the global built environment.

- B. To create a standard curriculum and road map to bridge the gap between college education outcomes and workplace performance requirements; to advance understanding of BIM's business value and foster further development of BIM use cases; and to prioritize BIM education and intellectual preparation in sustaining the BIM market transformation.

Based on the first goal, this is the natural follow-on goal to assess progress and will be an indication of how well the BIM BOK is adopted and implemented throughout the industry.

- C. To standardize the level of expectation and benchmark job task performance for emerging BIM job titles (e.g., BIM/VDC engineer, BIM/VDC manager, BIM/VDC coordinator, and BIM/VDC director) and to create the baseline performance measurement for BIM education accreditation, professional credentialing, and certification (Wu et al. 2017).

The BIM BOK allows for assessing progress at multiple levels. Ultimately, success can be measured on similar levels. The key will be for the industry to define an agreed upon baseline, which the BIM BOK can provide, and then take a long-term view to track improvement metrics over time. This process will not be a quick change by any stretch of the imagination, and we recognize that it will be many years into the future before the real impact of this initiative will mature and bear fruit. The AECO industry should have metrics that can measure not only an individual's success but also the incremental improvement to check the outcomes of education transformation and to ensure the actions practitioners are taking produce the desired results at intermediate stages during maturation. The end has by no means been defined, and this book is only providing a beginning and the structure to succeed. It will undergo many improvements over time and expand as the industry continues to adopt BIM, or whatever new terminology the industry invents to describe an interoperable open standards-based information life cycle.

This process and the work detailed herein should be applicable in the future, even as the name BIM changes in scope. Ultimately, the industry will need an information architecture by which it can organize

around as all facets of the AECO industry needs to understand what information and knowledge are required across the industry. Developing this architecture is not an easy task and will require all parties to be working in harmony. This new environment will, in time, encourage the creation of endless bounds because everyone will be working as a high-performance team.

There are at least a couple types of teams. Some teams focus on individual performance for team success such as swimming, wrestling, downhill skiing, and track and field, where each participant's time or score is captured and combined to identify the overall team success. Historically, the AECO industry has operated in this manner. However, the team envisioned for the future is far more like a baseball, volleyball, football, soccer, or ice hockey team. While individual performance is still vital to the team's success, each player has a specific role to play. If they do not perform in concert with the others, then the team will more than likely lose. If one player is not playing to the level of the others, then they will negatively affect the play of the entire team, either physically or mentally. For example, in volleyball, if the ball is not appropriately received and bumped to the setter, then they cannot feed it to the hitter for the score. If the team is in system, then a point is most often made by design. If not, then the best one can hope for is a lucky score. The AECO industry needs a fine-tuned business process in place so that all practitioners are working toward producing the best product for the least total cost over its life in the shortest amount of time. It will be the AECO industry in-system environment for which to strive. The industry is not doing this currently, for the most part, so practitioners and owners get only occasional wins. There are always successful exceptions, and practitioners need to systematically learn from those and replicate them by design as the industry moves forward, so a robust feedback process and change management process also needs to be in place.

### **1.3.1 The Rapidly Changing Industry Environment**

There are currently well over 250 organizations associated with AECO in the facilities and infrastructure industry. While most believe they are doing their best to improve their part of the industry, there are no checks in place to see if they are all working toward the same goals for their client, country, or for the planet. Therefore, organizations see advancements in many sectors in support of their constituents. However, there is little movement in the overall improvement of the built environment. Since there is little coordination, this ends up merely leading to much Brownian motion. While change is constant, change that will advance the body of knowledge is collectively somewhat stagnant today. BIM has been around for a relatively long time, as noted earlier. However, it is not yet demonstrating the potential it is capable of nor advancing at the rate necessary to meet the demands of society. The world needs answers to issues such as housing shortages, reducing energy use, reducing waste, providing potable water, and reducing CO<sub>2</sub> emissions. BIM has the potential of supporting meaningful change in all these areas plus many more, but only if schools are producing people who understand the scope of the issues and how the tools can help make a difference.

We recognize that some specific information in this book will be outdated in a short time – but not the strategy. The primary goal of this book is to create a starting point upon which others can build. It promotes a process rather than an endpoint. The industry is changing, not as rapidly as is needed, but it is progressing. By adopting some essential foundational concepts, the practitioners will be able to pull new ideas and technology into use more efficiently. Standards play a big part in this ability to change. People cannot accommodate everything changing at the same time. Humans can only bring in a few new items successfully concurrently. Professionals must rely on some basic tenants, either to compare new approaches to or to help validate results. The AECO industry continues to build taller buildings, but those could not be accomplished by not understanding issues that practitioners worked out on smaller buildings. Just as with old bridges, engineers found that with rolling loads such as railroads, many bridges failed because engineers did not understand dynamic loading (Petroski 1992). Adjustments were made using change management approaches. They did not start over from scratch but adjusted and improved on the knowledge they had developed.

Another example was the effect of wind on bridges such as the now-famous Tacoma Narrows Bridge in Washington in 1940 (Petroski 1992). These examples are not just of yesteryear. A case in point was the pedestrian bridge at Florida International University (Mazzei 2019). Knowledge gained by failure is a great but costly teacher. Practitioners want to be sure everyone learns from the success or failure of others by continuing to improve education.

These are but a few examples where change did not go well yet continue to change what the AECO industry does and must continue to do so. All change does not end up in disaster. Most do not. Again, just because a project does not end up as a disaster does not mean constant improvement is not necessary and possible. However, to make useful improvements, practitioners need to fully understand the business processes of the as-is model to identify how the AECO industry wants the to-be model to perform.

Even what practitioners may call a rapid change in the facilities and infrastructure world can often be painfully slow. An example of this was the  $M_w$  6.2 earthquake in Christchurch, New Zealand, in 2011, which was more significant because of an  $M_w$  7.1 earthquake in 2010, having weakened many structures. There were 185 killed due to several building collapses. The earthquake caused most of the central business district (CBD) to have to be rebuilt (New Zealand History 2016). In one case where the building did not collapse and no lives lost, it was found that the bearing surface of precast stairs was not adequate. Therefore, many stairways collapsed, leaving people stranded on upper floors in buildings, which made search and rescue difficult. The issue was identified after a forensic analysis was published several years after the event. Due to that analysis, proposals were advanced to change building codes to require more bearing surfaces worldwide. Those standards had to be developed and approved by localities. At that point, new facilities could then begin to be designed and built using the latest safety code. This change process will take nearly 20 years to accomplish. So while change may be identified somewhat quickly, actual implementation and effect come far more slowly.

The work proposed in this book will take the educators time to implement and discipline-specific accreditation boards time to acknowledge. Students will begin the learning process and emerge from school as entry-level practitioners. Time will be required for them to be in a decision-making position. Again a change that may come today will be years before its impact will be truly felt. Nevertheless, if the AECO industry does not begin today, the effect will never be realized, so we encourage our audience to become proactive as soon as feasible to ensure the strategies documented here bear fruit as quickly as possible.

### 1.3.2 The Skill Shortage

The shortage of skilled AECO or facility and infrastructure professionals is a multifaceted issue. One part is due to the economic downturn of the 2010s and pandemic of 2020, where a lot of specialized construction industry labor moved to other sectors to find work. Design and construction are leading indicators of economic turndowns. As work dries up in the construction industry, other industries are often still hiring, and there is a historically repeated migration away from the construction industry. When the economy recovers, then new hires need to be trained. Education and apprentice programs vary for different facets of the AECO industry. An architect will need 4–5 years of education plus a 3–5-year apprenticeship via an internship development program (IDP) or a new approach called the architectural experience program (AXP), both of which require approximately 3,740 hours of mentorship. One must also pass the Architect Registration Examination (ARE) administered by the National Council of Architectural Registration Boards (NCARB) to be registered in a state, and some states also require an additional state exam. The ARE consists of six divisions containing either graphical questions or multiple-choice questions. In many states, one may begin taking the exam as soon as the education portion is completed in parallel to the IDP or AXP.

Additional experience through mentorship is then needed before the architect is genuinely skilled. Skilled labor, another critical factor in the completion of facilities and infrastructure, also takes time to develop. A carpenter, for example, will require approximately 4 years of learning before they can

be identified as a skilled carpenter and then 6 years as a journeyman before they can be considered a master carpenter. So, the industry recovery rate is approximately 8–10 years on both sides of the equation. Just as the recovery was complete after the 2010 downturn, the pandemic hit and cast the AECO industry again into chaos. The recovery will vary from country to country. Therefore different parts of the world will take longer or shorter to respond to economic and other conditions affecting the facilities and infrastructure industry.

Another factor is that the facilities and infrastructure industries do not seem to be currently as attractive to younger people. This entry-level issue appears to be especially true for facilities management. A critical segment of the industry as facilities become more sophisticated due to the requirement of meeting reduced energy, and more stringent climate needs require more highly trained individuals.

There are many colleges and universities offering design and construction programs, but few offering a specific facility management curriculum. Typically, architects and engineers are the ones who populate the facility management positions. Another route is to become a facilities maintenance manager by either on-the-job training or additional education in a specific area such as heating and ventilating or plumbing and then after several years to move into a management position with further instruction.

All these approaches are very siloed between planning, design, construction, operations, and maintenance. Each of those primary categories is subdivided, with architecture, structural engineering, mechanical engineering, electrical engineering, civil engineering, and others just for the design silo. The same is valid for construction and facilities maintenance. Practitioners are increasingly gaining knowledge in a specific field, yet few take the route of looking at the big picture of how it all fits together. Therefore, who is looking to see how information flows from planning to design and then from construction to facility operation and maintenance (O&M)? This information flow is a primary tenant of BIM or any life cycle-oriented view.

The owner is the one who is most affected by any shortage of skilled professionals or skilled labor. However, most single facility owners turn over the responsibility of delivering new facilities to the professionals in the facilities and infrastructure industry, and the owner may be unaware they are the recipient of products developed by less skilled practitioners and less skilled labor and therefore end up with lower quality facilities. Those owners who build multiple facilities or have more extensive portfolios will hire and train staff to understand and manage the entire process in their best interest. They can help ensure that the product meets their quality standards.

While the facilities and construction industry has historically continuously experienced the ebbs and flows of the economy and has lost and gained skilled labor to support their needs over time, the AECO industry is now also facing a new issue of having to educate a new group of workers who also need to understand the bigger picture. Satisfying the demand for these new-age workers is an objective of this book. Currently, the education system is not able to meet the need on multiple levels, as has been eluded to thus far in the book.

Colleges and universities are being called upon to provide entry-level employees in the design, construction, and facilities management disciplines. Today, there are also expectations for expanding the role and scope of the practitioner. This new generation of practitioners possesses KSAs different from the historic general KSAs, as they can meet the needs of other practitioners and understand the relationships and the flow of information from and to each other practitioner. Addressing the delta between what a professional used to need to know and what a professional needs to know today to be successful in a life cycle focused interoperable BIM environment is a considerable challenge for the current educational infrastructure. The question is, can it be done incrementally, or will the process end up being more disruptive to meet the need? Those who implement the changes necessary first in the most effective way will position themselves to legitimately come in to win design, construction, and facility and infrastructure operating contracts. This rapid implementation will need to be done while offering higher-quality and lower-cost services, allowing for the faster delivery of facilities to remain competitive. Examples are emerging in China, where 30-story hotels are being delivered in 15 days (MacKenzie 2012), a 57-story skyscraper in 19 days (Peng and Tang 2015), or new hospitals in as short as 10 days (Talmazan 2020).

### 1.3.3 The Proliferation of BIM Use Cases

Up to this point, we have described in general the use cases being implemented in the AECO industry. Use cases are a way of organizing tasks associated with the industry. While they are not necessarily yet being developed in a structured way, nevertheless, they are evolving and emerging as building blocks for planning, design, construction, procurement, operations, and maintenance of facilities. The key is that teams agree before a new project how they will approach the project in a BIM execution planning guide that they develop.

The idea was first initiated in the United States at the Pennsylvania State University (CICRP 2010), and this concept is now in place in many locations around the world. The international community at this writing focused on 50 use cases organized by the bSI project phase categories (i.e., design, procure, assemble, and operate), as shown in Table 1.1 and maintained on the bSI use case management web site <https://ucm.buildingsmart.org/>. While these will undoubtedly change over time, we have included them here as a baseline on which to understand the relationships with the KSAs and JTA described. However, no direct matrix of relationships has yet been developed, and that will no doubt come as this effort continues to mature.

Dana Smith has been working with these use cases for multiple years and has seen their use continue to increase. As this book is going to press, an international committee is being formed to look at the use case classification issue more holistically to embody both facilities and infrastructure. Figure 1.13 identifies the distribution of application of the use cases for the 145 projects submitted for the 2018–2019

**TABLE 1.1 List of 50 BIM Use Cases by Project Phase Categories**

Phase	#	Description (Abbreviation)	Description
DESIGN	1	Existing Conditions Modeling (ECM)	<ul style="list-style-type: none"> <li>• A process in which a project team develops BIM(s) of the existing conditions for a site, facilities on a site, or a specific area within a facility.</li> <li>• This model can be developed in multiple ways, depending on what is desired and what is most efficient.</li> <li>• Once the model is constructed, it can be queried for information, whether it be for new construction or a modernization project.</li> <li>• A process in which BIM(s) are used to graphically represent both permanent and temporary facilities on-site, often with the construction activity schedule.</li> </ul>
	2	Site utilization planning (SUP)	<ul style="list-style-type: none"> <li>• Because the 3D model components can be directly linked to the schedule, site management functions such as visualized planning, short-term re-planning, and resource analysis can be analyzed over different spatial and temporal data</li> <li>• Additional information incorporated into the model can include labor resources, materials and associated deliveries, and equipment location.</li> <li>• A process in which BIM/GIS tools are used to evaluate properties in a given area to determine the most optimal site location for a future project.</li> </ul>
	3	Site analysis (SAN)	<ul style="list-style-type: none"> <li>• The site data collected is used first to select the site and then the position of the building based on engineering criteria (e.g., solar path, utility availability, hazardous material).</li> </ul>

*(continued)*

TABLE 1.1 List of 50 BIM Use Cases by Project Phase Categories (*Continued*)

Phase	#	Description (Abbreviation)	Description
DESIGN	4	Architectural programming (ARP)	<ul style="list-style-type: none"> <li>• A process in which an architectural BIM(s) is used to efficiently and accurately assess design performance regarding spatial requirements.</li> <li>• The developed BIM allows the project team to analyze space and understand the complexity of space standards and regulations, which saves time and provides the team with the opportunity of doing more value-adding activities.</li> <li>• Critical decisions are made in this phase of design and bring the most value to the project when needs and options are discussed with the client and the best approach is analyzed.</li> <li>• A process in which BIM(s) are used for creating images, diagrams, or animations to communicate a message.</li> <li>• They are used for rendering, understanding natural lighting, supporting site selection and positioning, marketing, understanding design intent, and constructability.</li> </ul>
	5	Visualization (VIZ)	<ul style="list-style-type: none"> <li>• Visualization through visual imagery has been an effective way to communicate both abstract and concrete ideas.</li> <li>• The development of augmented and virtual reality also supports advanced visualization.</li> <li>• A process in which BIM(s) are used to simulate the operation of a real-world process or system over time.</li> <li>• The act of simulating requires a model to represent the essential characteristics or behaviors/functions of the selected physical or abstract system or process.</li> <li>• The model represents the system itself, whereas the simulation represents the operation of the system over time.</li> </ul>
	6	Simulation (SIM)	<ul style="list-style-type: none"> <li>• Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training, education, and video gaming. Often, computer experiments are used to study simulation models.</li> <li>• Simulation is also used with scientific modeling of engineering designs, natural systems, or human systems to gain insight into their functioning.</li> <li>• Simulation can be used to show the eventual real effects of alternative conditions and courses of action.</li> <li>• Simulation is also used when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist.</li> </ul>
	7	Spatial analysis (SPA)	<ul style="list-style-type: none"> <li>• A process in which BIM(s) are used to perform spatial analysis on the space by considering the perceivable architectural element by their boundary and stress characteristics and intensity properties.</li> <li>• This type of analysis is capable of taking all sensorial factors into account during analyses in conformably with the perception process of architectural space, which is a multisensorial act.</li> </ul>

Phase	#	Description (Abbreviation)	Description
DESIGN	8	Specification production (SPR)	<ul style="list-style-type: none"> <li>• A process producing a data-based three-part specification system linked to the objects selected to be included in BIM(s), which responds to any changes or alternative items added or subtracted from the model during design and construction.</li> <li>• A process using BIM(s) to produce accurate QTOs. QTOs are the detailed measurement of materials and labor needed to complete a construction project. They are made from the BIM(s) developed by a designer and performed by an estimator during the preconstruction phase and for change orders during construction.</li> </ul>
	9	Quantity takeoff (QTO)	<ul style="list-style-type: none"> <li>• These measurements are used to develop a bid based on the scope of construction identified in the specifications.</li> <li>• Estimators review drawings and specifications and BIM(s) to develop these quantities. Some quantities will be for temporary work needed during construction, such as formwork or trenching.</li> <li>• A process in which BIM(s) can be based on an accurate quantity takeoff, produce a cost estimate early in the design process, and provide cost effects of additions and modifications with the potential to save time and money and avoid budget overruns.</li> <li>• This process also allows designers to see the cost effects of their changes promptly, which can help curb excessive budget overruns due to project modifications.</li> </ul>
	10	Cost analysis/estimation (CAE)	<ul style="list-style-type: none"> <li>• Cost analysis is the accumulation, examination, and manipulation of cost estimates for comparisons and projections.</li> <li>• It also encompasses the cost engineer's assessment of external impacts on a project to include items such as weather, labor, and skill set availability, material availability, and economic conditions.</li> <li>• It is ideally done in near real time as objects are selected and decisions made by designers.</li> <li>• A process in which BIM(s) are used to produce a financial estimate intended to help buyers and owners determine all direct and indirect costs of a product or system over its life to include end of life cost or value.</li> </ul>
	11	Total cost of ownership/service life (TCO)	<ul style="list-style-type: none"> <li>• It is a management accounting concept that can be used in full cost accounting or even ecological economics, where it includes social and skill acquisition costs.</li> <li>• A process in which 3D software is used to develop BIM(s) based on criteria that are important to the translation of the building's design.</li> <li>• Two groups of applications are at the core of a BIM-base design process are design authoring tools and audit and analysis tools.</li> </ul>
	12	Design authoring and briefing (DAB)	<ul style="list-style-type: none"> <li>• Authoring tools create models, while audit and analysis tools analyze or add to the richness of information in a model.</li> <li>• Most of audit and analysis tools can be used for design review and engineering analysis BIM uses.</li> <li>• Design authoring tools are the first step toward BIM(s), and the key is connecting a 3D model with an authoritative database of properties, quantities, means and methods, costs, and schedules.</li> </ul>

(continued)

TABLE 1.1 List of 50 BIM Use Cases by Project Phase Categories (*Continued*)

Phase	#	Description (Abbreviation)	Description
DESIGN	13	Design reviews (DER)	<ul style="list-style-type: none"> <li>• A process in which BIM(s) is used to showcase the design to the stakeholders and evaluate meeting the program and set criteria like layout, sightlines, lighting, security, ergonomics, acoustics, textures, and colors.</li> <li>• A virtual mock-up can be accomplished in great detail, even on the part of the building, like a façade to analyze design alternatives and solve design and constructability issues quickly.</li> <li>• If properly executed, these reviews can resolve design issues by offering different options and cutting down the cost and time invested considering basic construction, making modifications after studies, and final demolition and removal expenses.</li> <li>• Evaluation of the designed space can be facilitated by a high degree of interactivity to get positive feedback from end users and owner.</li> <li>• Some of the top criteria in the evaluation are sightlines, lighting, ADA compliance, safety, security, acoustics, HVAC, ergonomics, aesthetics, and millwork tolerances.</li> <li>• Real-time modifications of design are enabled based on the end user's feedback. Therefore, decision-making time is cut in half since the attention focus is on one issue at a time until a consensus is reached.</li> </ul>
	14	Sustainability evaluation (SEV)	<ul style="list-style-type: none"> <li>• A process in which BIM(s) are used on a project to evaluate its sustainable aspects through its life cycle based on certification categories and criteria such as:                             <ul style="list-style-type: none"> <li>• Leadership in Energy and Environmental Design (LEED);</li> <li>• Building Research Establishment Environmental Assessment Method (BREEAM);</li> <li>• Or other recognized sustainable criteria programs.</li> </ul> </li> <li>• To obtain the desired certification, the most common approach is condensing design analysis into a single database.</li> <li>• Evaluations can be applied across all phases of a construction project.</li> <li>• Sustainability evaluation is most effective when it is done in the planning and design stages and then applied in the construction and operations phase.</li> </ul>
	15	Design to maintain analysis (D2M)	<ul style="list-style-type: none"> <li>• An evaluation process where each object selected during design for inclusion in BIM(s) is evaluated for life cycle maintenance issues, such as clearances to perform routine maintenance activates.</li> <li>• In addition, consideration shall be given to including complete replacement of the object or any of its components.</li> </ul>
	16	Structural analysis (STR)	<ul style="list-style-type: none"> <li>• A process in which intelligent modeling software uses the structural BIM to determine the most effective engineering method based on design specifications.</li> <li>• These analysis tools and performance simulations can significantly improve the design of the facility.</li> </ul>

Phase	#	Description (Abbreviation)	Description
DESIGN	17	Lighting analysis (LTA)	<ul style="list-style-type: none"> <li>• A process in which intelligent modeling software uses the Architectural BIM to determine the most effective engineering method based on design specifications.</li> <li>• The development of this information is the basis for the validation of lighting levels and code compliance.</li> <li>• These analysis tools and performance simulations can significantly improve the design of the facility.</li> </ul>
	18	Energy analysis (ENA)	<ul style="list-style-type: none"> <li>• A process in which intelligent modeling software uses the mechanical BIM to determine the most effective engineering method based on design specifications.</li> <li>• The development of this information is the basis for building systems energy analysis.</li> <li>• These analysis tools and performance simulations can significantly improve the design of the facility and its energy consumption during its life cycle in the future.</li> </ul>
	19	Mechanical analysis (MEA)	<ul style="list-style-type: none"> <li>• A process in which the BIM(s) are used to determine the most effective mechanical engineering methods based on design specifications.</li> <li>• These analysis tools and performance simulations can significantly improve the mechanical design of the facility and its energy consumption over its life cycle.</li> <li>• The information provided from this analysis should be shared with the owner and operator for use in the building's mechanical systems.</li> </ul>
	20	Electrical analysis (ELA)	<ul style="list-style-type: none"> <li>• A process in which BIM(s) are used to determine the most effective electrical engineering methods based on design specifications.</li> <li>• These analysis tools and performance simulations can significantly improve the electrical design of the facility and its energy consumption over its life cycle.</li> <li>• The information provided from this analysis should be shared with the owner and operator for use in the building's mechanical systems.</li> </ul>
	21	Other engineering analysis (OEA)	<ul style="list-style-type: none"> <li>• A process in which BIM(s) are used to determine the most effective engineering method based on design specifications.</li> <li>• Development of this information is the basis for what will be passed on to the owner and operator (e.g., emergency evacuation planning, egress planning, ADA).</li> <li>• These analysis tools and performance simulations can significantly improve the design of the facility during its life cycle in the future.</li> </ul>
	22	Building system analysis (BSA)	<ul style="list-style-type: none"> <li>• A process that uses the BIMs to optimize a building's performance to the specified design.</li> <li>• This includes how the mechanical system operates and how much energy a building uses.</li> <li>• Other aspects of this analysis may include ventilated facade studies, lighting analysis, internal and external airflows, and solar analysis.</li> </ul>

(continued)

TABLE 1.1 List of 50 BIM Use Cases by Project Phase Categories (*Continued*)

Phase	#	Description (Abbreviation)	Description
DESIGN	23	3D coordination (3DC)	<ul style="list-style-type: none"> <li>• A process in which BIMs are used during the design and construction process to identify and coordinate potential field conflicts by comparing models of building systems.</li> <li>• During design, the goal of clash avoidance is to ensure there is adequate space to fit all designed components.</li> <li>• During construction, clash detection intends to resolve major system conflicts before installation.</li> </ul>
	24	3D control and planning (3DP)	<ul style="list-style-type: none"> <li>• A process that utilizes BIM(s) to help layout the building assemblies and produce lift drawings.</li> <li>• Lift drawings are 2D and 3D component drawings used by foremen during on-site construction to help with sequencing.</li> </ul>
	25	Product library (PRL)	<ul style="list-style-type: none"> <li>• A process that allows practitioners to access products BIM information from an external source.</li> <li>• Several organizations are currently developing product libraries with various formats of information to include natural forms for existing BIM software as well as open standards-based data in IFC format.</li> <li>• A process where BIM(s) facilitate accessing manufacturers' information, from a product library in a machine-readable format.</li> <li>• The product library will mature to ultimately include not only graphic and spatial information but also information related to technical specifications, engineering capabilities and tolerances, first cost, total cost of ownership, maintenance and repair, environmental, mean time to failure, as well as installation, warranty, and any other information pertinent to the selection of a product for suitability in a designed facility.</li> </ul>
	26	Manufacturers information (MAI)	<ul style="list-style-type: none"> <li>• This is detailed information about an object that can be used for accessing all known manufactured product information to potentially including parts list and identifiable nomenclature specific to ordering parts for maintenance and repair of existing objects. It may also include performance information and other information that could support product selections.</li> <li>• A process of using BIM(s) to identify objects and use the information provided in product libraries to support the selection of one product over another. The more information available, the higher the quality of the decision.</li> </ul>
PROCURE	27	Product selection (PRS)	<ul style="list-style-type: none"> <li>• This process is comparable to comparison charts provided for many products today.</li> <li>• The product library may also include information from users or people who have purchased the products, which indicate the suitability of the products to a specific use.</li> <li>• A process using BIM(s), where once selected, an object is ordered using electronic means to help in planning just in time delivery as well as providing complete documentation of the product life cycle management (PLM) process.</li> </ul>
	28	Perform procurement (PEP)	<ul style="list-style-type: none"> <li>• The process will provide information to the recipient, so the object can potentially be tracked throughout its manufacturer, fabrication, and shipping process.</li> </ul>

Phase	#	Description (Abbreviation)	Description
PROCURE	28	Perform procurement (PEP)	<ul style="list-style-type: none"> <li>• This capability is similar to existing processes in place for many industries and is similar to Amazon Prime or Google Express.</li> <li>• It can be used for initial purchase as well as supporting work orders in existing facilities.</li> <li>• It may even be tied into automatic ordering tools that order, stock, inventory, and track the availability of routine maintenance parts.</li> <li>• It can also support and link to IWMS systems for scheduled maintenance activities requiring product procurement during operations and maintenance.</li> </ul>
	29	Code validation (COV)	<ul style="list-style-type: none"> <li>• A process in which code validation software uses a BIM(s) to check model parameters against project-specific codes.</li> <li>• It could be considered a spell-check for building models.</li> <li>• As model checking tools continue to develop and update the software for compliance with more codes, code validation should become more prevalent within the design industry.</li> </ul>
	30	Construction system design (CSD)	<ul style="list-style-type: none"> <li>• A process in which BIM(s) are utilized to design and analyze the construction of a complex building system (e.g., congested mechanical rooms, curtain walls, glazing, formwork, tie-backs, seismic restraint systems, hangers) to increase planning and future programming.</li> </ul>
ASSEMBLE	31	Phase planning (PHP)	<ul style="list-style-type: none"> <li>• A process in which BIM(s) with the added dimension of time is utilized to effectively plan the phased planning to include construction, occupancy in a renovation, retrofit, addition, or to show the construction sequence and space requirements on a building site.</li> <li>• BIM with the time dimension (also known as 4D) is a powerful visualization and communication tool that can give a project team a much better understanding of project milestones, schedules, and construction plans.</li> </ul>
	32	Digital fabrication (DFC)	<ul style="list-style-type: none"> <li>• A process that utilizes fabrication machine technology to prefabricate objects directly from models for offsite construction.</li> <li>• This promotes such things as improved levels of quality control of building systems and their components while increasing the overall project safety</li> <li>• Using BIM(s) to keep track of materials delivered for the project tied to scheduling and sequencing of assembly.</li> </ul>
	33	Field and material tracking (FMT)	<ul style="list-style-type: none"> <li>• Allows the identification of materials the following procurement to include delivery and laydown area location.</li> <li>• For off-site construction, the process can be used for tracking progress toward completion and delivery.</li> <li>• A process that allows information in a BIM to be transferred to digital layout tools allowing use for a very accurate layout in conformance to the model.</li> </ul>
	34	Digital layout – BIM 2 field (B2F)	<ul style="list-style-type: none"> <li>• This information can be used to validate (QA/QC) the physical facility against the model.</li> <li>• The level of accuracy of the tools will allow the location and installation of hangers for pipe and ducts work as well as the location of structural members.</li> </ul>

(continued)

TABLE 1.1 List of 50 BIM Use Cases by Project Phase Categories (*Continued*)

Phase	#	Description (Abbreviation)	Description
ASSEMBLE	34		<ul style="list-style-type: none"> <li>The ability also exists to pass information to earth moving equipment to ensure proper grades and elevations are met.</li> <li>A process that incorporates the use of BIM(s) to support quality assurance (QA) and (quality control (QC) activities for a project.</li> <li>QA is a way of using a BIM to minimize mistakes or defects in manufactured products being included in the constructed facility to avoid problems when delivering solutions or services to customers, which ISO 9000 defines as “part of quality management focused on providing confidence that quality requirements will be fulfilled.”</li> </ul>
	35	QA/QC – consistency control (QCC)	<ul style="list-style-type: none"> <li>QC is a process by which the BIM supports entities review of the quality of all factors involved in production. ISO 9000 defines quality control as “a part of quality management focused on fulfilling quality requirements.”</li> <li>A business process that takes advantage of information stored in BIM(s) to help validate progress as well as ensuring that the owner’s intent for the facility is being honored both conceptually and contractually.</li> </ul>
	36	Owner approval (OWA)	<ul style="list-style-type: none"> <li>A process that uses BIM(s) to track work in place for validating work completed and payments made to the contractors and subcontractors.</li> <li>A process using a BIM to control the steering of laser beams followed by a distance measurement at every pointing direction to validate that construction is supporting the BIM.</li> </ul>
	37	Pay applications (PAY)	<ul style="list-style-type: none"> <li>This approach is used to capture shapes of objects, buildings and landscapes rapidly. The point cloud generated can be used and interpreted by software to create a BIM of the existing conditions.</li> <li>This process can be used with a BIM to add objects into an existing space or to run piping, ensuring the avoidance of clashes automatically.</li> </ul>
	38	Laser scanning (LAS)	<ul style="list-style-type: none"> <li>The process using BIM(s) for verifying all (or some, depending on scope) of all subsystems just before handover to ensure the owner’s project requirements as intended by the owner and as designed by the building architects and engineers are met.</li> <li>Recommissioning is the periodic systematic process of testing and adjusting the systems in existing buildings using the original projects BIM(s) to ensure continued efficiencies and to ensure sustainability analysis is in place.</li> <li>A process in which design intent BIMs revised to represent the completed facility and its assets more accurately.</li> </ul>
OPERATE	39	Commissioning (COM)	<ul style="list-style-type: none"> <li>This has the potential to contain information regarding not only the main architectural and MEP elements but equipment and asset information as well.</li> <li>The record model may contain information regarding design specifications allowing for validation that the as-constructed BIMs meets or exceeds these specifications.</li> </ul>
	40	Record modeling (REM)	

Phase #	Description (Abbreviation)	Description
OPERATE	41 As Constructed Modeling (ACM)	<ul style="list-style-type: none"> <li>• Furthermore, with the continuous improvement of the record model and the capability to store more information, the model contains an accurate representation of space with information such as serial numbers, warranties the components in the building.</li> <li>• A process in which BIMs contain an accurate depiction of the physical conditions and environment of a facility and its assets.</li> <li>• This has the potential to contain information regarding not only the main architectural and MEP elements but equipment and asset information as well.</li> <li>• These models would be an accurate depiction of space and likely to contain linked to information such as warranties to components in the building.</li> <li>• The as-constructed model differs from the record model as it is not a legal document but a more fluid model identifying changes that have occurred during the construction process.</li> <li>• As-built is often used interchangeably with as-constructed.</li> <li>• A process using BIM(s) in which an organized management system will efficiently aid in the maintenance and operation of a facility and its assets.</li> </ul>
	42 Asset management (ASM)	<ul style="list-style-type: none"> <li>• The assets included in BIM(s), consisting of the physical building, systems, surrounding environment, and equipment, must be maintained, upgraded, and operated at an efficiency that will satisfy both the owner and users at the lowest appropriate cost.</li> <li>• It assists in financial decision-making and short-term and long-term planning and is also supported by the BIM(s).</li> <li>• Asset Management utilizes the data contained in record BIM(s) to determine cost implications of changing or upgrading building assets, segregate costs of assets for financial tax purposes, and maintain a current comprehensive database that can produce the value of a company's assets.</li> <li>• A process in which BIM(s) are utilized to effectively allocate, manage, and track assigned workspaces and resources.</li> </ul>
	43 Space management and tracking (SMT)	<ul style="list-style-type: none"> <li>• BIM(s) will allow the facility management team to analyze the existing use of the space and appropriately manage changes in clientele, use of space, and future changes throughout the facility's life cycle.</li> <li>• Space management and tracking is an application of the record BIM(s).</li> <li>• A process to allow the collection and storage of maintenance and repair information about objects to be brought into BIM(s).</li> </ul>
	44 Maintenance and repair information (MRI)	<ul style="list-style-type: none"> <li>• All information is available electronically at some point in its existence. It is vital to be able to receive it in a form that will be usable and can be included in BIM(s).</li> <li>• Product libraries, once available, maybe the most straightforward approach to collecting this information.</li> <li>• The tool will also need to be able to update the BIM(s) as work orders are executed and if specifications about the objects change.</li> </ul>

(continued)

TABLE 1.1 List of 50 BIM Use Cases by Project Phase Categories (*Continued*)

Phase	#	Description (Abbreviation)	Description
OPERATE	45	FM documentation (FMD)	<ul style="list-style-type: none"> <li>• A process where a facility data schema is developed to ensure information is supplied to the BIM(s) in electronic form so that it can be easily exchanged between the BIM(s) and the organizations selected IWMS tool.</li> <li>• The capability should include textural as well as graphic entities.</li> <li>• The breadth of the facility data is dependent on the ability of an organization to capture and sustain it.</li> </ul>
	46	Building (preventive) maintenance scheduling (BMS)	<ul style="list-style-type: none"> <li>• A process in which the functionality of the building structure (e.g., walls, floors, roof) and equipment serving the building (e.g., mechanical, electrical, plumbing) are maintained over the operational life of a facility using BIM(s).</li> <li>• A successful maintenance program will improve building performance, reduce energy repairs, and reduce overall maintenance costs.</li> <li>• A process in which emergency responders would have access to critical building information in the form of BIM(s).</li> <li>• The BIM(s) would provide critical building information to the responders, which would improve the efficiency of the response and, more importantly, minimize the safety risks.</li> </ul>
	47	Disaster planning/ emergency preparedness (DRC)	<ul style="list-style-type: none"> <li>• The dynamic building information would be provided by a building automation system (BAS), while the static building information, such as floor plans and equipment schematics, would reside in BIM(s).</li> <li>• These two systems would be integrated via a wireless connection, and emergency responders would be linked to an overall system. The BIM(s) coupled with the BAS would be able to display where the emergency was located within the building, possible routes to the area, and any harmful equipment or material locations within the building.</li> </ul>
	48	Security and key management (SKM)	<ul style="list-style-type: none"> <li>• A process to identify and evaluate the security zones in the facility using BIM(s). The evaluation ensures that there are no leaks in the security strategy.</li> <li>• Further, the process includes identifying the door keys required for openings through the security perimeters established to ensure that the level of security as designed is maintained.</li> </ul>
	49	Communication move/add/change management (CMA)	<ul style="list-style-type: none"> <li>• A process tying the BIM(s) to personnel management to help ensure that telephones are in place and the minimum number of lines are being paid.</li> <li>• This item also ensures that hard-wired computers are operational when a person is in space.</li> </ul>
	50	Wayfinding (WAF)	<ul style="list-style-type: none"> <li>• A process of using the BIM(s) for documenting and aiding facility or site occupants. Wayfinding encompasses all the ways in which people (and animals) orient themselves in physical space and navigate from place to place.</li> </ul>

Source: Dana Smith.

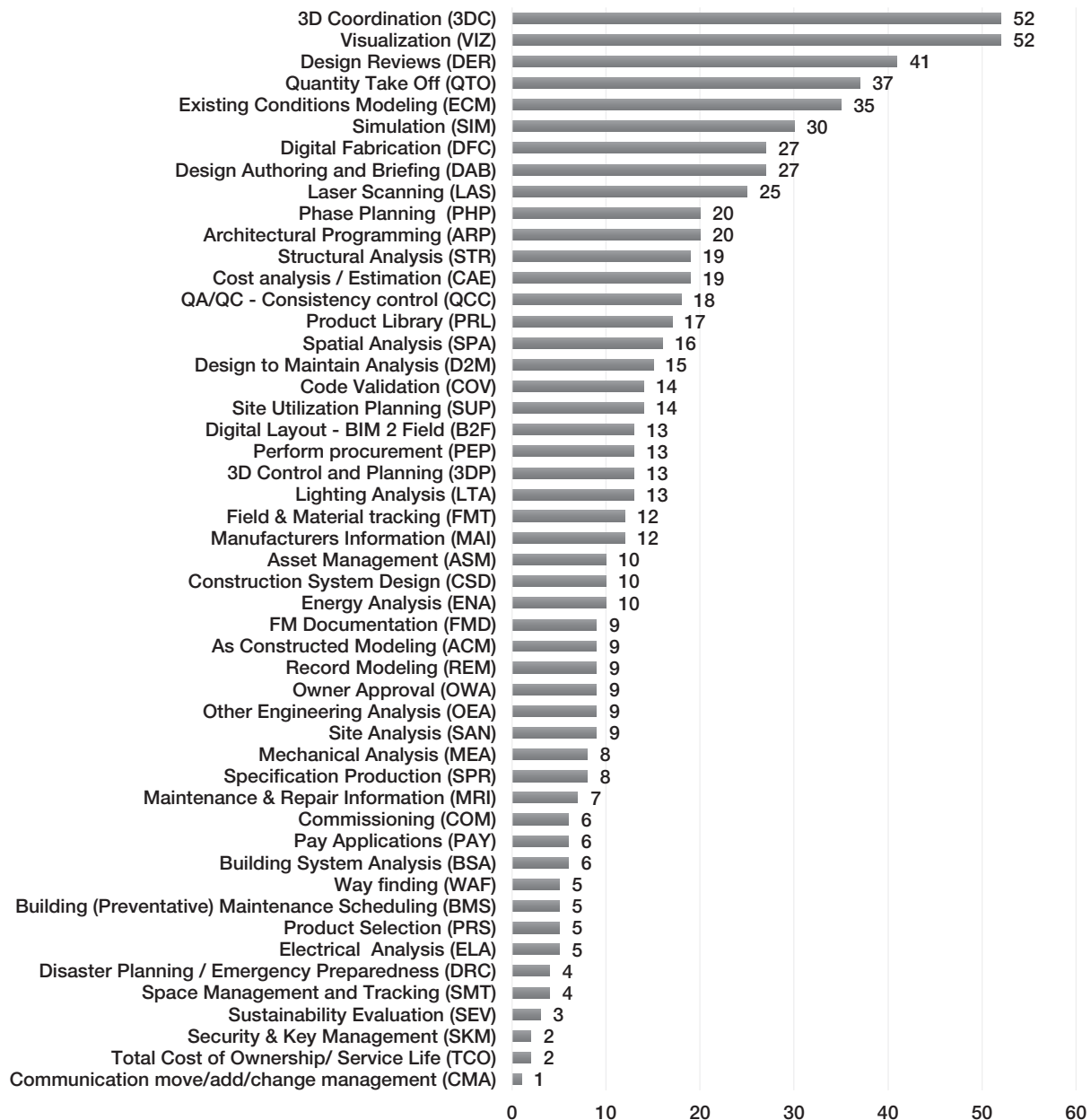


FIGURE 1.13 Combined BIM use cases of BSI 2018–19 awards projects.

Source: Dana Smith.

bSI awards program. Some are far more prevalent in their use, and therefore bSI has more material on which to base case studies. Using these use case categories to identify job tasks would be a valuable cross-check in that educators can ask what job tasks are necessary to accomplish each of the various use cases developed to ensure the required KSAs support them. The 2019 bSI awards were a milestone as it was the first year that provided examples of all fifty use cases. While not all were good examples, at least the worldwide community is beginning to address all currently defined aspects of BIM. This demonstration will help create demand for new software tools to continue to improve the application of the use cases as well as help further identify any additional issues.

As these become more well defined with instruments such as bSI's use case management tool (bSI 2019), it will also be easier to plot a data model on top of them to further define the flow of information

from one to the next. While a significant amount of data is generated during the planning, design, and construction processes, only a small fraction of that data is of value to the operating and maintaining of the facility. While many items require low maintenance nor require any operational support such as concrete walls, most other things are tracked far more regularly. They do have life cycles of their own and are maintained on a monthly or annual basis. Should they need to be replaced, warranty, maintenance, and engineering design specifications are essential data points for the renewal or procurement of repair parts or replacements. Therefore information management becomes a significant issue. Knowing what information is necessary for the O&M and what information is required for unique needs such as modernization, change in use, expansion, and end of life is critical.

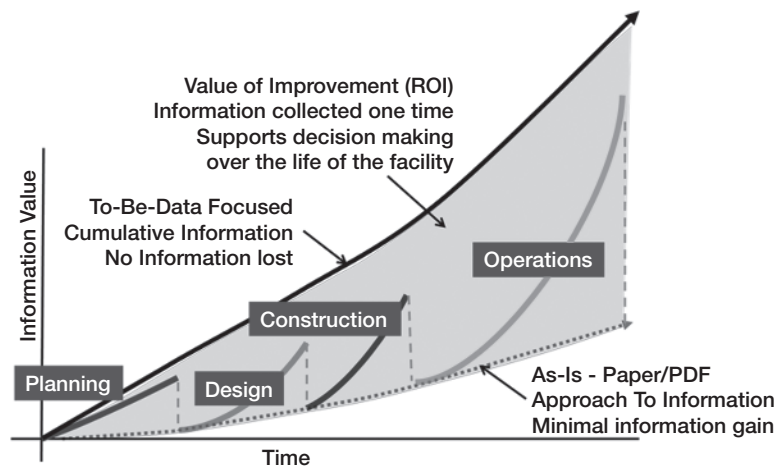
Similarly, there are times when additional detail may be needed even for those less often changed items. For example, design loads of concrete walls may be needed to make the owner requested changes. Consequently, students and emerging professionals should understand the data needs for specific use cases at each phase and across the spectrum of a project. Such understanding is established via education and training of applying the KSAs defined through the process described herein. Educators and trainers should teach and train based on use cases because eventually, owners will typically identify the building elements and systems for which they need data for O&M. The rationale for doing this is to receive a lighter model that is more manageable. A construction manager will identify use cases and populate data accordingly. For instance, there is no need to have the *rooftop unit* (RTU) model number for a 4D simulation model, which can be added later in the recorded model for O&M purposes.

### 1.3.4 The Emergence of a Global BIM Culture and Community of Professionals

BIM use has been on a steady exponential growth since its introduction in the 1980s. There were several Smart Market Reports produced by McGraw-Hill Construction in the 2010s, which demonstrated BIM's increase in various phases of the facility life cycle. The only downside of these levels of use was that there was no definition of what using BIM entailed. It could be anything from someone just purchasing a copy of the software to someone who had a very mature implementation of BIM. Nevertheless, BIM usage continues to be on the rise. BIM has been applied in small, large, or megaprojects, as noted in the case studies earlier in this chapter.

While BIM in the United States is also increasing, the growth is constrained, wherein BIM is implemented the same way historically within a single discipline such as a design office or on a construction project. It is not as often as the case studies demonstrated earlier. Despite recent increase of using alternative project delivery methods such as design–build (DB) and IPD, most projects today still create a design model and hand over little information more than plans and specifications did to the contractor portion of the company who builds another model from scratch for construction. This siloed approach is not how a life cycle implementation of BIM is intended. It is essentially implementing BIM using the design–bid–build model that has been in practice for decades, and therefore many see BIM as only “CAD on steroids.”

Unfortunately, using this approach, one will see few advances in information flow, any decrease in time to deliver, or other improvements in the total cost of ownership for the owner by implementing in this manner. The as-is paper (or PDF) based approach yields the least usable information. Since the owner decides as to what delivery process is used, the designer or contractor will not take the initiative to hand over any additional data due to the looming liability of such an action. Far more progressive implementations are expected to emerge worldwide. Initially, more integrated modeling was seen in the Scandinavian countries, then the UK, based on some government-wide dictates. There is also an integrated form of BIM being implemented in China recently and is growing significantly every year. It is the enlightened owner who asks for the process to produce the information they need to operate their facility to include the delivery of the data on the date of the facility handover. Properly implemented BIM will create an information thread from planning through design, construction to operations, and maintenance (Figure 1.14).



**FIGURE 1.14** Time value of information in different BIM implementation scenarios.

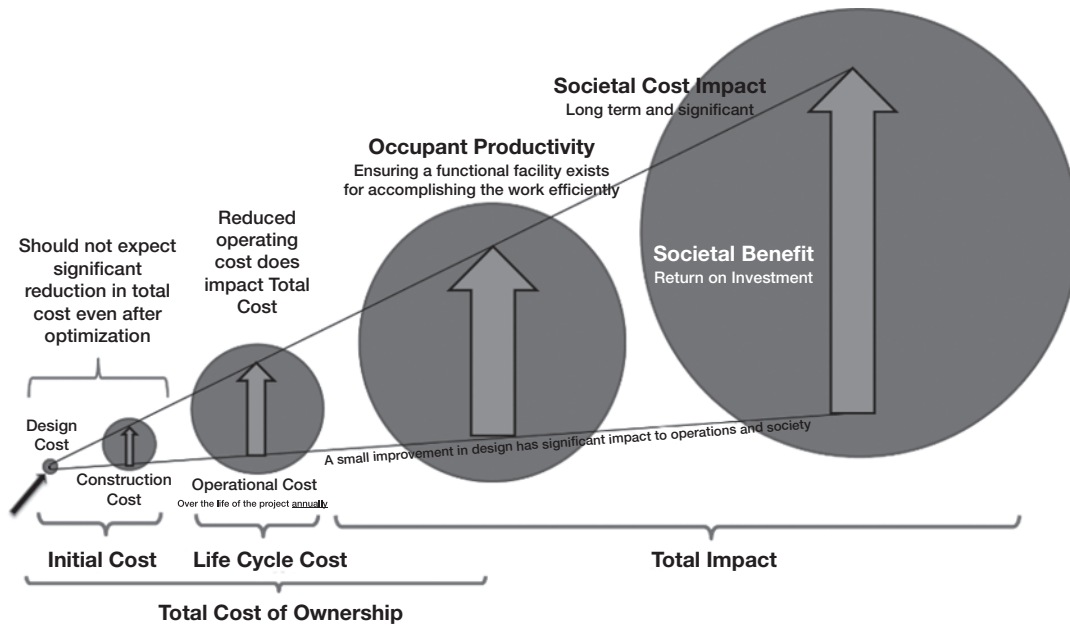
*Source: Dana Smith.*

While an information thread approach will still allow for the creation of the same contract documents as previously created, if needed, it will not lose any information as the life cycle of the project grows. Engaging the designer, contractor, and operations and maintenance principles collectively in the process provides a much higher-quality project which has the potential of reducing time to deliver, lower total cost of ownership, and improved quality simultaneously. The difference between the two curves in Figure 1.14 represents the enhanced return on investment to the owner. If practitioners in the United States do not adapt to this new model for doing business, not only are the practitioners not serving our project owners, but practitioners are also exposing themselves to foreign design and construction firms legitimately winning projects because they can deliver higher-quality projects, faster, and for less money.

Several areas of change are addressed here. Changes in the way disciplines interact with each other, changes in business processes, changes in information management, changes in how the AECO industry delivers the product to the owner, and changes in the richness, quantity, and quality of the information provided. These changes must be addressed in the education of future practitioners. Defining the BOK is only the first step in identifying the necessary adjustments to learning that are required to develop exceptional BIM talent for the future. Once the information thread approach is adopted, then the AECO industry can experience the transition from a stove-piped or siloed approach to the disciplines making up the facility and infrastructure industry, where each discipline functions as an island to themselves. They are not concerned with receiving information from another phase of the life cycle or passing credible and trusted information to a later discipline involved with a project.

Dana Smith, with intellectual contributions from Mark Bew (University of Kentucky) and Matthew Hallowell (University of Colorado–Boulder), developed **Figure 1.15** to depict the impacts of various phases of a project's life. While the sizes indicate relative values, they are certainly not to scale. The effects of design decisions on occupants and society will vary significantly for each project. For example, the impact on society of an office building is likely considerably less than a hospital. This diagram intends to indicate that a small decision made during design can have an immense effect on the societal impact of a project. The selection of one product over another, while maybe cheaper initially, may have significantly higher additional costs related to operations and maintenance.

These costs would dwarf the minor differences in the initial or first cost. Enabling the designer (and owner) to understand the impact of these design decisions at the time they are made will have a profound effect on the project, potentially the owner's profitability as well as sustainability and possibly the environment. BIM, as well as total cost of ownership (TCO), addresses a holistic life cycle vision of the project and therefore are well suited for each other as TCO can provide the metrics to identify the value associated with BIM for the owner. The visibility of these impacts will vary by project delivery and contracting



**FIGURE 1.15** Cost impact of design decisions on a project’s life.  
**Source:** Dana Smith.

approach. Traditional DBB would allow the most restricted view. At the same time, DB, construction management at-risk (CMAR), and IPD could potentially increase the visibility and thus significantly improve the outcome. However, to accomplish such change, to the AECO industry will need to continue to substantially and profoundly not only change the current business models but also produce transformed practitioners through education. This change in culture will only be accomplished by creating a common BIM BOK that can be implemented across all institutes of higher learning.

The transformation of the design and construction industry is a worldwide phenomenon. While there are successes in various projects, there are few substantive changes across the industry. This is likely due to smart individuals in each organization needing to figure out the changes on their own. This one-off approach exists because of the gaps in college AECO programs. New strategies are not currently being taught in a classroom as much as being learned on the job. One outcome of the BIM BOK will be to elevate the level of interoperability and collaboration of new practitioners by ensuring they have visibility into all other roles associated with project delivery, including design disciplines, construction means and methods, as well as the availability of manufactured products and supply chain implications. Understanding how projects will be operated and maintained, as well as renewal periods and renewal tasks, will also be critical to ultimate success. This transition, as noted earlier, will not be quick, and indeed, this first BIM BOK will be a significant first step to a long and fruitful future. It is a first step in defining how the AECO community will effect such change in the way educators educate. The rest of this book will expand on the thoughts promoted in this call to create a BIM BOK.

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