Information in construction

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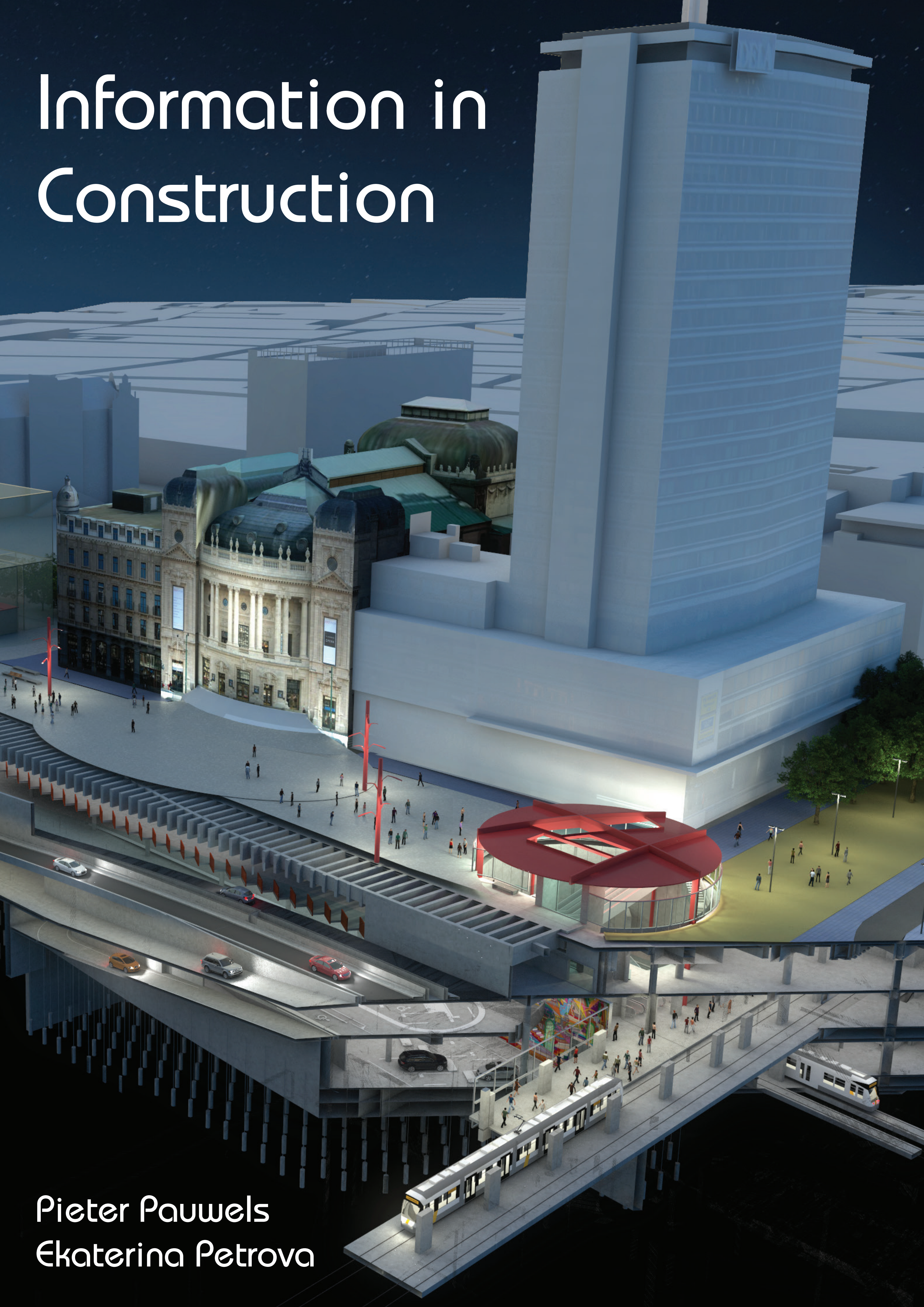

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1. Introduction

1.1 The origins of Building Information Modelling

Building Information Modelling (BIM) has established itself as the preferred technique to model, structure and use building information. Even though the term is considered relatively new, its origins lie within the Building Description System (BDS) proposed by Charles Eastman in 1975 in the article “The use of computers instead of drawings in building design”[1]. Already at that time, his work shows clear references with what BIM is today, namely a model that resembles the backbone of all information related to the building. Eastman proposes a Building Description System (BDS) with the following main features, which have also been recognised as the key features of BIM:

- Models instead of drawings
- Database-oriented
- For visual and quantitative analyses

The focus on models proposed and put forward by Eastman started a research era in the 1980s that focused on Building Product Models (BPM) in the United States, and similarly on Product Information Models (PIM) in Europe. From that moment onwards, a long research and development (R&D) track on PIMs and BPMs was initiated (Figure 1.1). This track focused heavily on building data and models stored in databases. The main goal of these R&D efforts was not software development by itself, but rather data handling, database oriented systems and changing the way in which Architecture, Engineering and Construction (AEC) industry professionals work.

The concept of Building Information Modelling emerged around late 1990s- beginning of 2000. This is also the moment when some of the most seminal publications about BIM emerged, including Eastman’s “Building Product Models: Computer Environments Supporting Design and Construction” from 1999[2], and the first edition of “The BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors” by Eastman et al. (2008)[3]. That lead to the commercialisation of the term and created ‘hype’, boosted continuously by software vendors actively promoting the use of BIM and BIM software. The focus then shifted to the software, rather than data handling or the change in the way in which we work. Nowadays, in the end of the 2010s, focus is slowly shifting back to overall information management strategies, data handling and exchange methods and BIM-based workflows in general.

[1] C.M. Eastman. The use of computers instead of drawings in building design. AIA Journal 63 (3), pp. 46-50, 1975.
[2] C. Eastman. Building Product Models: Computer Environments Supporting Design and Construction, 1999, CRC Press, Inc. Boca Raton, FL, USA.
[3] Chuck Eastman, Paul Teicholz, Rafael Sacks, Kathleen Liston. BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors. 2008.

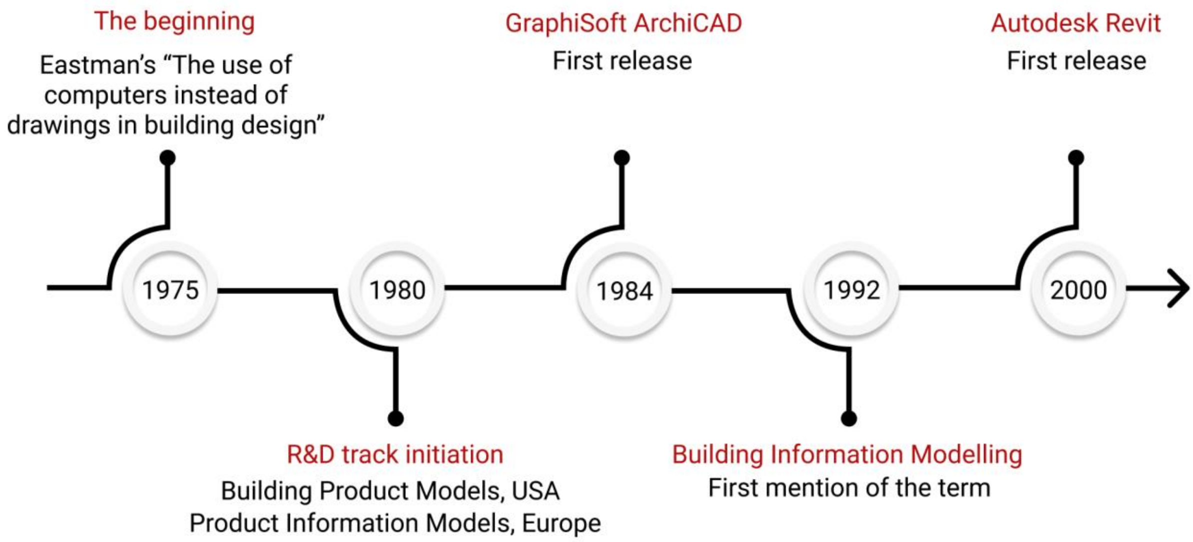


Figure 1.1 Research and development track on Building Product Models and Product Information Models from the 1980s onwards.

1.2 What is BIM?

The term BIM has proven to be very ambiguous. Hence, when faced with the term, many different interpretations and opinions arise. These terms and interpretations do not necessarily exclude or overrule each other. Therefore, in the following section, we will provide a brief overview of the most commonly used definitions.

1.2.1 BIM vs. 3D vs. 2D

First, BIM is often said to be something new and different from the many existing 3D and 2D CAD applications. In this case, BIM is often said to be about the unique combination of "3D and information". The focus on information makes it stand clear from the informationless 3D and 2D modelling approaches and applications. In this sense, it builds on 2D Computer-Aided Design (CAD) and advanced 3D modelling. As mentioned above, the acronym BIM only emerged in the dawn of 2000. The traditional CAD and 3D modelling approaches have been around for much longer and are therefore much better established as concepts.

While the traditional CAD approaches used 2D drawing elements that later evolved into 3D, BIM integrates 3D modelling with intelligent data parameters. These parameters are assigned to the individual objects that constitute a BIM model. In other words, while 3D CAD represents only graphical entities, BIM models carry information related to the entire building life cycle. Key CAD applications include AutoCAD and Vectorworks, which emerged in the early 1980s (see Figure 1.2). Advanced 3D modelling applications such as 3DS max, Rhinoceros, and SketchUp emerged later, in the 1990s. Even though the BIM acronym appeared later, one of the main BIM applications known today, namely ArchiCAD, already existed in 1984, and was then known as a CAD application.

Thus, the key difference between BIM applications and other applications is often said to be the co-existence of information and 3D geometry. This gives a possibility to work in an integrated manner. For example, if something is changed in a plan view, the change is reflected in the elevations, sections and the 3D view. Furthermore, this allows the integration of information, resulting in a detailed definition of the project, including schedules and object properties. Designing in a BIM environment by definition thus requires the presence of 3D geometric information in this definition. A significant part of the value of BIM lies within the fact that it allows integration of the design, analysis and drafting processes, thereby facilitating the achievement of project deliverables in a much more efficient way.

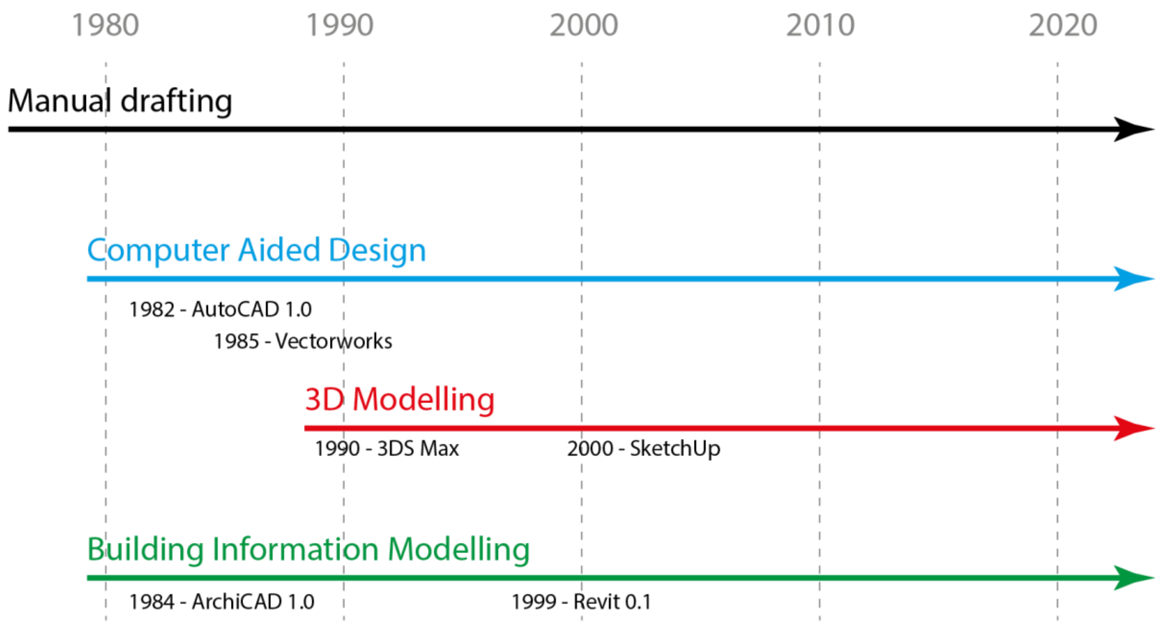


Figure 1.2. The evolution of 2D CAD, 3D and BIM over time (Image after Ruben Van de Walle, HOWEST).

Even if 2D CAD, 3D, and BIM are nowadays considered to be related to different kinds of applications, they are not that far apart in the sense that they all deal with 'information about the building' and they 'aid in the modelling of a building with a computer'. Furthermore, existing 2D and 3D modelling applications are often enriched with information handling features, making them not that different from BIM environments any more. Defining BIM as "3D + information" may thus be considered a rather narrow definition. In many design processes, the focus on "3D + information" is less important than the fact that users follow a process in which information about buildings gets exchanged between people in a construction project. In such BIM processes, not only BIM models will be used, but also 2D CAD and 3D models, and the focus will still be on high-level information management, regardless of the additional use of "informationless" geometric modelling and representation approaches.

BIM differs from the traditional methods, as it requires that all objects are considered, while the traditional 2D drawings do not represent objects. When using BIM software, the need for information regarding each component, is required much earlier in the process (object type, placement, properties). That information helps ensure the ability to affect the design as early as possible, at the lowest possible cost. Therefore, the difference between the traditional methods and BIM-based practice is a change that affects all industry practitioners and that complete change in the practical approaches is essential to reaching the overall goal of the concept behind BIM.

So, BIM modelling results in a gem full of information, which is used and enriched throughout the entire building life cycle. This model can be used for many purposes, generating lots of added value for the different disciplines involved throughout the entire building life cycle. This opposes to the traditional workflow, where it was necessary to carry out an important number of operations to synchronize the information between the different stakeholders or the members of a team. Nowadays, that usually happens in a different way, in the sense that the synchronization incorporates the different members of the team directly, and the extraction of information (2D plans, 3D geometry, schedules, etc.) from a BIM model is the norm.

1.2.2 BIM as a product vs. BIM as a process

A second definition distinguishes between BIM as a product and BIM as a process. When referring to BIM as a product, one typically indicates that BIM deals with a 3D model enriched with information (BIM = 3D + Information). As such, it gets distinguished from regular CAD, which focuses purely on geometry (Figure 1.3).

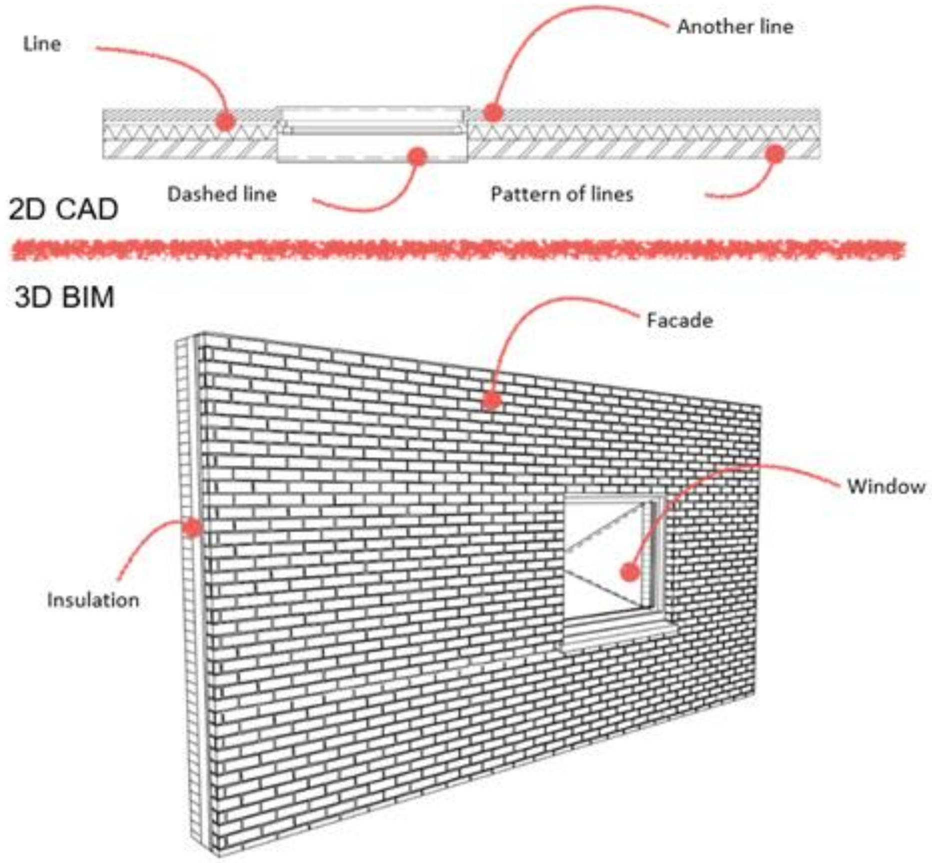


Figure 1.3 BIM is 3D + Information (Image by Ruben Van de Walle, HOWEST).

A Building Information Model (BIM) can then be defined as the digital representation of a building that contains semantic information about the building elements. When BIM is interpreted as a process, however, the focus of the definition shifts away from software and 3D models, emphasizing instead that information is managed and exchanged over time. In order words, the keyword BIM also defines an information management process based on the collaborative use of semantically rich 3D digital building models in all stages of the project's and building's life cycle.

Thus, BIM as a process can be defined as the information management process, which mainly focuses on enabling and facilitating the integrated project flow and delivery by collaborative use of semantically rich building information in all stages of the project and building life cycle. The BIM process is unique as it is based on digital, shared, integrated and interoperable building information models. From that perspective, the Building Information Modelling process can also be defined as a facility that enables information management throughout the life cycle of a building, while a Building Information Model is the (set of) semantically rich shared 3D digital building model(s) that form(s) the backbone of the Building Information Modelling process.

A number of other definitions can also be mentioned:

"Building Information Modeling (BIM) is an intelligent 3D model-based process that equips architecture, engineering, and construction professionals with the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure."

Autodesk[4]

"BIM is an acronym for Building Information Modelling, or Building Information Model. It describes the process of designing a building collaboratively using one coherent system of computer models rather than as separate sets of drawings. Don't be misled by the word 'building' – BIM is just as relevant to the civil engineering sector. […] BIM is a digital representation of physical and functional characteristics of a facility… and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition."

WSP & Parsons-Brinckerhoff[5]

In other words, BIM is the digital pre-construction of a project in a controlled digital environment. This includes the management and exchange of information among stakeholders, thereby typically relying on 3D models enriched with information.

According to NBIMS (2006)[6], a BIM model is a computable representation of all the physical and functional characteristics of a building and its related life cycle information, which is intended to be a repository of information for the building owner/operator to use and maintain throughout the life cycle of a building. The US General Services Administration BIM Guide (2006)[7] indicates that the information in a BIM model catalogues the physical and functional characteristics of the design, construction and operational status of the building.

4 https://www.autodesk.com/solutions/bim
5 http://www.wsp-pb.com/en/Who-we-are/In-the-media/News/2013/What-is-BIM/
6 http://portal.opengeospatial.org/files/?artifact_id=20644
7 https://www.gsa.gov/real-estate/design-construction/3d4d-building-information-modeling/bim-guides/bim-guide-01-bim-overview

However, despite the profound change that BIM has brought, the traditional by nature construction industry is 'document-centric'. The documents contain drawings, regulations, specifications, etc. and the information stored in them is rich and multidimensional. When parties in the construction process are required to exchange or share information using documents, immense barriers to communication are faced among the various stakeholders, which in turn significantly affects the efficiency and performance of the industry. The advancements in information technologies have changed the way in which we collaborate and interpret design, analysis, construction management and facilities management. Therefore, BIM has emerged as a cure for the illness of poor information exchange practices and miscommunication in the industry.

BIM is applied in different areas and at different levels; that is, either the models are used as a resource to enable information exchange or BIM is realized as a process of managing a project through a single shared information backbone. Today, BIM is an active research area that addresses problems related to efficient information exchange and collaboration in AEC.

1.2.3 Open BIM vs. Closed BIM vs. Little BIM vs. Big BIM

Apart from the difference between BIM vs. 3D vs. CAD, and BIM as a product vs. BIM as a process, a number of other common definitions and terms are often used, namely, open BIM, closed BIM, little BIM, and big BIM. Open BIM is *"a universal approach to the collaborative design, realization, and operation of buildings based on open standards and workflows"*[8]. As such, this approach stands apart from the Closed BIM approach, in which proprietary data formats and closed and intransparent workflows are used. This would typically be the case when using software from one vendor only and keeping all information in-house (closed).

OpenBIM focuses on a couple of main goals, as communicated by buildingSMART International[9].

- *openBIM supports a transparent, open workflow, allowing project members to participate regardless of the software tools they use.*
- *openBIM creates a common language for widely referenced processes, allowing industry and government to procure projects with transparent commercial engagement, comparable service evaluation and assured data quality.*
- *openBIM provides enduring project data for use throughout the asset life cycle, avoiding multiple input of the same data and consequential errors.*
- *Small and large (platform) software vendors can participate and compete on system-independent, 'best-of-breed' solutions.*
- *openBIM energizes the online product supply side with more exact user demand searches, and delivers the product data directly into the BIM.*

The terms open and closed BIM are very often used in defining the way in which BIM is adopted within a company. In this regard, also the terms little BIM and big BIM are of big importance. Throughout the years, the incremental adoption of BIM has happened in various

[8] https://www.buildingsmart.org/standards/technical-vision/
[9] https://www.buildingsmart.org/standards/technical-vision/

ways. The most widely accepted subcategories for BIM adoption, relying on the mentioned terms, are listed in Fig. 1.4.

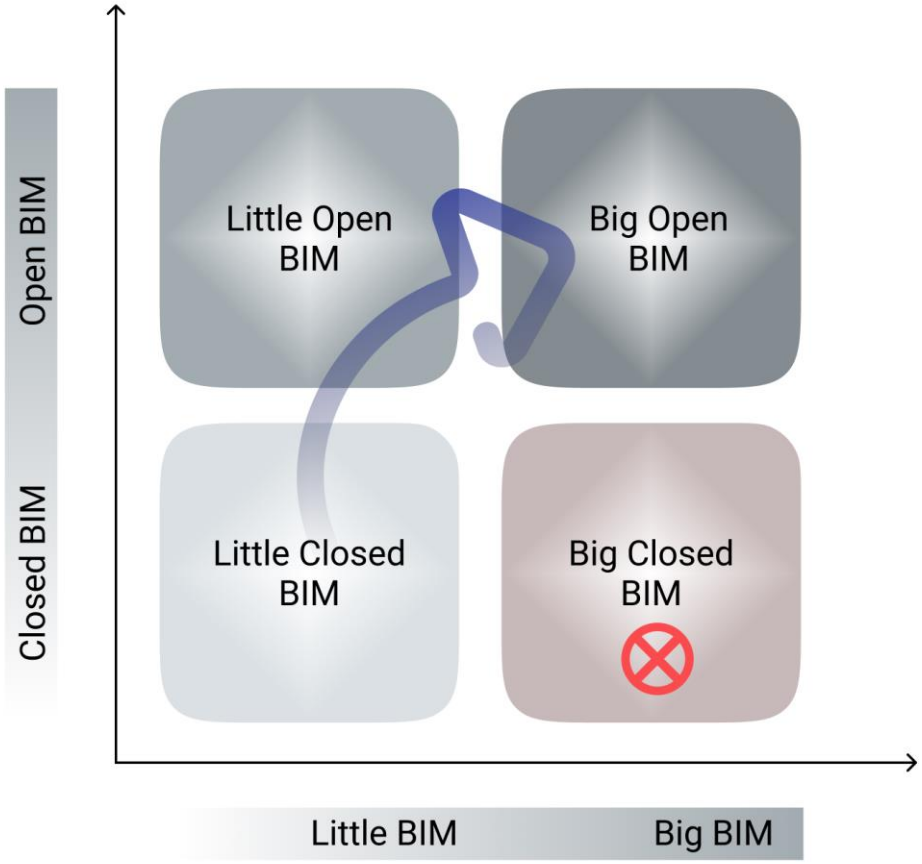


Figure 1.4 Little BIM vs Big BIM and Open BIM vs Closed BIM.

Little BIM is conceived as setting up an internal BIM process on company level. This usually happens in the early phases of a BIM implementation plan, when design professionals prefer to become familiar with BIM within their own organization, before they fully engage in BIM-based workflows with external parties. The first step in this process is to make a well-informed choice of software and hardware that is most applicable to achieving the goals. However, Little BIM is also about optimizing the internal business processes and workflows. All these aspects need to be considered in the initial setup of a BIM implementation plan. For a construction company that is starting to 'do' BIM, the Little BIM approach is a good first step: there are many advantages and efficiency improvements to achieve at company level. Moreover, Little BIM is a necessary condition for being able to get to Big BIM level.

In a Little BIM approach, several professionals from the same company work together on the same project and the related models. In communication to other parties (e.g. consultants, contractors, manufacturers), the model(s) serve as a reference. In a Little BIM approach, this often means that schedules, plans, PDFs, are generated and shared, rather than complete model(s). Therefore, a Little BIM setup typically includes the BIM technology required to carry out a project, but also requires other means to exchange information with external parties (2D CAD and 3D modelling applications and approaches). This often naturally leads to realizing the need of Big BIM and Open BIM. In transitioning towards a Big BIM approach, the focus then shifts entirely towards the exchange of BIM models.

Big BIM has a lot to do with optimizing processes and working more efficiently, not only within the company, but across the entire chain at project level. Using BIM in a collaborative setting requires a different way of working and other competences than just doing it internally. Transparency and cooperation are the central values here. As a result, Closed Big BIM usually does not exist, and Big BIM is by definition open. Big BIM is obviously more complex to achieve than Little BIM, since the company is dependent on the collaborative partners. Moreover, there are a lot of practical aspects that need to be taken into account: how to exchange information, how to manage the accessibility of data platforms, how to evaluate and so on.

These larger Big BIM constellations take advantage of efficiencies and control scales with greater traceability. Many multinational companies seek business outside their territory and face new markets having to get used to the management of local human resources. With the adoption of BIM, your local resources, whether internal or with other collaborators, will be able to participate in distant projects with a national cost, which will make them more competitive.

1.3 Who needs BIM?

Many different stakeholders are facing the question or requirement of “doing BIM” or “implementing BIM”. Most commonly, the requirement is targeted at the key players in the AEC industry, and then most notably those who are in charge of modelling the constructions that are to be built. Looking at the entire information delivery cycle depicted in Figure 1.6, this includes mainly those stakeholders that are involved in the capital expenditures (CapEx) phases: from defining the employer’s information requirements (EIRs) to the actual handover. Stakeholders that are most prominently involved in those phases are:

- Architects
- Engineers
- Contractors

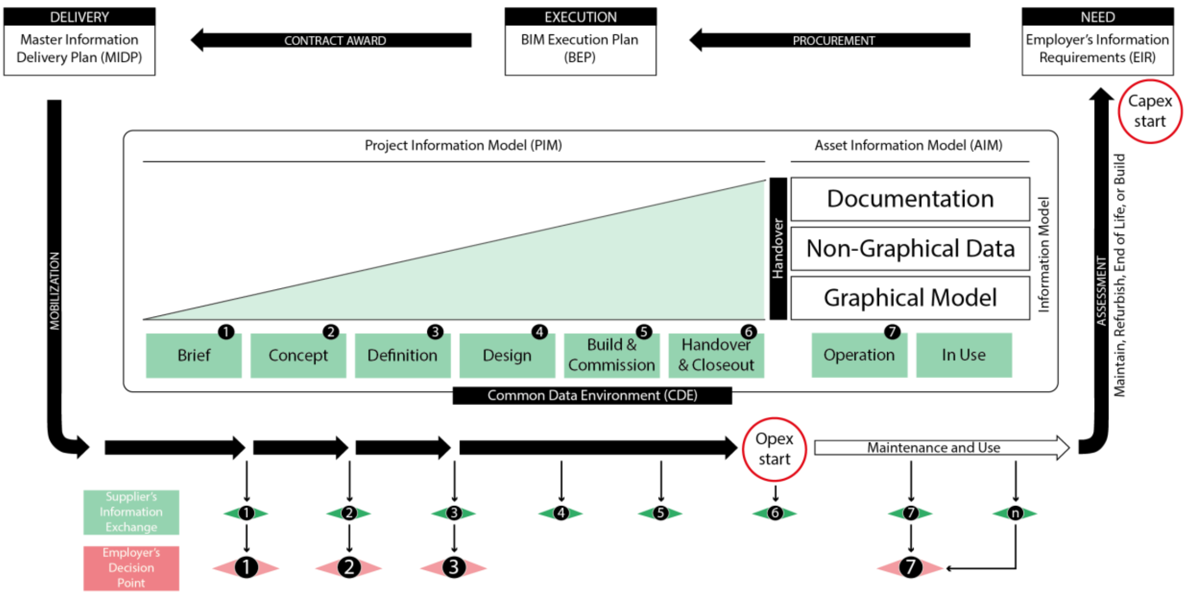


Figure 1.5 The information delivery cycle, as included in the PAS 1192-2.

These main stakeholders can usually refer quite well to the many BIM Reference Guides (see Chapter 5) for the implementation of BIM, as they are directly involved in preparing the BIM models in collaboration with all other stakeholders involved at that stage.

There are a number of other stakeholders that are also facing the requirement or question of implementing BIM, which are not as directly involved in the BIM process that takes place in that CapEx stages. Many of these stakeholders are active in the operational phase of the built environment and are thus more concerned with Operational Expenditures (OpEx). This includes:

- Facility managers
- Owners
- Product manufacturers
- Infrastructure-oriented companies (Rail, Road, Waterway, Bridge, etc.)
- Governments

In the sections below, we will go through some of these stakeholders, indicating the profiles they represent and how they implement BIM in general.

1.3.1 Architects

Architectural design offices come in various configurations. They vary in size and organisational structure, and tend to either focus on the creative architectural design task or on the construction supervision task, or both.

Small architectural design offices

Small architectural design offices, usually consisting of only a handful of professionals (e.g. 2 to 4), typically have a limited scope. Such studios are typically aiming at the design of smaller scale projects (e.g residential buildings). Most commonly, these are local buildings, built by equally small-sized local contractors (small and medium-sized enterprises (SMEs)). In such cases, the architect as a stakeholder tends to be responsible for capturing the owner's project requirements, design according to them, and then supervise the construction site. Each of the architects working in the office is typically required to be able to do all those tasks.

In most cases, the small architectural design studio confines itself to the creative design only. In such cases, engineering analyses are done by one or more external engineering consultancy companies. Also, the construction site itself is often managed in very close collaboration with the contractor. In such cases, the task of implementing BIM becomes an aim towards a Little BIM approach. And even then, it should strongly take into account the nature of the company. Key aspects of these companies include:

- Small and not so complex projects (buildings)
- Focus on architectural design, less on engineering analysis or construction site management
- Limited resources

Considering that the engineering analyses and construction site management often reside with other stakeholders, the effect of information re-use is limited for the individual architectural design offices as a single stakeholder. For instance, the architectural design firm can choose to adopt BIM and model buildings as complete BIM models, so that these models can be re-used by the engineers and the contractors. For many design firms, this will imply additional effort compared to the traditional way of working, and the added value in fact does not lie directly within their own company. Instead, the added value lies with the engineers and the contractors and presumably even more with the building owner.

So, when the implementation of BIM in a small architectural design firm is aimed to be the creation of BIM models, then clear caution should be taken that some of the added value also returns to the small architectural design firm as a form of return on investment. This can mean that the owner pays more to the architect to value the additional effort of building a BIM model. Alternatively, the design firm may choose to find added value elsewhere. For example, when many designs are fairly similar in kind, the use of BIM can be profitable not only for visualization, but also for reducing the reworking and remodelling efforts across different design projects sharing particular levels of similarity. In this case, added value of BIM lies in visualization and less reworking and remodelling.

To further improve internal work processes and improve the speed at which designs are developed and completed, the small architectural design firm may choose to adopt programming (plug-ins) or visual programming tools (e.g. Rhino or Dynamo) to further streamline the information flow within the office and/or between the projects.

Big architectural design offices

Big architectural design offices are different in kind and can thus implement BIM in a different manner. The main characteristics of such companies include:

- Large and more complex buildings
- Often including various engineering analyses and construction site management
- Larger amount of resources

The differences in the company profile change the way in which BIM can be implemented. Because of the focus on large and more complex projects, the use of BIM makes a lot more sense, as BIM software makes it easier to keep track of the diverse aspects (disciplines) models of a building. Furthermore, as the larger design office often includes engineering analyses and construction site management, a Big BIM approach is much more within reach. Close collaboration will be needed with other disciplines (e.g. engineers and contractors), and this will need to be done with many of the available tools: coordination, simulation and analysis tools, role play in a construction project, protocols, ICT agreements, modelling agreements, and so forth.

1.3.2 Engineers

Engineering companies are most commonly occupied with various design aspects and analyses (e.g. structural analysis, energy performance, indoor environmental quality, etc.) and systems design (e.g. HVAC systems) for various kinds of buildings, although this task can also, to some extent, be undertaken by architectural design companies. In most traditional process diagrams and collaboration workflows, these companies and therefore related tasks, get involved after the development of the architectural design and its corresponding model. Engineers are then typically required to take into account continuous changes made by the architect. Because of the dependency on the architectural design models, engineering companies are often by default involved in a BIM collaborative workflow; most commonly a Big BIM approach, which also includes also the contractor. However, involvement in itself does not guarantee good results and it is not unusual for engineering consultants to be involved in the process too late, i.e. after the design is completed. That makes their input much harder to implement, which is against the core principles of BIM-based practice.

1.3.3 Contractors

Contractors usually also vary in size, from very large multinational contractor companies to local SMEs. These stakeholders are typically among the first ones mentioned in BIM reference guides, BIM adoption plans, and so forth, because they are so actively involved in the CapEx phase of the building life cycle. They are typically among the first ones to effectively gain the benefits of adopting BIM early in the design and construction process. In many ways, BIM Reference guides give a good idea of how contractors may want to implement BIM in their company (Little BIM, Big BIM, incentives on failure cost and efficiency gains, and so forth).

The more interesting challenges arise when looking at the diverse divisions in the company and getting each of them one by one effectively on board in terms of BIM implementation. A contractor company may consist of some of the following divisions:

- Technical design or modelling division
- Planning and work preparation division
- Quantity surveyor division
- Construction site management
- Construction workers
- Company management

In many cases, a BIM implementation plan and strategy results first and foremost in the conversion of the drafting division into a BIM modelling division. This results then in a Little BIM approach towards BIM implementation in the company. The downside of this, is that the other divisions (planning, site management, quantity take-off, project management, design, etc.) benefit little from the BIM approach, as they still work in their traditional ways.

A Big BIM approach is thus much more worthwhile, in which not only the technical drawing office becomes a BIM modelling office, but also the other divisions gradually shift focus towards reusing and exchanging information with the rest. This does not mean that planning and quantity take-off divisions should become entirely proficient in BIM modeling. On the contrary, as much as the modeling division should start from its inputs and requested outputs, the other divisions also need to start from their information needs, inputs and requested outputs. A BIM implementation plan for the planning and work preparation division might then include the adoption of, for instance, a software product such as Autodesk Navisworks, but it also needs to specify which input this division requires from colleagues in order to work efficiently.

1.3.4 Facility Managers, Owners, and Governmental Institutions

A stakeholder who is almost always meant to be included in the CapEx phases of a design and construction process, but is often still on the very edge of this phase, is the facility manager or facility management organisation. The facility manager typically serves the needs of the owner. Additionally, the owner is often a governmental institution or the state itself. The facility manager, owner, and governmental institutions, are therefore considered to have the same profile, aiming at the same purpose and needing to implement BIM in similar ways: they are involved with maintaining the project (operational phase - OpEx) and/or specifying and contracting the project (construction phase - CapEx).

Although such a stakeholder is meant to be included in the CapEx phases of a design and construction project, they are a lot more prominently present in the OpEx phases of the same project. In many cases, these stakeholders therefore play multiple roles, particularly in the case of a governmental institution owning public infrastructure.

One of the key roles of this stakeholder is to maintain the facilities over time and optimize operational performance. To do so, they rely heavily on Facility Management Information System (FMIS) software. This software is different from BIM modelling tools, as it is much less oriented towards 3D geometric editing. At best, a 3D geometric viewer is included to give the end user an idea of the space and environment they are working with. Furthermore, not all details of a building are included in the FMIS. Only some of the design information is kept, and that information is then typically extended with FM-oriented information (schedules of operation, system descriptions, manufacturer product data, etc.). Therefore, one of the key targets for a facility manager, owner, or governmental institution should be the definition of what information needs to be delivered in order for the handover to be useful in the FMIS software.

A second role often played by the Facility Manager – Owner – Governmental institution is that of a client. Whenever a facility needs to be built or renovated, this stakeholder takes on the role of the client, while also participating in the design and construction process. In the case of a governmental institution, this implies setting up a public tender. In this case, the client is required to set up a number of constraints in the form of a design brief that serve as the main drive for the architect, engineer, and contractor companies.

1.3.5 Product Manufacturers

Product manufacturers are less often within scope in documentation about BIM. Yet, they play an important role as they supply the required materials, components and/or systems to the diverse construction sites. However, it is seldom that a manufacturer deploys BIM authoring tools fully and takes active part in BIM processes. Product manufacturers typically rely on highly detailed product modelling software (e.g. Autodesk Inventor) and equally elaborate Product Information Management Systems (PIMS). The level of geometric detail and the number of associated attributes in a PIMS often heavily exceeds the detail and number of attributes required in a BIM model.

Yet, there is a clear incentive for a product manufacturer to be involved in the overall BIM processes on the market. For one, the earlier a manufacturer company can get their products referenced in a BIM model that is under development for a building, the higher are the chances of being selected as product supplier for that particular site. Effectively getting involved in a construction project can be achieved in a number of manners, which again need to be elaborated in a clear BIM implementation strategy. The following strategies may be targeted:

- *Provide product data to designers in the form of parametric BIM objects, assuming they will remain in use.*

  In this case, parametric BIM objects are modelled, either in-house or by an external partner. These BIM objects are typically simplified versions of the detailed product data in the PIMS. Yet, through the use of identifiers, clear links can be maintained to the PIMS for later re-use. The main difficulty here is that the BIM objects supplied often expose too high level of detail. Architects often require only a very simple geometric 'placeholder', which then points directly to the PIMS of the corresponding product manufacturer. Furthermore, the geometric parametric data involved with a real product often has a much more complex structure compared to the geometric data that can be included in a BIM object (e.g. window frame thickness depends on weight of the glazing). Hence, the geometric parameters in a BIM object often have little to do with the actual product offered by the product manufacturer and a full configurator will still need to be used in a later phase when contacting a product manufacturer.

- *Provide plug-ins in key BIM authoring environments, allowing to import product data directly from the manufacturer's web services and PIMS.*

  In this case, the product manufacturer chooses not to model all geometry explicitly in a BIM object, but instead aims to build plugins for the BIM authoring tools that are connected to the manufacturer's database. Such a plug-in may for example add product data to any 3D geometric object modelled in the BIM model. The difficulty here is that it is likely impossible for a stakeholder to keep track of all the diverse plug-ins offered by all the diverse product manufacturers.

- *Provide a service to other stakeholders by manually replacing generic BIM objects with manufacturer-specific BIM objects that are ready for production.*

  In this case, the product manufacturer takes part in the CapEx BIM process more actively, by contributing directly to modelling a part of the BIM model. In other words, the main strategy here is to provide a service to any other stakeholder, allowing them to submit their model and request to replace BIM objects with manufacturer-specific BIM objects. In this case, of course, agreements related to data needs, ownership and modelling responsibilities need to be considered explicitly, which will then naturally be the main challenge in this scenario.

The three scenarios presented above are examples for BIM implementation strategies within the product manufacturer organisation. Even when one or more similar strategies is chosen, clear decisions need to be made to make them achievable for all specific employees in a company. Each of these strategies requires different technical choices. For instance, if plug-ins that connect to an in-house web service configurator are to be built, then specific data requirements need to be set for that web service configurator to work. These data requirements depend heavily on the product that is offered, the data infrastructure of the PIMS, as well as the processes they support.

1.3.6 Rail-, Road-, and Waterway companies

Finally, the infrastructure domain also houses a number of companies that are confronted with BIM. This typically includes companies working with railway infrastructure, road and bridge infrastructure, waterways, and so forth. Because of the nature of the objects (horizontal, large-scale, geospatial constructions), these stakeholders naturally have different considerations regarding the use and implementation of BIM compared to stakeholders that are more commonly involved with BIM (architect, engineer, contractor).

Infrastructure projects are furthermore characterized by very specific clients. Usually, the clients are infrastructure management companies, which often cover large areas of land, in the cases where they are not national organizations. These organizations also need to consider implementing BIM in their workflows. An organization that manages a full national railway system typically relies heavily on large databases with very diverse data sets (track data, geospatial data, station data, electric systems data, geometric data in diverse levels of detail, and so forth). Full 3D geometric data representations are seldom available, as the organization primarily uses the raw data, rather than its visual 3D representation. A lot of the data is also two-dimensional (geospatial map data). Hence, clients in the infrastructure domain often rely on 2D representations and databases, and much less on 3D and BIM (similar to Facility Managers in general). Yet, a lot of the content delivered by contractors, engineers, and architects will be supplied in the form of BIM models. For these clients, it is therefore of utmost importance to specify how data needs to be provided, so that it can be loaded into the management systems of the infrastructure client.

2. Why BIM?

The use of BIM has increased dramatically in the last decade. Of course, nobody would use BIM software or a BIM-based approach if there would not be any added value. In this chapter, we therefore look into the reasons why one would implement BIM and the main incentives and drivers behind the use and adoption of BIM.

2.1 The technical incentive

BIM should ideally be implemented first and foremost because of the technical advantage(s) it offers. Hence, this section starts with listing some of the most important technical incentives related to BIM adoption, namely:

- Visualization
- Collaboration through Coordination of Information
- Less Reworking, Remodeling and Manual Data Input
- Accurate Simulation with Accurate Information

2.1.1 Visualization

One simple benefit of using BIM, is that the BIM software often serves as an excellent visualization tool. The BIM model in a stakeholder company is often the single reference for the project team, as it effectively serves as the sole source of information. As this sole reference (BIM as a product) is a 3D model, it is therefore no longer necessary to mentally (or in other ways) visualize what the plan says against what is seen in the elevation or section. At any given moment in time, a full 3D visualization is available for anyone to view and take decisions based on that visualization.

From this direct visualization, a full understanding of the project is possible and readily available. This allows any stakeholder to make visual checks (aesthetics, clash detection) and assess, for instance, the constructability of the project. Furthermore, the end user and owner are able to experience the building as it will be built, thus enabling them to assess to what extent the building responds to their requirements. That opportunity is further enhanced technologically by technologies such as Virtual and Augmented Reality (VR and AR). Visualization of the construction site allows to check the construction sequence of the building, which is particularly important in specific critical areas. Also, visualizing the combination of the building process together with the construction equipment and worker activities is a considerable benefit of the visualization power of BIM. It provides significant opportunities when it comes to both building site organization and work environment assessment (e.g. health and safety in the building site). This visualization opportunity allows making comparisons important for decision making by the owner, without later saying "this was not what I imagined".

2.1.2 Collaboration and coordination

Collaboration and coordination are key aspects of any construction project, both internally (within the company) and externally (among project partners and stakeholders). Traditionally, a lot of time is spent on verifying plans and documents, eliminating inconsistencies between plans, elevations and sections, and communicating changes across the involved stakeholders. However, since the information in a BIM model is integrated, this coordination effort becomes much easier to manage. The use of a BIM process furthermore allows to make sure that accurate information can timely be supplied to those actors who need it.

This is, therefore, one of the most important features of a BIM-based project, in particular in Big BIM setups. The project occupies the focal point, in the form of a coordinated BIM project, from which information is extracted and federated from those who produce it to those who need it. This way of working is clearly closely associated to a Big BIM setup. As already indicated before, the mere shift from a Little BIM setup to a Big BIM setup requires the adoption of open (non-proprietary) standards (Open Big BIM) to ensure that communication of information within the project team occurs as smoothly and transparently as possible, according to agreed standards and processes.

Of course, this Big BIM approach has a tremendous impact on the design and construction process itself, as a considerable management and coordination overhead is put in place, and all design actions are tracked and maintained. If done appropriately, this can become a major strength for the project, impacting heavily on effectiveness and efficiency for the entire team. The division of tasks is usually clearly defined in the BIM Execution Plan (BEP), and specific roles are maintained according to the professional inputs of the diverse stakeholders in the project.

As the size and project complexity increases, visual inspection allows some degree of control over coordination. Yet, a majority of the coordination and control tasks are in that case taken over by coordination tools. With an appropriate workflow and with the use of a BIM coordinator, stakeholders can reach a high degree of confidence in terms of coordination. Coordination tools and approaches hereby allow not only the coordination of the project itself or the coordination within a team, but also involving teams in the study and communication with external agents, thereby directly including and deploying the relevant responsibility assignments.

The considered Big BIM approach also has a clear impact on construction site management. Whenever a design is near completion, or whenever it reaches execution on a construction site, the number of changes to the models drops significantly. The project serves as a more static reference to retrieve information from, rather than a reference to import information to. This has a clear impact on construction site management and construction site handling, which can then happen in a much more real-time manner .

Anyone who knows the project well enough, and this most predominantly includes project coordinators, can visually find the necessary information with relative ease and perform the necessary checks. The use of BIM hereby allows both a visual check and coordination of information across stakeholders. This happens not only in meeting rooms, but also in the construction site container where weekly construction site meetings are held to track progress.

Additionally, it also happens on the site itself, where issues can be communicated back to the contractors or engineers using, for instance, tablets and issue coordination tools.

Enabling this way of collaborating, communicating and coordinating requires a clear process change that aims to involve all interested stakeholders. Collaboration is key; it is the means by which a project can be effectively developed in a BIM environment, allowing to reap the benefits to obtain an improved communication and coordination process (from Little BIM to Big BIM). The following aspects are then typically available out of the box as 'by-products' of the improved collaboration process and environment.

1. Ability to undertake larger projects,
2. Transparency,
3. Clear definition of roles and responsibilities,
4. Traceability,
5. Generation of direct information for all.

For collaboration to be a positive thing, it is necessary to clearly define the responsibilities and roles in the process. The exchange of information via open standards and clearly outlined process maps allows the Intellectual Property (IP) of each stakeholder to be protected and maintained. The federation of BIM models and the traceability of actions gives the entire project team, and in particular the coordinator, a clear view of what other stakeholders have done. That promotes collaboration, in which modifications are made by the designated authors, thereby reinforcing roles and responsibilities.

2.1.3 Less reworking, remodeling and manual data input

A third important incentive for the use of a BIM-based process with BIM tools, is the fact that it reduces reworking, remodeling and manual data input. A higher level of efficiency is achieved if drawings and models have to be less reworked and remodeled, and the reduction in remodeling, redrafting and manual data inputs also reduces the risk of errors and inconsistencies in the project. In a traditional 2D CAD project setup, almost all the geometrically descriptive information resides in a lot of different files, each with a lot of various sorts of layers, that the team has to coordinate manually. The traditional process of carrying out a 2D project therefore involves a large number of repetitions, in which plans and sections and elevations have to be reworked independently from each other, over a diversity of layers and CAD files. This clearly generates a considerable waste of time and badly influences consistency and accuracy in the project.

Within a BIM process, the different team members see single models that act as single sources of truth, which contrasts heavily to the 2D CAD workflow. In a BIM process, all the information stems from one and the same consistent truth, which should be the federated 3D BIM model. Manual redrafting and remodeling is heavily reduced, allowing designers and stakeholders to work and concentrate on what matters for and in the project. Each time a change is made, all the information affected by it is updated, e.g. 2D plan views and section views and elevations that are generated from the 3D BIM model. It is therefore no longer necessary to coordinate the numbering of the plans, the cross references between details and plans or sections and elevations, updating the lists, manually revising the plans, etc.

The above often happens extensively on a small scale, namely when making changes within a particular phase of the design and construction process. Such changes take place in response to requirements. For example, if the client changes his requirements, the architect needs to respond to that. Furthermore, if an architect makes changes, changes also need to be made in engineering and contractor models and files.

Yet, the above also happens when making large information handovers between partners in a project. For example, at a certain moment in time, the final design will go into a procurement stage, and that involves handing over the final design documentation of the project to the next stakeholder in the project. In a 2D CAD workflow, a lot of the information needs to be redrawn and remodeled, resulting in inefficiencies and errors, and a major drop in the information gain throughout the project timeline. This information drop is clearly displayed in the saw-tooth diagram in Figure 2.1. By following a BIM process, these information drops are greatly reduced (see the smaller teeth in Figure 2.1), resulting in a clear efficiency gain, not only for the individual partners, but for the entire project.

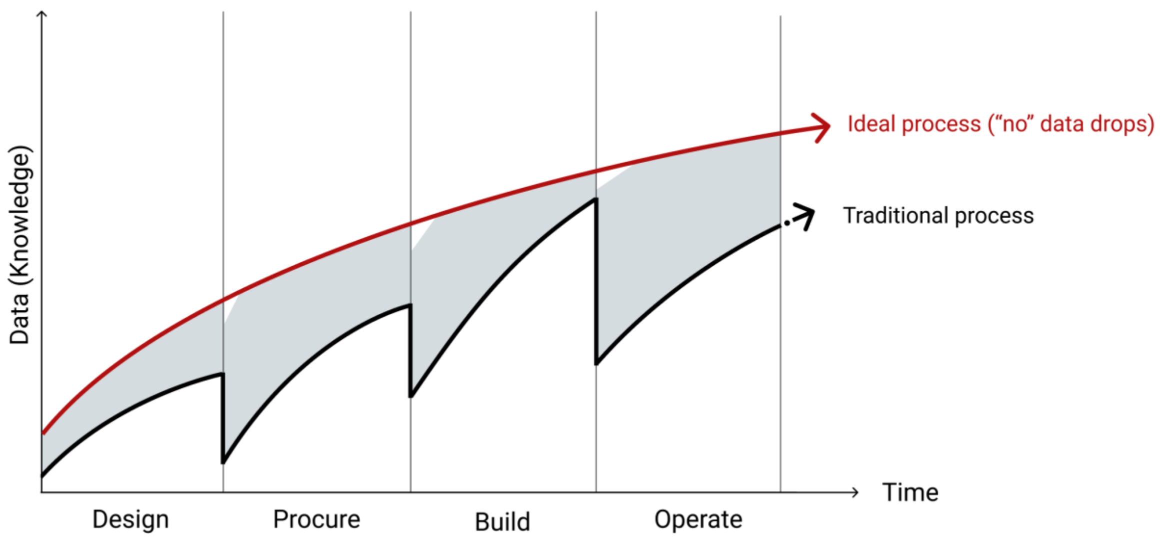


Figure 2.1 Saw-tooth diagram showing the data/knowledge losses that occur when handing over models and information from one phase to the next.

Even though information drops can be reduced, this is not always guaranteed. Even more, it is not always desirable. During handover from one stakeholder to another, one should not assume, or even target, that the next stakeholder does not need to make an effort to get used to the project and get to know all its features. The newly involved stakeholder will always require time and effort to get to know the project well enough to be able to take it over. Hence, also a standard BIM approach will include data drops at handover moments, in which stakeholders aim to ingest and make sense of the data they receive (Fig. 2.2).

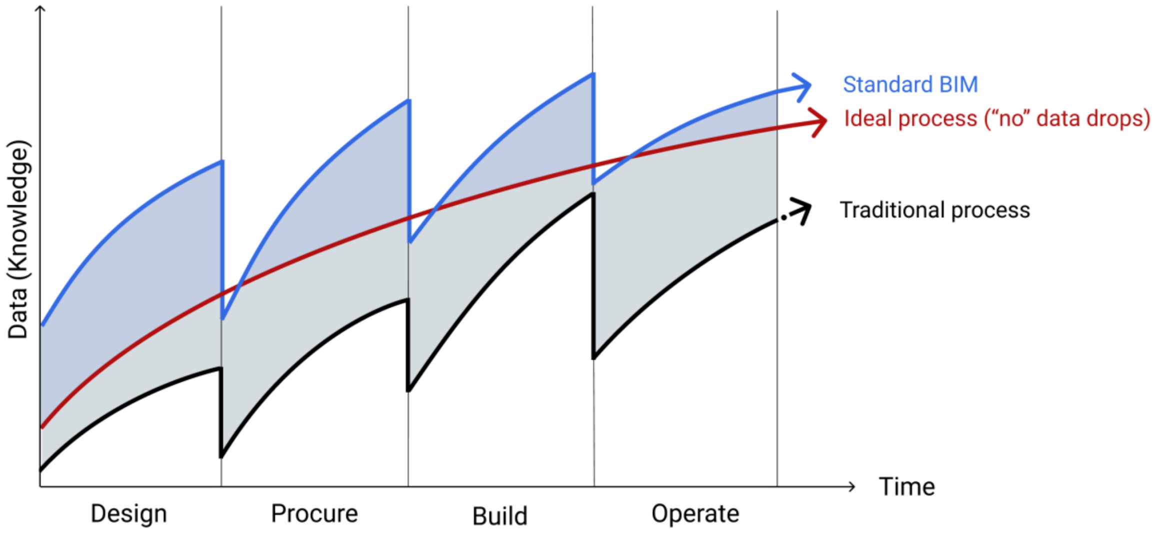


Figure 2.2 Saw-tooth diagram in a standard BIM approach (Image after Ruben Van de Walle, HOWEST).

Additionally, due to the different perspectives on matters, (e.g. a systems engineer sees a building differently than an architect), the new stakeholder will always be inclined to make changes to the project. In fact, he will be required to make changes in the project. As stakeholders also can communicate before and after the handover moment, this effort of sense-making and adapting for handover ideally happens before and after handover, in direct interaction by partners. As this needs to take place in a separate aspect model, in order to maintain track changes and responsibilities and scope, a certain amount of remodeling will always happen. Therefore, it is unrealistic to assume that rework and remodelling should be reduced to zero. Instead, a much more fluent information handover diagram needs to be assumed in practice (Fig. 2.3).

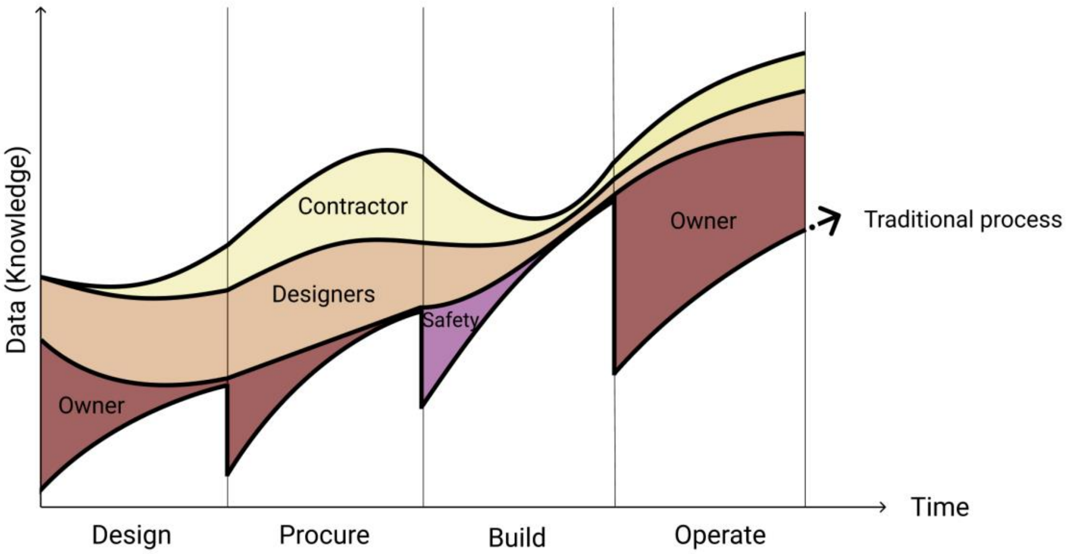


Figure 2.3 Saw-tooth diagram and its much more fluent information streams in practice (Image after Ruben Van de Walle, HOWEST).

Nevertheless, the improved information stream between partners, also in the case of Fig. 2.3, will allow to greatly reduce information losses during handover and exchanges. This effect should not be limited to the core AEC stakeholders, namely building owner, architect, engineer, and contractor. Ideally, this improved digital information stream also addresses other stakeholders, such as product manufacturers and fabrication halls. Indeed, as long as the information in a BIM project is correct, consistent and well-structured, the prefabrication of systems, elements, facades, and so forth, can to some extent be automated from the output generated from the BIM project.

2.1.4 Accurate simulation with accurate information

As a BIM project serves as a repository full of highly valuable information, huge added value is generated in terms of performance of various simulations. This is also a key incentive for many stakeholders involved in the life cycle of a BIM project. The added value of correct and detailed simulations has already been, to some extent, discussed in the sections documenting the other technical incentives for the adoption of BIM (Section 2.1.1 to 2.1.3). Simulation tools allow to test the project, without having to build it first. One can perform all the tests and/or simulations necessary to check diverse available design and construction solutions in a safe manner. Furthermore, assuming that the information included in the BIM model is accurate and correct, these simulations can provide a picture of the building that is near or identical to the expected reality.

Of course, there are many stakeholders in a project, and many of them focus primarily on simulating along their dimension (e.g. cost estimation, energy performance analysis, structural analysis, and so forth). Any stakeholder involved in the process would want to check the constructive feasibility of the project first along their own dimension. In fact, one of the most common problems associated with communication based on 2D drawings during the design phase is the time and resources required to generate information for the critical assessment of a proposed design, even when limiting to one of the considered dimensions (e.g. structural analysis). The possibilities in this regard are greatly improved when adopting a BIM workflow and appropriate BIM tools.

Moreover, the collection of construction data in a central repository, following agreed standards and processes, also allows more holistic simulation processes, in which a building design is simulated and tested along different dimensions simultaneously (e.g. energy use and daylight simulations). In a 2D CAD workflow, such holistic analyses were at best done at the end of the design process, when it is too late to make important changes. As a result, the design was typically “patched” at best. Only minor changes can be made to the design, aiming to somewhat improve the design. However, these last minute changes in fact often harm the design, as the change or “patch” is not integrated in the entirety of the project.

Instead, the holistic analyses should be implemented throughout the entire design and construction process. They need to drive multiple iterations of design improvements in an integrated design process, which is what a BIM process offers. Aiming for accurate simulations with accurate information as an inherent part of an integrated design process greatly helps the decision making in the entire process, thus resulting in a better design and higher quality buildings.

2.2 The financial incentive

Besides the technical incentives outlined above, BIM is often also adopted for financial reasons. In fact, if there are no good financial reasons, not many companies and users would take the step towards using BIM software and a BIM-based approach.

2.2.1 Reasons to adopt BIM: failure cost reduction and efficiency gains

The BIM environment allows the integration of information in a coordinated manner, so that all stakeholders involved can provide their disciplinary input and have a clear understanding of the project and how it is meant to be built. The technical merits typically lead to efficient processes, good and clear communication, and detailed preparations. Consequently, the main advantages of using BIM are said to be[10]:

1. Reduction of failure costs
2. Efficiency gains

These are the two most commonly mentioned reasons throughout the entire AEC industry to advocate the adoption of BIM. With these two focus points, the move towards BIM responds to the finding that labor productivity in the construction market remains stable, in contrast to other markets (Figure 2.4). Where other industries have steadily increased their productivity over the years, construction industry has remained stable in its productivity index. The main causes for the stagnation in the curve of labor productivity in the construction industry are related to its fragmented nature, the traditional approach of project delivery, and the use of 2D CAD technology.

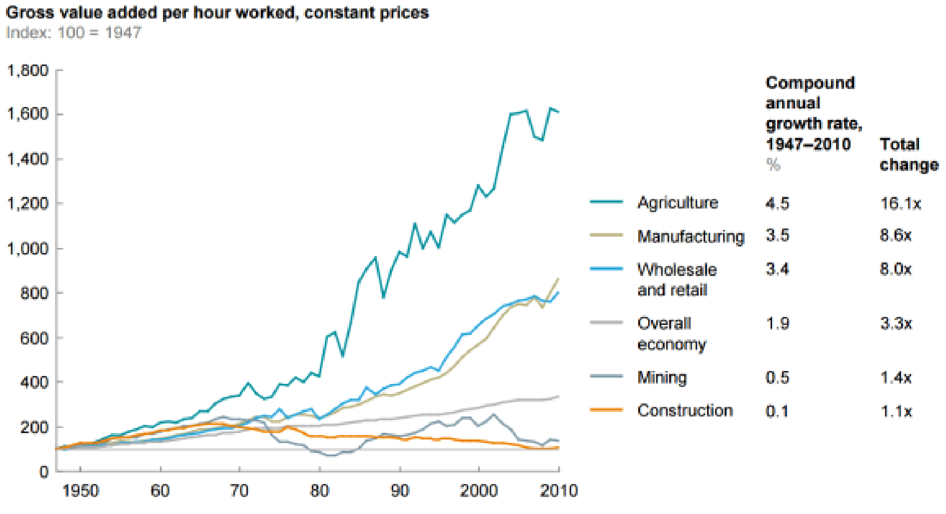


Figure 2.4 Labor productivity graph for construction (orange) in the United States (Source: McKinsey & Company).

The traditional project procurement form Design-Bid-Build fragments the roles of the participants during the design and construction phases. In other words, it prevents open collaborative participation during the entire project. Second, the use of traditional 2D CAD

10 NIST Report - Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry - https://nvlpubs.nist.gov/nistpubs/gcr/2004/NIST.GCR.04-867.pdf

drawings, schedules and 3D geometry (Little BIM) does not promote a collaborative approach. Architects and engineers traditionally produce their own CAD documents in a fragmented manner, responding to what is asked by project stakeholders (contractors and owners), namely plans and schedules. These plans are not integrated and usually pose conflicts that lead to inefficiencies in productivity (Fig. 2.4).

2.2.2 Frontloading design effort and cost

The collaborative BIM approach, on the other hand, allows changes to be made at any point during the building design, which adds value to the entire project. Figure 2.5 represents the MacLeamy curve, which showcases the relationship between design effort and time. It illustrates how impactful design decisions made in the early stages are to the overall functionality and cost of a construction project. In the early phases, the possibility to have an impact on cost and functionality are significant (1 in Figure 2.5), while the cost of change is lower (2 in Figure 2.5). The model in the MacLeamy curve describes how the preferred design process (4 in Figure 2.5) should evolve compared to the traditional design process (3 in Figure 2.5).

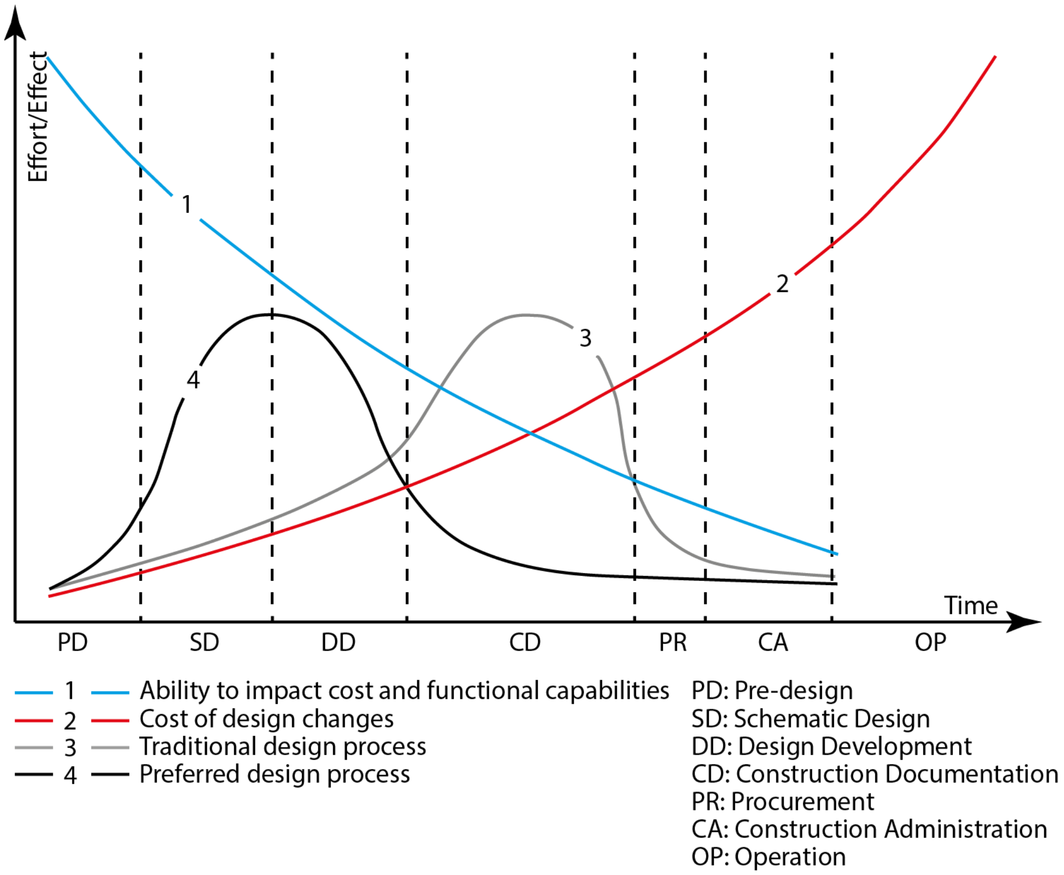


Figure 2.5 The MacLeamy curve[11]

11 http://www.hok.com/thought-leadership/patrick-macleamy-on-the-future-of-the-building-industry/ (Patrick MacLeamy, HOK), see also http://codebim.com/wp-content/uploads/2013/06/CurtCollaboration.pdf

When adopting BIM, a number of the above described effects can usually be seen in practice. Most prominently, a lot of the effort shifts from the project execution phase (build) towards the project design phase (design). The total time that would usually be spent during the construction phase, is now spent earlier in the design phase. In addition, due to the efficiency gains, only 50 to 80% of the total time that would usually be required is actually spent (Fig. 2.6).

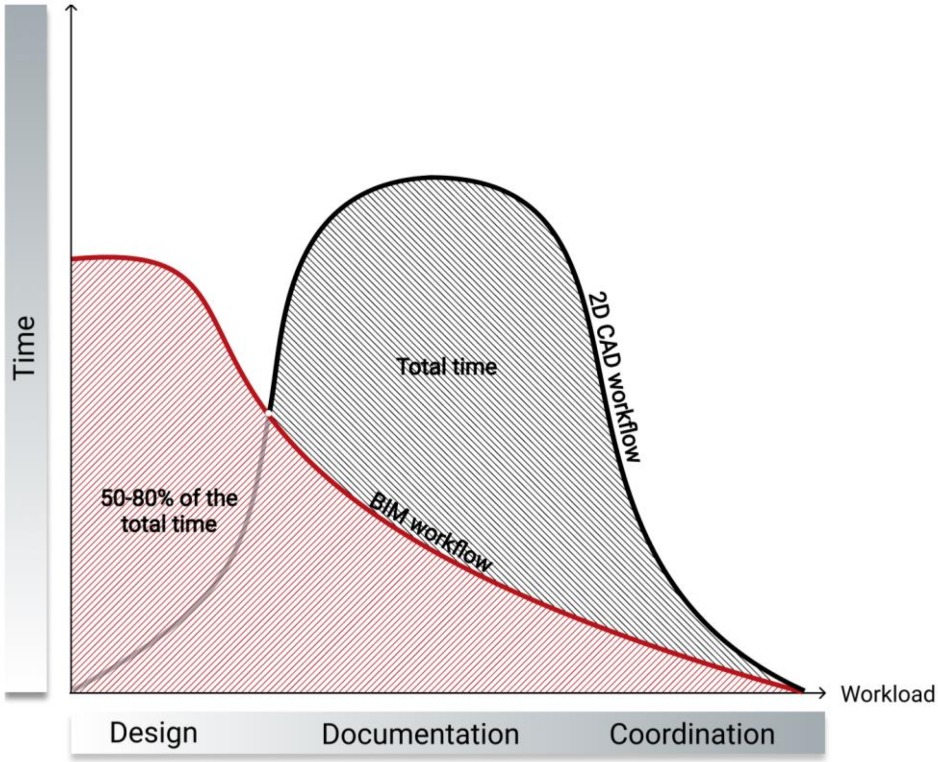


Figure 2.6 Workload is much earlier in the building design and construction project, furthermore reducing the time and resources spent.

The overall workflow change outlined in Figure 2.6 shifts labor to the start of the design and construction process. For companies and people who are not used to or are not expecting that effect, it often appears that workload and resources spent go entirely out of control. The result is that beginning teams and disciplines tend to revert to their traditional way of working, which includes traditional 2D and 3D CAD, schedules, PDFs, and so forth (Figure 2.7). They then switch to a BIM-to-CAD workflow, in which all information that was previously modelled in the BIM environment needs to be transposed to a set of CAD drawings. This remodeling effort takes additional time and effort in addition to what has already been spent on modelling the BIM model. Furthermore, the project then returns to a traditional setup, which means that the errors that were supposed to be avoided (failure cost) and project inefficiencies return (2D CAD Workflow in Figure 2.7). As a result, the total effort and time for the project become even larger than what they would have been in a traditional CAD workflow project.

This effect often forces high level managers and technical employees to abandon the BIM workflow for the wrong reasons. It may seem that costs are initially way higher than the original, but that is mainly caused by the decision to revert back to a traditional way of working.

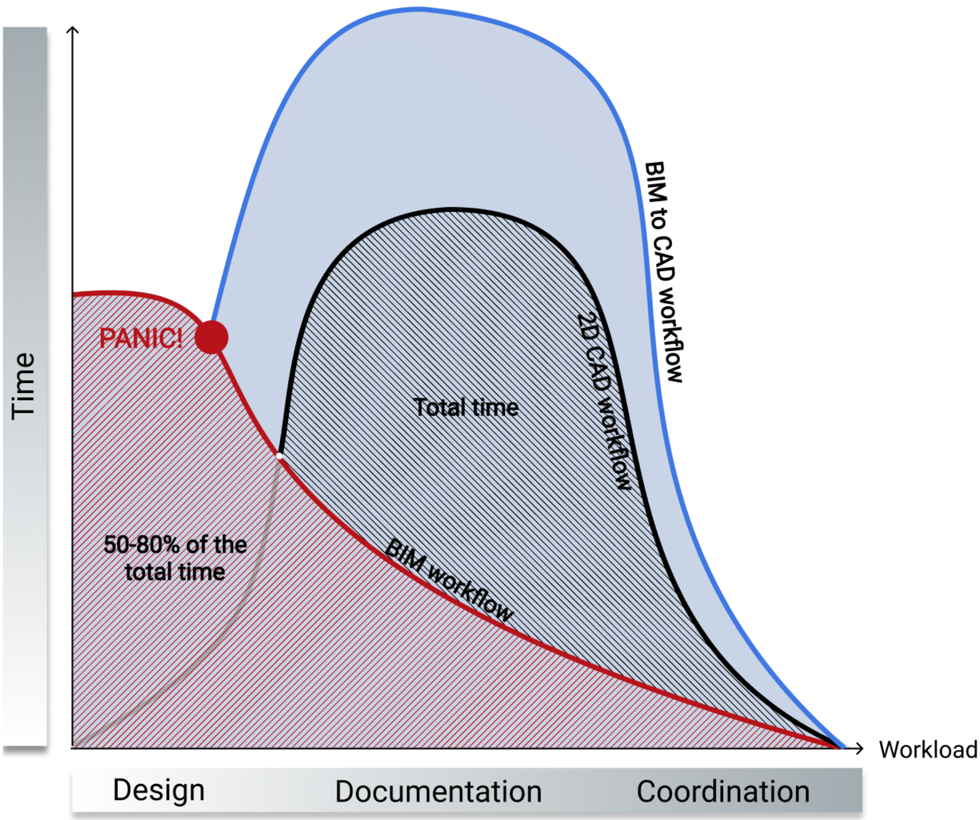


Figure 2.7 Comparison between a traditional 2D CAD workflow, a BIM workflow, and a combination of the two caused by a "panic reaction" during the BIM workflow process.

To acquire the new capabilities and harvest the benefits that BIM has to offer, a paradigm shift at a personal level, company level, project level and at an international level is thus necessary.

2.2.3 Quantifying the impact of BIM

BIM is one of the most discussed, but also potentially most misunderstood concepts in the construction sector. Industry professionals and software providers refer to BIM as a process for information exchange, while real estate agents and marketing experts call it a visualization tool. Contractors see BIM being best in project management, manufacturers in manufacturing, but BIM is more than singular interpretations. Due to the multiple kinds of information, definitions, interpretations and phases associated with BIM in a project, it becomes difficult to quantify the direct financial impact on individual stakeholders of using BIM.

Another reason why it is difficult to determine the savings in a project, is because they are usually a result of avoiding or resolving various issues. So, when a virtual conflict is found in BIM, it is difficult to calculate the consequences that this conflict can lead to and how much has been saved by avoiding it, as it will not happen in the real world. Therefore, the quantification of the impact of BIM is a difficult venture, which is not often realized in precise numbers. However, some statistics are available, such as the ones reported in the 2014 McGraw-Hill report on "The Business Value of BIM for Construction in Major Global Markets" (see Fig. 2.8).

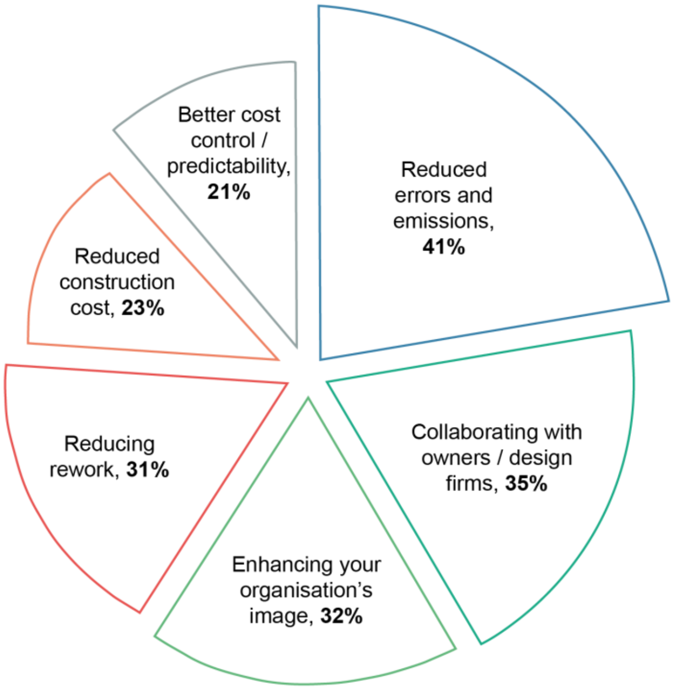


Figure 2.8 Reasons why one would want to adopt BIM processes and BIM tools.

According to McGraw Hill Construction's SmartMarket Report from 2014[12], the largest percentage of companies declare an estimated Return on Investment (ROI) on their BIM investments between 10% and 25%. The findings of the survey demonstrate that different sets of metrics and drivers are considered important by construction companies in the different regions. Reduced costs, higher profitability and higher productivity are generally considered most important for measuring ROI on BIM, followed by project delivery process, such as fewer RFI's, fewer unplanned changes, higher customer satisfaction and less disruption in the project process.

According to the same McGraw Hill report, the following consistent patterns emerge in terms of Return on Investment because of the use of BIM:

- Companies in their early years of BIM adoption exhibit negative or break-even ROI on BIM investments, especially smaller organizations for which it takes longer to absorb the initial costs of software, hardware, training and development of content and business processes to support BIM.
- Contractors generally reach positive ROI more quickly than design professionals, because they generally receive a greater share of the financial benefits of BIM (e.g. reduced rework, increased profits, etc.) than design firms.
- Users with the deepest BIM engagement, as represented by their skill, years of experience and level of BIM implementation, report the highest ROI on their BIM investments.

It is generally agreed on and appreciated that BIM helps to reduce project costs. The value that BIM as product brings, lies in its capacity to help various systems and companies work

[12] https://www.icn-solutions.nl/pdf/bim_construction.pdf

together efficiently. Rudimentarily simplified, BIM is similar to making a cake. The multidisciplinary input is similar to the ingredients of a cake that the design professionals create in a BIM model. Depending on the level of detail, a BIM model can be divided (just like a cake) into digital information delivery packages and distributed to any member of the project team. Therefore, compared to CAD, BIM is an important cultural change in the AEC industry. BIM is an intensely organized process with people who value reducing risk through better predictability of results, better visualization, greater precision, greater productivity and greater potential for high-quality design.

A higher ROI is one of the key reasons for the growth of BIM in different countries. As previously mentioned, the two key reasons that trigger the higher ROI are: reduction of failure costs and higher efficiency.

2.3 Government policies and marketing-oriented incentives

Besides the clear benefits related to the reduction of failure costs and increase in efficiency, a large share of the market is also incentivized by government policies and clear marketing-oriented reasons. Clearly, the level of internal self-motivation towards the adoption of BIM in that case and actually realizing both the financial and technical revenues is considerably lower, which is alarming. Incentivizing people and companies to adopt BIM (external motivation) is in itself not a bad thing, but the better incentives always come from the company profile itself (internal motivation).

2.3.1 The marketing-oriented incentive

By now, a large number of companies is actively adopting BIM workflows and processes. This results in a market that requires companies to *also* provide BIM services. Due to the increasing adoption of BIM, clients consider a company that does *not* follow a BIM approach as a lesser qualified candidate compared to fully BIM-compliant companies. Hence, companies are pressured to also implement BIM. This peer pressure is a typical feature underlying any kind of technology adoption. Similar peer pressure can be recognised in the adoption of smartphones, tablets, Virtual Reality, and so forth.

The curve in Figure 2.9 indicates the typical trend in such a technology adoption period. The market can be subdivided in innovators, early adopters, early majority, late majority, and laggards. At the moment, many national markets are in a stage of late majority. Many companies already provide BIM services. Newcomers feel that they also need to “do BIM” and thus aim to do so, so that they can include this in their services, regardless of the kind of BIM they implement or any financial or technical reason.

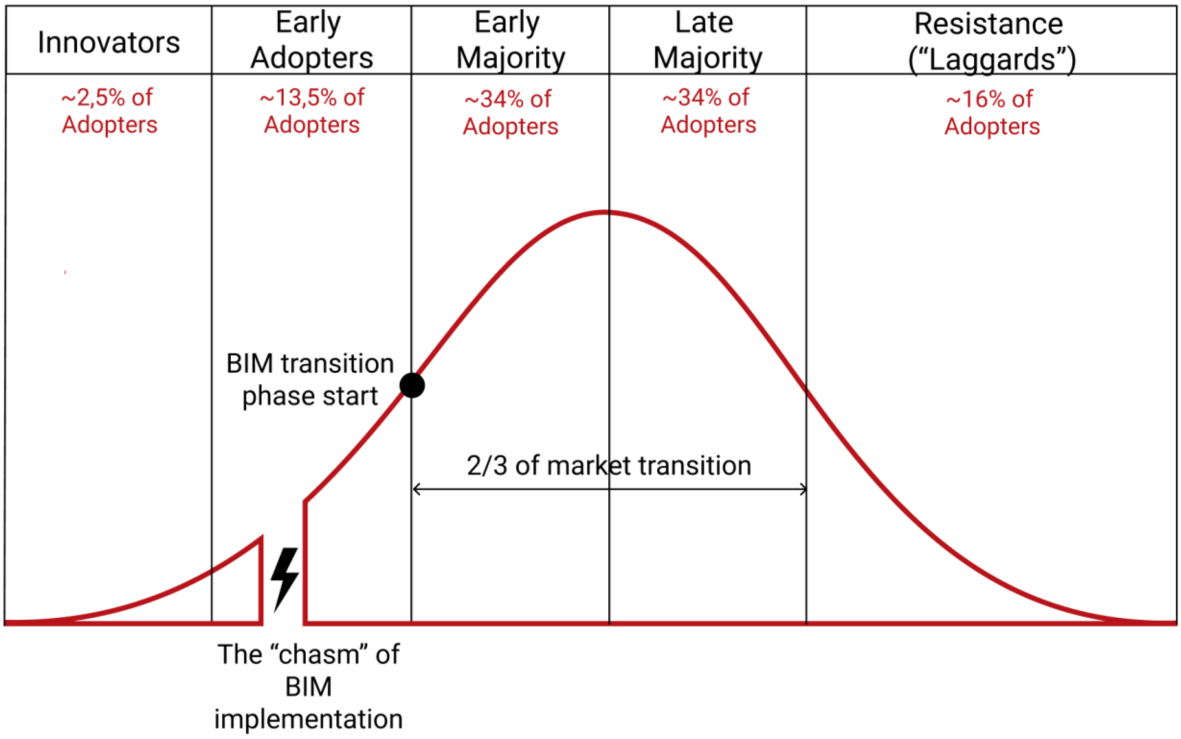


Figure 2.9 Technology adoption curve applied to BIM processes and BIM tools.

In such cases (early and late majority), the aim to implement BIM is often governed or impacted heavily by marketing purposes. The adoption of a BIM approach and BIM toolset appears to offer a considerable competitive advantage by opening a range of services that can otherwise not be offered. The market expects a company to be BIM-ready. Offering BIM services also makes it possible for a company to participate to bids that otherwise would not be accessible. In many cases, the type of BIM workflow that is offered in such cases (beginners' implementation) is a Little BIM workflow.

This in itself is not bad, but one needs to be aware that this is different from the Big BIM implementations that are already in place with early adopters and innovators. Moreover, because of the clear focus on obtaining a competitive marketing position, the true incentives of using a BIM process often get lost behind the (almost hollow) message that "we do BIM", which is there to enhance the company's position on the market. This can in the long term often result in anti-advertisement, due to bad services, not to mention the loss of financial return because of the undetailed BIM implementation plan. As the marketing incentive prevails, it would be enough to add the acronym to a company's services, buy a BIM authoring tool, and keep working as before. This disregards many of the incentives and advantages that were already discussed. Hence, one must be careful not to make a purely generic marketing-oriented plan only, in which the true services of the company are disregarded.

2.3.2 The governmental push

Somewhat similar to this marketing-oriented incentive is the governmental incentive. In a number of countries, the use of BIM is heavily promoted and even required, in particular for public projects. In such cases, companies willing to bid for a particular project, are required to be BIM-ready or BIM-compliant. As such, the government actively stimulates companies to implement a BIM workflow.

Although this in itself is clearly a good initiative, because the government is, in such cases, taking its responsibility to indicate the good work practices, the inherent risk of this approach is similar to the marketing-oriented incentive outlined above. Namely, companies hastily purchase BIM tools and implement a number of BIM processes, but the actual value for the company, both in-house and externally, is under-evaluated. Furthermore, the technical plan (human resources, software, hardware, education) is then often hardly thought through and the legal plan is missing. In other words, a lot of companies take the risk of picking up a badly thought through Little BIM approach.

The sole remedy for this effect is not to oppose or reduce the governmental push, but instead to make sure that appropriate creation of awareness is offered along with the governmental push, and hence the appropriate implementation choices are made. This creation of awareness needs to target BIM beginners first, which typically means Little BIM approaches that must first look inside the company. Consequently, it is of utmost importance for those Little BIM starters to outline their internal processes and start the use of BIM processes aiming to improve those explicitly, rather than limiting to simply complying with the governmental requirements.

3. BIM adoption and implementation

3.1 BIM Adoption and Maturity Levels

Depending on the national market, BIM adoption usually goes slow, is inexistent, is encouraged by the government, or is explicitly mandated by the government. Despite a fluctuating pace, BIM adoption is accelerating globally, which is a result of the efforts of major private and governmental organisations, targeting institutionalization of the benefits that BIM has to offer. After the early years (1975-2000), hype and commercialization started only around the start of the 21st century and mainly from a software perspective, which initiated the curve in the market indicated in Figure 3.1 around 2000.

Namely, end users and companies that aim to adopt BIM have started from a technology trigger, thereby going to a high peak of inflated expectations. Next, they entered a trough of disillusionment, a slope of enlightenment and a plateau of productivity. This is typically the process that everyone goes through when adopting a new technology. Depending on the market situation, each country nowadays is somewhere along that curve. Most Western countries can by now be considered either on the slope of enlightenment, or on the plateau of productivity, as the way in which BIM can successfully be implemented in regular AEC projects is becoming more and more clear.

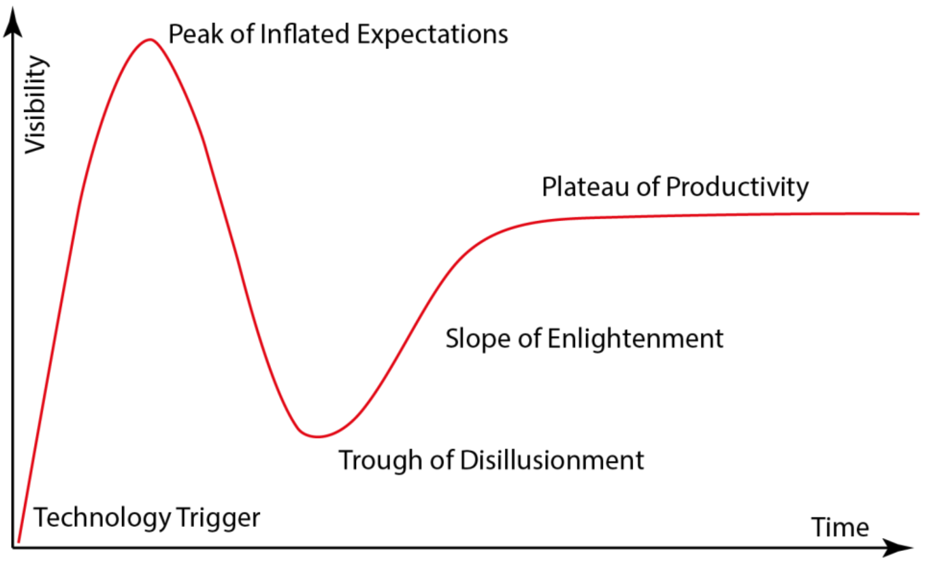


Figure 3.1 Commercialization and the BIM ‘hype’ (technology trigger).

A very strong impulse has later been created by the European procurement directive that was put out in 2014. This EU procurement directive indicated that: *“For public works contracts and design contests, Member States may require the use of specific electronic tools, such as building information electronic modelling tools or similar.”*

This procurement directive thus essentially stimulates the use of BIM tools and processes by allowing governments to require the use of BIM in public projects. This has effectively stimulated a considerable number of countries in Europe to require the use of BIM, thereby stimulating also the larger economies (UK, Germany, France) to require or advocate the use of BIM. By now, almost all countries in Europe are explicitly encouraging or requiring the use of BIM.

A number of stages can be recognized in the adoption of BIM. These stages are commonly known as BIM maturity levels. Namely, people and companies exhibit a certain proficiency or maturity in the adoption of BIM. This maturity is captured in a system of BIM maturity levels, which is graphically displayed in Figure 3.2. This graphic is typically referred to as the 'BIM wedge'. The different BIM maturity levels are level 0, 1, 2, and 3, and each of them represents an increasing BIM maturity level. These levels allow to categorize (1) types of technical and collaborative working, as well as (2) levels of understanding of construction processes, techniques and tools.

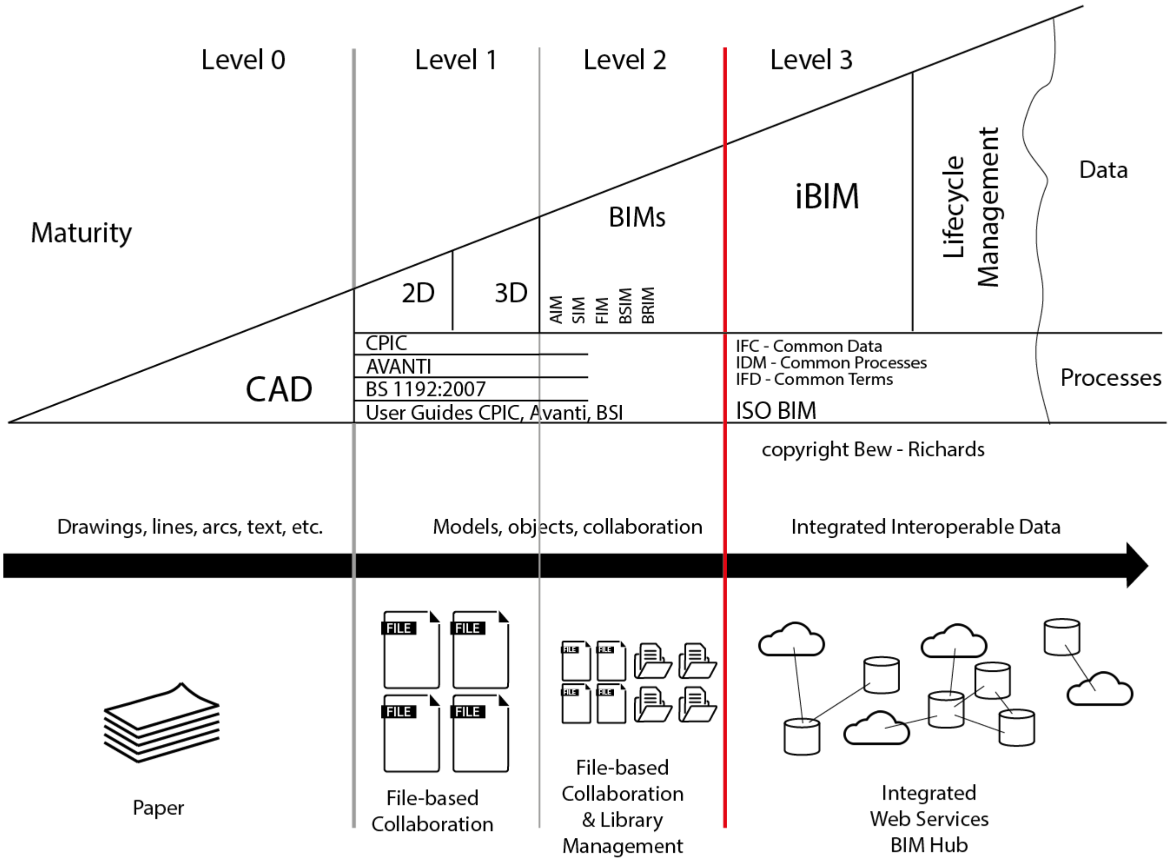


Figure 3.2 The BIM wedge displaying the BIM maturity levels and what they mean.

This wedge of BIM maturity levels is widely referred to from almost anyone aiming to implement BIM. At the moment, it is widely accepted that no company effectively achieves BIM maturity level 3, as it is not entirely clear what this maturity level implies in terms of software implementation. The majority of AEC companies currently aims at implementing BIM up to Level 2.

According to RIBA (2012), Level 0 is certainly not used by the majority of the companies any more, but has been the drawing beginning of BIM. Nevertheless, some companies are still forced to implement both 2D drawings and 3D modelling in their work processes.

Level 1 is introduced by RIBA as containing mainly 3D software, which could be used by the architect in the early project stages for visualization of the main ideas for the client. The drawings contain three-dimensional data of the building, with a fair level of information regarding materials, performance, and so forth. This form of BIM where only one party utilizes the benefits of the model is frequently referred to as 'Lonely BIM'. The BIM model is not used collaboratively between team members.

BIM maturity level 2 is currently the most often targeted BIM maturity level. BIM Level 2 requires 3D information models from all the key members and designers, and can ensure that all information can directly and appropriately be passed to the other integrated team members. This BIM maturity level relies very heavily on file-based information exchange, local software platforms and coordination environments. In such cases, a very precise and clear definition of the BIM process (BIM Execution Plan) is crucial for an effective exchange of information.

All parties involved in a project are using their own 3D BIM model, and work is not necessarily done on one shared central model. Still, it is a collaborative way of working and it is the most commonly used way of working nowadays. A combination of different kinds of information is exchanged between everyone involved. This typically includes a Common Data Environment (CDE) and a neutral data model (IFC). As such, this way of working can typically be considered a Big Open BIM project approach. The use of a CDE and a neutral data model ensures that information can be used by all stakeholders when required, and that a federated or coordinated BIM model can be created and used in a BIM coordination tool. The data is maintained in separate file-based aspect models, which clearly responds well with the idea of dividing responsibilities, tasks and information over the diverse responsible stakeholders. Note, however, that this also results in the creation of data silos along the boundaries of precisely the same divisions. In other words, each stakeholder works in a separate file-based silo. This explains the huge importance of an appropriate BIM execution plan or a BIM process that defines the boundaries of those silos, and the way in which they can be connected or merged in a coordination model.

The last stage or Level 3 is described by RIBA as the 'Holy Grail'. This level abandons the file-based approach, in favor of a purely web-based and data-based approach. In such case, the aim is not to work in file-based silos, but rather to achieve a fully online collaborative project, in which silos are placed online and explicitly connected. Furthermore, permissions, authority, and privacy are handled by the online platform that implements the web-based and data-based BIM approach. At the moment, no technology is fully able to support a file-less and instead web-based building information platform. Arguably, a web-based linked data approach as it is set out by the Linked Building Data Community Group in the World Wide Web Consortium (W3C) might eventually enable the implementation of such a BIM Level 3 platform. In general, however, the implementation of software that supports BIM Maturity Level 3 still requires the resolution of a number of unsolved technological and legal challenges. The main aim of this level is to provide a single collaborative web-based project.

3.2 BIM implementation

When starting with BIM in a company, an appropriate BIM implementation plan needs to be set up. Such a plan makes sure that the software and overall approach are implemented step by step, and result in the desired effects.

3.2.1 BIM implementation plans

A BIM implementation plan can be made in a number of ways, and can hence take a number of shapes and forms. In this document, we distinguish three different types of BIM implementation plans, namely:

1. One Plan for All
2. The company-wide BIM implementation plan
3. The person-specific BIM implementation plan

This document considers the last kind of BIM implementation plan (person-specific) as the most important one and the one with the highest impact and success rate in actual AEC practice. Yet, the other types of implementation plans are outlined here as well.

One Plan for All

A number of BIM implementation plans exist that aim to be applicable for a wide target audience. It is true that many companies in the AEC industry have similar structures and desires. Especially on a very abstract and less in-depth level, AEC companies seem to have the same goals and incentives, especially when limiting to specific trades (e.g. contractors often seem to be much alike). It is thus understandable that one might consider the creation of a BIM implementation plan that can be applied to all.

In such cases, however, there is little depth in the actual practical details of the plan. This lack of detail is present in all parts of the BIM implementation plan, thereby making it difficult or near to impossible to implement it with measurable success. At best, a BIM approach and a set of BIM tools can be implemented using such a plan with a purely marketing-oriented goal or incentive.

Most prominently, these plans typically start from similar global and less tangible incentives. Incentives often named in such cases are:

- Reduction of failure cost
- Increased levels of efficiency
- Better marketing position

In addition, many companies simply “don’t want to miss the BIM train”, and hence they feel the need of adopting BIM as fast and efficiently as possible. The reliance on a generic one-plan-for-all BIM implementation plan is in such cases an easy to consider option. In this case, a company aims primarily to achieve a better marketing position.

Second is the company diagram that is typically proposed in such more BIM generic implementation plans. These diagrams often consist of adding a number of BIM advisors, changing the technical drawing office into a BIM modelling office, and advertise at least one position for a BIM coordinator.

In terms of software, little investigation is typically done, after which either (1) a large set of BIM tools is acquired and adopted, or (2) the company chooses to adopt the software solution offered by the market leader (in other words, he adopts the BIM tool that all other companies are adopting, without really analyzing the needs to the company). Corresponding training sessions are included, targeted mainly at making it possible for employees to use the acquired software (BIM modelling). Clear objectives in terms of information exchange, coordination, work separation, and so forth are seldom really targeted in these more generic plans. At best, an overall process map is built that very much resembles the traditional way of working, yet added with a BIM touch. Legal implications and data exchange processes are kept to a minimum, giving maximum freedom to the BIM modelers. This often generates a lot of confusion and information loss, not to mention wasted effort in remodeling and redrafting BIM models.

The company-wide BIM implementation plan

A company-wide BIM implementation plan is a difficult, yet often needed venture. Of course, the size of the effort depends a lot on the size of the company in this case. Clearly, the creation of such a BIM implementation plan is in this case often a top-down approach, which is initiated by the upper level management. This management aims to set out a plan for the management and exchange of information throughout the entire company, in all its facets, referring to all relevant documents, such as BIM Execution Plans, Protocols, standard modelling agreements, template contracts, and so forth.

The structure of this implementation plan ideally follows the following structure:

1. Background and context
2. Business plan
    a. Internal business plan
    b. External business plan
3. Technical plan
    a. People
    b. Software
    c. Hardware
4. Legal plan
5. Reference project

Very important in this regard is that the scope and purpose is very broad as the plan spreads the scope of the entire company. As a result, such BIM implementation plans become very big reference documents that can be used throughout the company as a complete compendium of reference documentation. This also implies that each section of the BIM implementation plan becomes very long, as each aspect of the company is considered and documented in full depth.

The diverse divisions of the company need to be outlined in the background and context. The internal business plan needs to find a balance between the needs and aims of the different divisions in the company. The purpose is to create a BIM implementation plan that is understandable across the entire company and makes clear what the main company-wide goals are. This requires that not too much detail is presented as this would get focus away from the overall goals, in favor of very specific lower level goals, yet enough detail needs to be included as well in order not to make the plan generic and without criteria and specific added values and milestones for the different divisions of the company. Documenting the background and context (company structure) and the business plan for the company is thus a difficult journey, requiring to balance between small detail and overall goals.

A similar effect can be found for the technical plan. Ideally, a clear outline is given in the background and business plan of the company structure and the diverse divisions and people of the company, including their goals. From this very broad overview, one should be able to distill a technical configuration of software (modelling software, coordination software, planning software, cost calculation software, simulation software, and so forth) and hardware (servers). Yet, also in this case, the company-wide BIM implementation plan is likely too broad in scope to capture the details and purposes of the different technical setups in the different divisions of the company.

What is very important and typically incredibly useful in a company-wide BIM implementation plan, is the legal plan, which outlines the overall BIM process diagram (BIM Execution Plan). Legal decisions should be made on a company-wide scale anyhow, and a process diagram typically best fits in a company-wide strategy. So, this legal plan has a very prominent place in this company-wide BIM implementation plan.

Lastly, the possibility to gather reference documentation, templates and materials in one location, documented from a central text, is an incredibly useful asset for a company implementing BIM. A complete overview of materials can hardly be gathered by single individuals or divisions of a company, so this company-wide BIM implementation plan is the perfect candidate or reference point for gathering this material.

The person-specific BIM implementation plan

The third option in building a BIM implementation plan starts from the employees themselves; the people on the work floor. In this case, a clear bottom-up approach is adopted towards the construction of the BIM implementation plan, in contrast with what is the case in setting up a company-wide BIM implementation plan (top-down). In this case, a similar structure is ideally followed, namely:

1. Background and context
2. Business plan
    a. Internal business plan
    b. External business plan
3. Technical plan
    a. People
    b. Software
    c. Hardware

4. Legal plan
5. Reference project

In this case, a different approach is taken in setting up and filling the diverse sections of the BIM implementation plan, compared to the company-wide BIM implementation plan aims. Namely, instead of starting to write the document from the perspective of the entire company, it is advised to start writing the document from the perspective of a single employee in that company. In fact, any employee in an AEC firm that somehow interacts with information about the design and construction of buildings and infrastructure, should be able to write a BIM implementation plan. This includes not only draughtsmen or modelers that work in a drawing office or modelling office. It also includes workers who need to track construction planning on site and send back issues about the site back to the office. It also includes managers who are responsible for entire teams, product manufacturers, and production hall managers. Authors can include simulation engineers or structural analysis engineers. Even direct modelers and single person architects gain from writing a full BIM implementation plan for their specific everyday scope and tasks.

This implies that the background and context (part 1 of the BIM implementation plan) not just includes the company context, but also documents the position of the specific person writing the actual BIM implementation plan.

3.2.2 Managing Expectations

BIM implementation plans should be handled with care, because they are seldom a complete success from the very first moment. In order to keep track of the success of a BIM implementation plan, early stage BIM users need to compare performance metrics and criteria from projects following a 2D CAD process with the performance metrics and criteria of BIM projects. This allows them to establish the value of basic BIM benefits and to justify their continued BIM investments. More experienced BIM firms should analyze their completed BIM projects to refine the approach to more complex BIM uses on their new projects, such as determining in advance the best ratio of model-driven prefabrication to site-built construction to optimize cost, schedule and site logistics.

As is usually the case when adopting a new system or process, the first few projects typically show a loss in productivity (Figure 3.3). It is highly important to take this into account when implementing BIM. Ideally, a BIM implementation plan should be given at least 2 years of time for the first evaluation of the effectiveness of the new approach. After an initial period of time, the next few projects show a clear increase in productivity, as working methods and data handling mechanisms have been set in place and optimized.

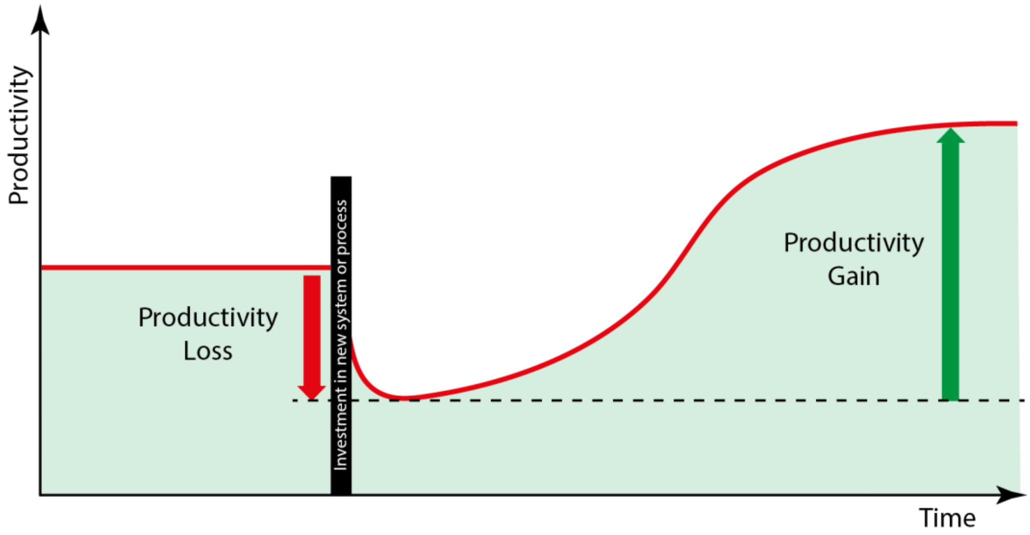


Figure 3.3 Productivity loss becomes productivity gain only after a certain period of time.

Furthermore, the emergence of new technology initiates an expectancy curve as displayed in Figure 3.1. The technology trigger typically generates a very high peak of inflated expectations in a very fast rate after discovery of the technology curve. This is a clear signature of a technology hype. From the very beginning, high expectancies are in place regarding the adoption and implementation of BIM in a company. In many cases, a miracle effect is expected, including the assumption that all incoming information can now easily be put in a BIM model, this information can very easily be shared to everyone else in the project, without them having to remodel anything. Exchanges with other software packages (energy simulation, structural analysis, and so forth) are assumed to happen flawlessly and effortlessly.

As soon as is realized that BIM tools and BIM processes cannot handle or solve everything, the peak of inflated expectations is left, after which a trough of disillusionment follows. This can particularly be the case when a bad choice is made in the selection of the BIM pilot project. In such cases, early BIM adopters often lose their faith and belief in the usability of BIM processes and BIM tools, in the worst option leaving the opportunity entirely. In case the BIM implementation plan is not abandoned, BIM adopters typically follow a slope of enlightenment that leads to a plateau of productivity.

When starting a BIM implementation trajectory, it is therefore important to set up a full BIM implementation plan that makes sure that expectancies are set as precisely and realistically as possible. This requires the plan to be set as specifically as possible, directly responding to specific user needs and processes that are present on the working floor (bottom up, person-specific). Furthermore, generic BIM implementation plans that can presumably serve for a majority of companies, should be avoided, as they generate (inflated) expectancies that do not match the expectancies on the work floor.

In the presentation of a BIM implementation plan, one has to include a training and education plan, which makes it possible to also manage expectations among other employees in a company that implements BIM. This education plan thus not only serves as a list of what is needed to be covered to make sure that employees are technically capable of working according to a BIM process that includes BIM tools. It furthermore allows to induce the right expectations, so that the desired results can be attained.

A BIM implementation plan needs to consider the type of company, its personality, current workflow, focus, predisposition, and so forth. This company profile defines the business plan, and the technical choices (people, software, hardware) directly follow from that business plan and company profile. Software needs to be chosen in function of the company, and not the other way around.

Finally, to manage expectations in a BIM implementation plan, it is also very important to describe a clear implementation process and timeline, with clear milestones and agreed expectations.

3.2.3 Propagating BIM throughout the company

The implementation of BIM typically starts in one part of a company, with the majority of the company either being skeptic, less certain or trailing behind. The different definitions and approaches towards what BIM is, do not help, because they bring alternative interpretations and opinions in people. Employees within a company then create wrong expectations based on wrong definitions, making them less eager to adopt BIM. Why change the way in which we have always worked?

Those employees that are enthusiastic about the implementation of BIM and effectively see the added value are then typically somewhat left on their own with the challenge of convincing the others in the company: propagating BIM throughout the company. A person-specific BIM implementation plan needs to take this situation properly into account and indicate how this propagation will be handled.

We discuss here the three profiles where BIM implementation most typically starts:

- The young technical enthusiast
- The middle ground mediator
- The manager

The young technical enthusiast

In often cases, the use of BIM starts with the younger employees in a company, as they are more amenable to learning the new software and seeing the advantages of the software. Furthermore, they are not used to the existing traditional workflows in a company and they consequently do not by default fall back on ‘the way we always did things’. This then creates the profile of the young technical enthusiast, eager to try new ways of working and to push these ways of working to all surrounding colleagues, often before they have actually proven their value.

In the case of BIM, this young technical enthusiast often sits in the drawing division or modeling division of the company. This is where BIM modeling environments get introduced because of their technical added value. When adopting BIM starting from this point (technical enthusiast in a modelling office), the incentive for implementing BIM typically becomes more focused on the technical gains, rather than the commercial gains, which is in itself a very good thing.

There are a number of important challenges when this situation occurs:

- *Overenthusiasm*: The young technical enthusiast is often too enthusiastic, which leads to too high expectations and then a lot of disappointments. This relates heavily to the challenges of managing expectations (Section 3.2.2). It is important for a young technical enthusiast to be aware of the limitations of solutions, and to consider that not everything is going to work magically by installing the right software.

- *The skeptic colleague:* In many cases, direct colleagues are very skeptic towards the new solutions and ways of working that are proposed and considered. Especially when the initiator is 'blinded' by enthusiasm, the distance between initiator and colleagues can be very big and that can then work adversely. In this case, middle ground needs to be sought, and colleagues need to talk and stepwise see potential advantages in their both respective working methods. This is where a person-centric BIM implementation plan becomes very useful. The way in which your colleagues work with building information (inputs, outputs, required work) can be very different from yours, and the usage of BIM tools and processes can then bring very different advantages to the different people. It does not work for everyone to install a BIM authoring tool and start modelling. Instead, the focus needs to be on the flow of information through the different tools, including those that are already used long time before. If everyone writes this down in a person-specific BIM implementation plan, plans with processes, tools and data needs can be aligned, and the required middle ground between colleagues can be found more easily.

- *The distant upper management*: In often cases, a technical enthusiast does not randomly perceive full support from the middle and upper company management. The management team seems to be distant, "not really aware of all the amazing possibilities within reach". In order to be able to propagate new BIM workflows and processes and tools throughout the company, especially when facing a range of skeptic colleagues, any technical enthusiast often seeks support and help from the middle and upper management. He often also really needs it, not just to convince colleagues, but also because the different specific BIM implementation plans need to be aligned with each other, so that they support the joint company targets. Convincing the middle and upper management requires time. It is hereby often important to realize that a technical enthusiast typically starts from the purely technical incentives towards implementing BIM, whereas the upper management will be looking for the financial incentives. When aiming to convince the upper management, it is therefore important to not limit to explaining the great new tool, but also specifically indicate the numbers and statistics related to using the software (added value).

The middle ground mediator

We use the term 'middle ground mediator' here to refer to more senior employees in a company, who have been responsible for a range of projects before and who are often in charge of a number of technical people in the office. These employees have a very important role in propagating BIM in a company. Namely, they are typically those people in the middle between technical workers and upper management, thus understanding the needs and incentives in both areas. Furthermore, they are in charge of groups of people and divisions. They are thus also able to mediate between people and different ways of working in different people and divisions. For example, middle ground mediators can align modelling divisions with simulation teams and construction site managers, thereby making sure that information flows, data needs, and tool choices align with each other. Person-specific or division-specific BIM implementation plans are hereby tremendously useful tools.

Because of their involvement with multiple divisions and their supervision role over multiple technical colleagues, including BIM modelers, these middle ground mediators also often function as BIM coordinators in projects and in companies. They bring together multiple aspect models of their colleagues, perform the necessary clash detection and quality control, and then deliver externally.

In their role, they ideally also aim at training their colleagues and workers, which not only allows those workers to be educated, but also to build a common agenda and a common way of working across colleagues.

The manager

Finally, in some cases, BIM implementation starts not on the work floor, but rather in the management of a company. In these cases, the incentive is very often financial in kind: higher Return on Investment is expected because of the mere adoption of BIM processes. A BIM implementation plan by the management team will naturally evolve into a more company-wide BIM implementation plan. This company-wide implementation plan needs to stay on a much higher level, yet it needs to connect to individual work methods as well. Ideally, this more company-wide BIM implementation plan gives a clear indication of the structure of the company, and the way in which the use of BIM is meant to propagate throughout the entire company.

There are a number of risks associated to a management team aiming to adopt BIM, namely:

- *Total focus on the financial incentive:* As much as an employee may focus entirely on the technical benefits of using a BIM approach and BIM tools, a management team might equally focus entirely on the financial incentives, leaving out any thoughts on technical incentives. As a result, focus might be put on target numbers and statistics, but the way in which they can be realized technically is far from clear. This may lead to unrealistic goals and impractical implementation plans.

- *How to convince and stimulate employees:* This obstacle often goes hand in hand with the above. Because of the total focus on numbers and financial incentives, a gap of understanding between the management team and the employees emerges. The employees don’t see what they need to do, let alone how they are supposed to show that they reached required goals. To resolve this, it is important to have a stepwise implementation approach into the technical workings of a company (likely through middle ground mediators).

When implementing BIM as a manager, it is of high value to take on a training plan for BIM managers. In aiming to also enable BIM managers to take into account the technical incentives, an appropriate training plan should include technical content.

3.2.4 Emerging roles

With the implementation of BIM in any company, a number of new roles typically emerge, namely the roles of BIM modeller, BIM Coordinator, and BIM manager. Although a number of other names and roles are often also mentioned in the industry, these three roles are key, and many other names and roles can be subsumed under any one of these three.

- BIM Modeller
  A BIM modeller is actively occupied with modelling BIM models in BIM authoring tools. To be able to model a building, one needs the have the necessary construction knowledge and modelling skills. This role has emerged because BIM came with new types of software with which many people were unfamiliar. Those who master the BIM authoring software are now typically considered to be BIM modellers. As they are the ones that know in detail how the BIM model is built, where the difficult points are in the BIM model, and how they were solved, BIM modellers are typically most informed about the design and construction techniques of the modelled building.

- BIM Coordinator
  A BIM coordinator is a more senior person who typically has been active as a BIM modeller for a number of years, and who often is still involved in modelling BIM models. This person is actively occupied with the coordination tasks in BIM-based projects. In other words, he works on projects and performs clash detection, model quality checks, and coordination between modellers and partners. This person sets up the different aspect models, the scopes of these aspect models, the links between them, and the interaction between BIM modellers doing the modelling work. For the coordination of the project, his main tool is an information delivery manual, which includes process maps, guidelines, and agreements on how the overall BIM process for the project should happen. This person is in charge for the company and for the project to make sure that the agreed process is followed and sufficient quality is achieved.

- BIM Manager
  A BIM manager is also a more senior person, who typically has been active as a BIM modeller and BIM coordinator for a number of years. The BIM manager does not work on project level, but more on company level. This person is responsible for anything that is related to BIM within the company. He communicates between the management of the company and the BIM coordinators and modellers. This person is responsible for the gradual implementation of BIM within the company; he manages object libraries, BIM projects, BIM development and so forth across projects. This person calculates the added value of BIM for the company and continuously evaluates the level of success and quality delivered.

3.2.5 Key features of a BIM implementation plan

In this chapter, the overall structure of a BIM implementation plan is explained, indicating a number of options and directions for constructing the plan. The BIM implementation plan as it is explained here, is not aimed to be a grand BIM implementation plan that is written for a complete company in all its subdivisions. Neither is this BIM implementation plan here aimed to be a generic document that can be used for any company in the AEC industry. Instead, the BIM implementation plan as it is targeted here, aims to be a reference document that can be created by and for anyone on the working floor in any domain handling with information in construction.

Of course, the creation of a BIM implementation plan requires direct and specific knowledge on the way in which BIM applications and BIM processes function. It summarizes how BIM can be effectively introduced in construction projects and companies in the construction industry, thereby aiming at implementation in a granular level, by the people who actually work with the information. Therefore, the BIM implementation plan should reflect the technical focus and incentive that is aimed for in the specific context of the (part of the) company and the person for which it is made. In larger companies, a combination of these person-specific BIM implementation plans can be used to synchronize the diverse company teams and services into a larger company-wide BIM implementation plan.

The BIM implementation plan is built according to a template, of which the main structure is given below. The structure of this template needs to be followed. Of course, the precise details and extents of the content depend heavily on the company structure and purpose.

1. Background and context
    a. Company context
    b. Added value of BIM
2. Business plan
    a. Internal Business Plan
    b. External Business Plan
3. Technical plan
    a. People
    b. Software
    c. Hardware
4. Legal plan
5. Example project

With this BIM implementation plan, one can clarify how one plans to implement BIM tools and BIM processes effectively within one's company context. Furthermore, one is meant to specifically indicate where the added value is located for one's personal job description. Ideally, the BIM implementation plan is illustrated at length with very concrete details of reference example projects and example company processes. Yet, in addition, a section is provided which allows to elaborate on how a specific example reference project will be implemented.

The BIM implementation plan is furthermore meant to be aiming at a future implementation track. Hence, of course, each section includes a tangible timeline that provides an indication of how advances are planned, and how one is aiming to track advancements. For each section, and in particular in the business plan section, concrete numbers and statistics are given, so that direct tangible criteria are available of how much progress is made in reference to key company numbers.

A BIM implementation plan is expected to count minimum 10 pages. Longer implementation plans are possible, in particular if they cover larger areas within a company, or when they are company-wide. Ideally, a number of appendices lists key reference documents, such as BIM modelling agreements, BIM execution plans, protocols, definitions, and so forth.

4. Open BIM standards

The main purpose of BIM is to improve efficiency, collaboration and information exchange in the AEC sector. Standards play a crucial role in this regard and thus constitute the cornerstone of ‘OpenBIM’ (see Section 1.2.3). In this chapter, we look specifically into the international initiatives that promote and enable open BIM. Key to enabling a collaborative approach towards design, realization and operation of buildings, are open standards. They are agreements made across (large) groups of people, companies and industries. The main standardisation bodies are the International Organization for Standardization (ISO) and the European Committee for Standardization (CEN). National and regional standardisation bodies also exist and work towards standardisation locally. In the AEC industry, buildingSMART International plays a special role, as it typically aims at preparing standards for the AEC industry, before they are proposed to ISO and CEN. In other words, buildingSMART International does the preparation of standards, so that they are more easily accepted and published by the ISO and/or CEN standardisation bodies.

4.1 BuildingSMART International

buildingSMART provides an important number of international standards regarding process and product modelling. These standards are then typically put forward to ISO and CEN for standardisation. As a result, BuildingSMART and its standards are a primary reference for the implementation of BIM in practice, particularly when an Open BIM approach is followed.

buildingSMART, formerly known as the International Alliance for Interoperability (IAI), was established in 1995 as a private alliance of 12 design, engineering, construction and software development companies, the purpose of which was to demonstrate the benefits of full information exchange between the software products used in the construction industry. In 1996, the International Alliance for Interoperability was officially established and made a non-profit organization. The goal of the organization was to make a neutral data model considering all parts of the building life cycle. The name of the organization was changed to buildingSMART in 2008 and reflects the goals of the organisation with regards to the high digital standard demands in the construction industry.

The IAI was set up with the three following messages or statements:

1. Interoperability is viable and has great commercial potential
2. Any standard must be open and international, not private or proprietary
3. The alliance must open its membership to interested parties around the globe

buildingSMART International gathers a number of national buildingSMART chapters. These chapters have an incredibly important role, as they gather key end users in the AEC industry in specific countries all over the globe. Without input from such users, it is near to impossible to set up standards that can be followed in national practices. Furthermore, the local buildingSMART chapters play an important role in community building, as each of them gathers a local community, thus providing room to disseminate good BIM practice. An overview of the buildingSMART International chapter is given in Figure 4.1.

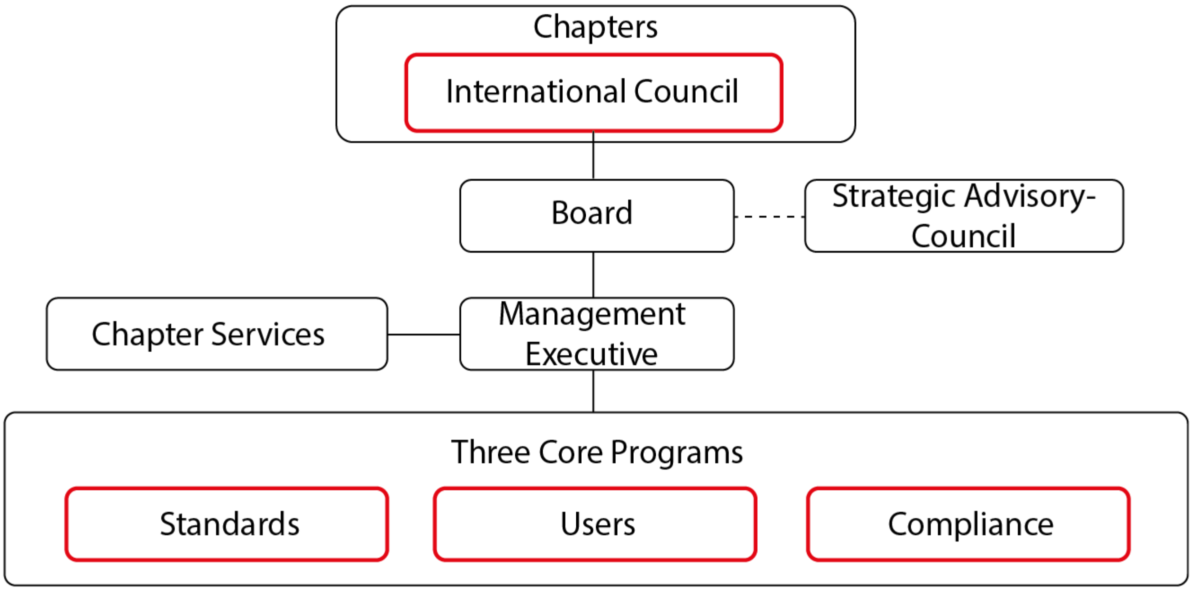


Figure 4.1 The overall structure of buildingSMART International.

buildingSMART International has by now developed a number of standards that are of use for the implementation of BIM in practice. They are ISO standards that are meant to be applied in practice. The standards developed by buildingSMART are oriented in three directions, namely data, process, and terms (Figure 4.2):

- Data: Industry Foundation Classes (IFC)
- Process: Information Delivery Manual (IDM)
- Terms: International Framework for Dictionaries (IFD)

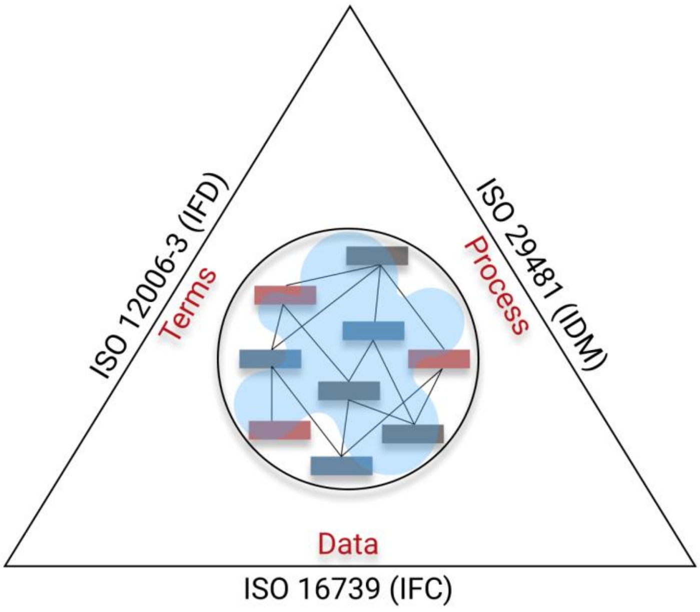


Figure 4.2 BuildingSMART implements standards for data, processes and terms.

Two key standards in terms of data exchange are IFC and IDM. These two standards focus on data that needs to be exchanged, as well as the processes that should be followed for exchanging the data. As such, these standards align well, and are in fact at the basis of many of the workflow and exchange mechanisms in practice. They focus on data and process modelling. In the sections below , we will focus on documenting precisely these two standards. Furthermore, a separate section will be devoted to the explanation of Model View Definitions (MVDs), which are tailored to capturing Exchange Requirements (ERs) and are hence directly referenced in an IDM. MVDs are standardised within buildingSMART, but not in ISO or CEN.

A fourth buildingSMART standard documented in this chapter, is the IFD standard. The IFD standard is nowadays primarily used in the implementation of the buildingSMART Data Dictionary (bSDD). In short, IFD provides a schema that allows to represent dictionaries or vocabularies of terms. This schema is used in the bSDD, thus providing an implementation with interlinked AEC terminology.

The last standard published by buildingSMART is the BIM Collaboration Format (BCF). BCF is specifically developed as an open XML format file (bcfXML) that supports workflow communication in BIM processes. As such, it plays a crucial role in communicating issues, change requests, and proposals across different BIM software platforms.

4.1.1 Industry Foundation Classes (IFC)

Open interfaces should allow for the import and export of relevant data in various formats (to support integration and exchange with other applications and workflows). There are two primary approaches for such integration: to stay within one software vendor's products (closed BIM) or to use software from various vendors that can exchange data using neutral open standards (open BIM).

As a result, in an attempt to ensure interoperability in the industry (open BIM), buildingSMART developed the Industry Foundation Classes (IFC). IFC is an open neutral data model that allows users to exchange detailed and task-specific models between AEC software applications (see videos[13]). The purpose of IFC is to address multiple types of information, over the whole building life cycle. That includes all phases, from feasibility studies and planning, through all design stages (including various analyses and simulations), construction, occupancy, as well as building operation and maintenance. In other words, the purpose of IFC is to enable everyone involved in an AEC project to share information using a common and neutral data model (see Figure 4.3). This includes everyone from the early design stage, through project execution and delivery, as well as demolition, and potentially even further in the cases where building elements or components are being recycled or reused in a new facility. The ability to share information, for example about the operation and maintenance phase, as well as information about geometry of specific building components, is what makes IFC a match for the collaborative working methods involving BIM.

[13] https://www.youtube.com/watch?v=g_jmGQvr6dQ and https://www.youtube.com/watch?v=vTyB96O7Xeg

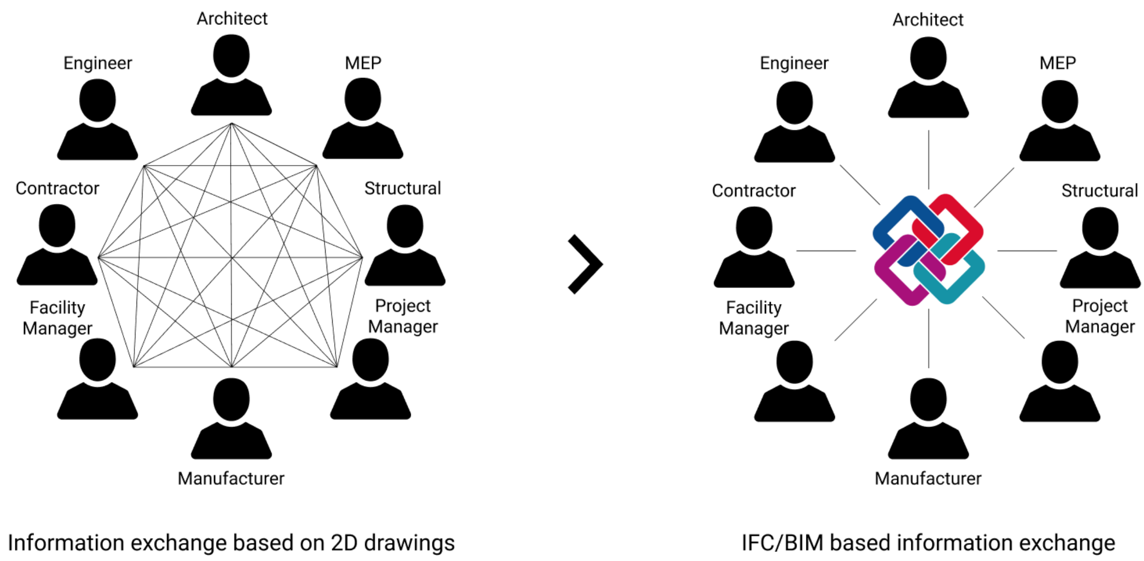


Figure 4.3 IFC as a data model stands central in the exchange of information between all stakeholders in any AEC project.

The data model is organized to hold and exchange data from many disciplines and that brings advantages to the whole project from conception, through design, construction and operation, to refurbishment, demolition and recycling. Furthermore, the IFC model stores information for tangible components, such as walls, windows, columns, furniture, and so forth, as well as the more abstract non-physical concepts of shape, geometry, materials, schedule, activities, and so forth.

The IFC data model is captured in the IFC schema, which is openly available online[14]. This schema is originally encoded as an EXPRESS schema, which is a standard data modelling language for product data. By now, also an XSD (XML Schema Definition) and an OWL (Web Ontology Language) version of the same schema are available (see Figure 4.4). These schemas are automatically generated from the original EXPRESS schema. The schema only captures what kind of data *can* be represented (e.g. an IfcWall should have a globally unique identifier (GUID) and a name) and holds the definitions and terminology that can be used to express information about any building. Data about specific buildings can then be exported according to that schema (using the terminology of the schema). This results in the IFC-SPF files (STEP Physical File). This IFC-SPF file matches the EXPRESS schema (Figure 4.4). Alternatively, XML files (eXtensible Markup Language) can be exported as well, then following the XSD schema of IFC. Similarly, RDF files (Resource Description Framework) can be exported as well, then following the OWL schema of IFC.

In short, IFC is a neutral data model, which is used to capture building data in a vendor- neutral file.

[14] http://www.buildingsmart-tech.org/specifications

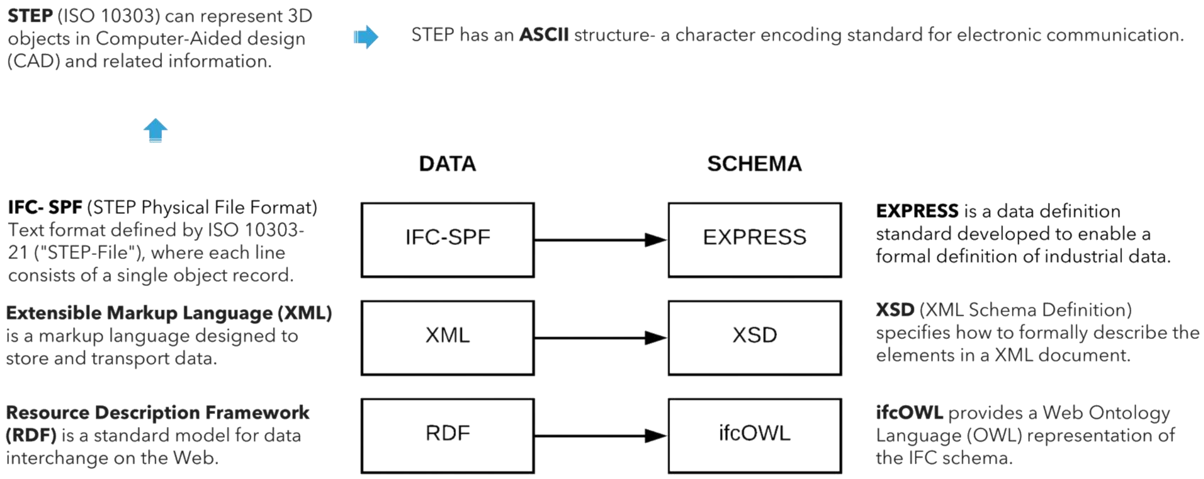


Figure 4.4 The IFC schema is available in EXPRESS, XSD, and OWL.

The use of open data models such as IFC provides more flexibility for data exchange, because it is an open file format that can be read and used by many BIM applications. As such, it is very different from proprietary data formats, which can only be used in the corresponding software applications (vendor lock-in). This of course also has its downside. Namely, the data that is created and captured in a BIM application (the BIM model) needs to be translated and exported to the IFC data model, which is different from the native application. Hence, there is a possibly reduced level of interoperability, especially if the various software programs in use for a given project do not support, or only partially support with some data loss, the same exchange standards. As an example, exchanging data from Autodesk Revit to Autodesk Revit still goes better via the native file format (.rvt) – thus the higher level of interoperability is achieved by using proprietary file formats. On the other hand, when exchanging data from, for example, GraphiSoft ArchiCAD to Autodesk Revit, the use of proprietary formats has a lower level of interoperability compared to the use of IFC as a data exchange mechanism.

While IFC can represent a wide range of building design, engineering and production information, the range of possible information to be exchanged in the AEC industry is huge. The IFC coverage increases with every release and addresses limitations, in response to user and developer needs. All application-defined objects, when translated to an IFC model, are composed of the relevant object type and associated geometry, relations and properties:

- **Geometry:** IFC has means to represent a wide range of geometry, including boundary representations (BREPs) and Constructive Solid Geometry (CSG).
- **Entities:** Entities capture object types (walls, windows, doors) and their semantics (meaning).
- **Relations:** Relations are typed and link one object with another.
- **Properties:** IFC places emphasis on property sets, or PSets, used together to define material, a performance, and contextual properties.

In summary, the Industry Foundation Classes (IFC) is a schema developed to define an extensive set of consistent data representations for building information exchange between AEC software applications. IFC was designed as an extensive "framework model". That is, its developers intended it to provide broad, general definitions of objects and data from which more detailed and task-specific models supporting exchanges could be defined. In this regard, IFC has been designed to address all building information, over the whole building life cycle.

4.1.2 Information Delivery Manual (IDM)

With regards to information exchange in the construction industry, it is vital that all sub-processes constituting the main process, as well as the specific needs related to them are well defined. It is well known that the AEC industry brings many different actors, (professionals, companies and authorities) together every time a project is about to begin. In order to work in an efficient way, it is required that all professionals in the organization know when, how and in what form, different kinds of information have to be communicated. This is even more significant when ICT tools are applied, since most of them have low tolerance of interpretation of different digital data. Therefore, buildingSMART International has developed and introduced the use of Information Delivery Manuals (IDM). An IDM is meant to provide a common understanding of what information is required during collaboration and when it needs to be exchanged in what manner:

> *"An IDM is a process standard that has been proposed to define information exchanges between any two project participants in an AEC/FM project, with a specific purpose, within a specified stage of the project's life cycle."*[15]

Hence, the IDM is a methodology that can be used to document business processes (both new and existing ones) and gives a detailed description of the user information exchange, which therefore makes the benefits from BIM much more achievable. In documenting processes, the IDM methodology relies heavily on the use of Business Process Modelling (BPM) diagrams. An example BPM diagram using Business Process Model and Notation (BPMN) graphical representation is provided in Figure 4.5.

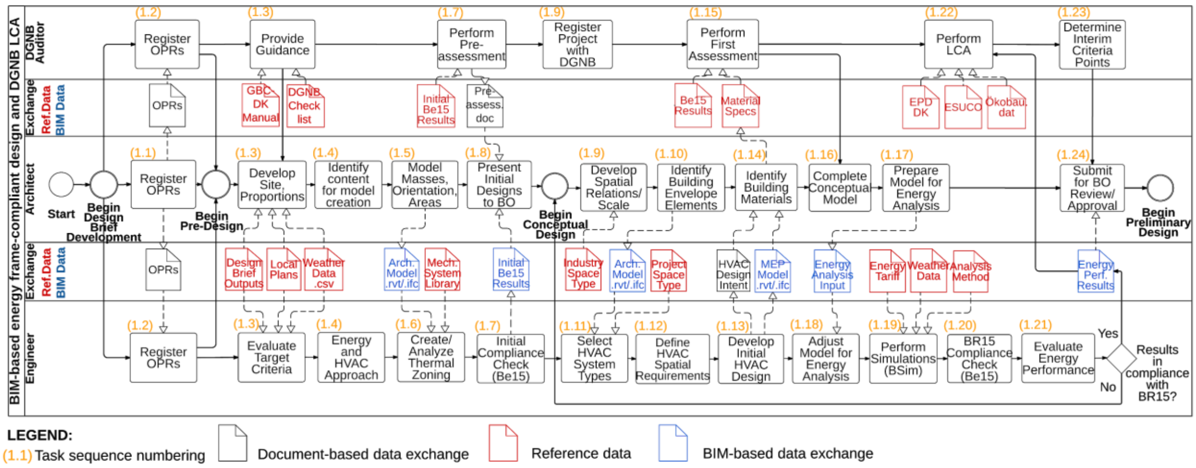


Figure 4.5 Example BPMN process map, as it may be included in an IDM.

15 http://iug.buildingsmart.org/idms/methods-and-guides/Integrated_IDM-MVD_ProcessFormats_14.pdf

From another perspective, buildingSMART defines that the purpose of an IDM is to supply a cohesive reference for the processes and data, which BIM requires. For that to be achieved, first of all an identification of all distinct construction industry processes has to be made. In addition, the IDM needs to outline different data exchanges in support of specific purposes. By doing that, any stakeholder is able to build up knowledge concerning:

- the relevance of the process and where it fits;
- the main actors involved and how they contribute to and benefit from the process;
- what kind of information is used and exchanged;
- what kind of software solutions are necessary to support that.

"An Information Delivery Manual defines an industry process that involves at least two types of software applications, and the information that should be exchanged between those applications. IDMs include four primary deliverables, using standard formats. These are:

- *Process Maps which define the industry process,*
- *Exchange Requirements which define the information to be exchanged,*
- *Exchange Requirements Models which organize the information into Exchange Concepts that will be linked to Concepts in the MVD and enable verification that all requirements have been satisfied,*
- *Generic BIM Guide which documents guidance to the end user about what objects and data must be included in the BIM to be exchanged. Product specific versions of the BIM Guide will be developed later by vendors of certified software products."* [16]

In other words, it can be stated that an IDM answers the following set of questions:

- WHO is requesting information?
- WHY in relation to a process or decision?
- WHEN as in what stage in a project?
- WHAT information is to be exchanged?
- WHO is delivering/receiving the information?

The entire process of setting up an IDM is initiated by forming a working group among AEC professionals initiating a collaborative design and construction process that would benefit from an IFC-based information exchange (Figure 4.6). The first task is to develop a business use case for the targeted process. This use case defines the participants, the information that should be exchanged, the formats, and the purpose. The next step includes the development of process maps by the use of standard BPMN templates.

[16] http://iug.buildingsmart.org/idms/methods-and-guides/Integrated_IDM-MVD_ProcessFormats_14.pdf

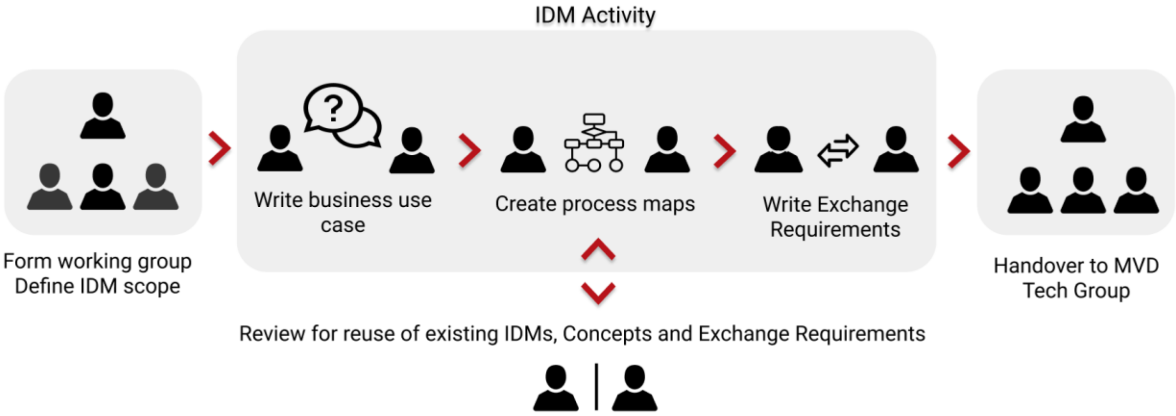


Figure 4.6 Initiation of IDM development and identification of processes that should be supported by IFC based data exchange.

Thereafter, the IDM development continues with the definition of Exchange Requirements (ERs). They document the data to be included in each exchange, as it has been identified in the created process map. ERs are normally documented in tabular format or spreadsheets. These serve as a basis for the creation of entity-relationship diagrams (Exchange Requirements Models (ERMs)), which are made for each high level object in the information exchange (e.g. Project, Site, Building, Building Storey, Space, Wall, Door, Window, etc.). The ERM diagrams consist of Exchange Concepts, defining the information to be exchanged, the type of data, and so forth.

An important feature of an IDM process (Figure 4.6) is that, in order to be functional, it has to be implemented in and supported by software. Its output, which consists of a number of explicit Exchange Requirements (ERs), is actually what can serve as a basis for a software development process (extreme right in Figure 4.6: handover to MVD Tech Group). The below section briefly indicates what Model View Definitions (MVDs) are (the second phase of the IDM Process). After the definition of MVDs, the IDM process continues with two other phases, namely (1) implementation / certification and (2) BIM data validation.

In reality, the resulting MVDs are highly complicated and large. Therefore, the implementation of these MVDs in software applications is typically limited to the most commonly used data exchange phases in the AEC industry, namely, Design Transfer View, Coordination View, and Reference View.

4.1.3 Model View Definition (MVD)

A Model View Definition (MVD) is defined by buildingSMART as a subset of the IFC schema that is needed to satisfy one or many Exchange Requirements as specified in an IDM. In short, an IDM refers to a large number of exchanges with specific exchange requirements (ERs). These exchanges are captured in the BPMN diagrams of the IDM, which refer to specifically defined MVDs.

An MVD also specifies the software requirements which are necessary for the implementation of IFC interfaces, so that the particular Exchange Requirements are fulfilled. In short, MVD's title role is to provide IFC-based technical solutions which are needed by the end users and are defined according to particular requirements.

"A Model View Definitions document a subset of the IFC Model Specification that is required for the information exchanges defined in one or more related IDMs. As such, it is the 'design' for support of those information exchanges in software products. MVDs include three primary deliverables, each using standard formats. These are:

- *MVD Overview/Description which describes the scope of the MVD; especially the IDM that are addressed,*
- *MVD Diagrams which define the MVD Concepts that will be used in the exchange, as well as the structure and relationships between these Concepts*
- *Concept Implementation Guidance which defines the IFC entities used to exchange each concept and the Implementer agreements that general reduce the implementation scope that would otherwise be required by the extremely general IFC schema.*
- *Binding to the IFC schema is documented in mvdXML."*[17]

MVDs have usually been developed for implementation of information exchanges based on IFC, yet it is also possible to define exchanges based on other languages or data models. The definition of Model Views aims at finding a useful balance between the end user requirements and the possibilities of software developers, as the developers are eventually the ones that need to implement the ERs captured in the MVDs. The IFC Model View Definition Format (mvdXML) is used for documenting the outcome. Its main structure is shown below (Fig. 4.7) and discussed briefly in the following paragraphs.

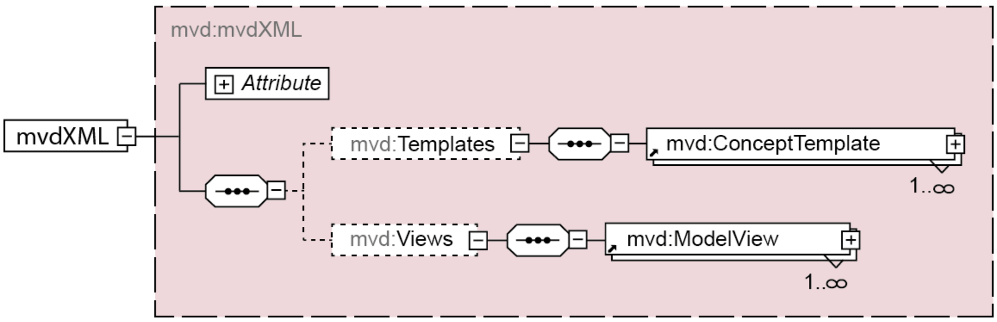


Figure 4.7 Structure of an mvdXML document[18].

An mvdXML document contains an instance of *mvd:mvdXML* as the only single valid root element. The mvdXML element defines two main sub elements:

- *mvd:Templates*: a list of reusable concept templates, *mvd:ConceptTemplate*, that defines the graph within the base IFC schema representing the entities and attributes needed to support the functional unit addressed by the concept.

[17] http://iug.buildingsmart.org/idms/methods-and-guides/Integrated_IDM-MVD_ProcessFormats_14.pdf
[18] http://www.buildingsmart-tech.org/downloads/mvdxml/mvdxml-1.1/final/mvdxml-1-1-documentation

- *mvd:Views*: a list of model view definitions, *mvd:ModelView*, that contains the necessary entities and associated concepts to define the sub schema of the base schema to support the exchange requirements.

In short[19], the mvd:Templates node groups a number of generic templates including the main entities and attributes that are needed for an exchange. These templates include many attributes that are part of the overall IFC schema (e.g. attributes of IfcProductDefinition, IfcRoot, IfcProduct, and so forth). The mvd:Views node collects a number of specific entities (e.g. IfcWall, IfcBeam, ...) for which these attributes need to be exchanged. The views thus make reference to the ConceptTemplates, as indicated in Fig. 4.8. Examples of a ConceptTemplate and a ConceptRoot are given in Fig. 4.9 and 4.10, so one can see how they rely on each other.

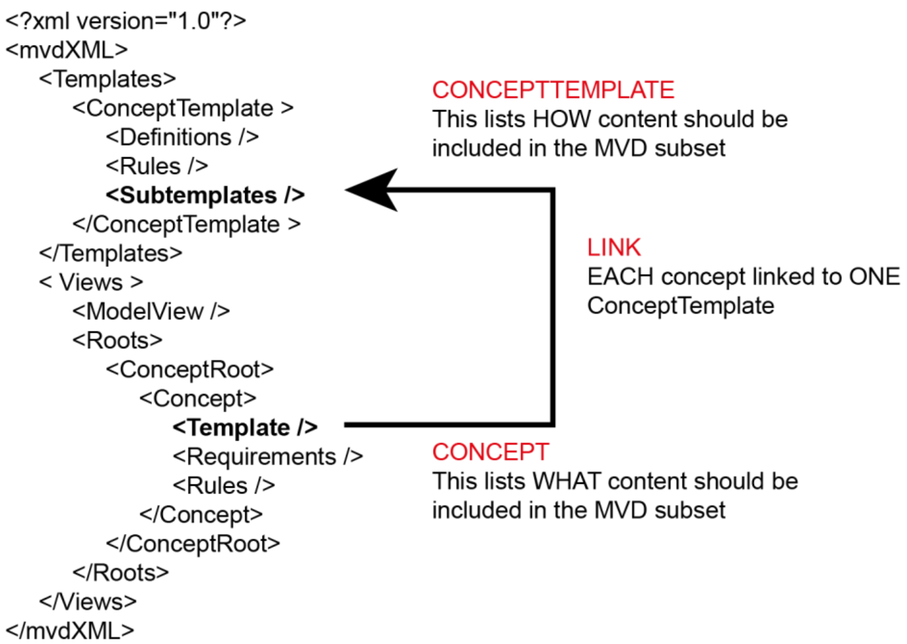


Figure 4.8 Every ConceptRoot in a ModelView refers to a ConceptTemplate for indicating what content needs to be included in any MVD.

[19] The complete documentation is available at http://www.buildingsmart-tech.org/downloads/mvdxml/mvdxml-1.1/final/mvdxml-1-1-documentation

```
<ConceptRoot uuid="83c2915f-08f1-4027-a32c-23fd3ee588b6" name="" applicableRootEntity="IfcBuildingStorey">
    <Concepts>
        <Concept uuid="64802040-8b87-4ed2-87bc-b9cc16a587df" name="Identity" override="false">
            <Template ref="f7cb0a08-fee7-4cc0-85fe-43f6a6a0bce1" />
            <Requirements />
            <Rules />
        </Concept>
        <Concept uuid="9e903641-5cb8-4e64-a479-4d4619c2ddc1" name="with Property names" override="false">
            <Template ref="d5449a96-e8a9-48f0-bc9a-c3829f5fc668" />
            <Requirements />
            <Rules>
                <TemplateRule Parameters="Name=Pset_BuildingStoreyCommon;PropertyName=Reference;" />
                <TemplateRule Parameters="Name=Pset_BuildingStoreyCommon;PropertyName=EntranceLevel;" />
                <TemplateRule Parameters="Name=Pset_BuildingStoreyCommon;PropertyName=AboveGround;" />
            </Rules>
        </Concept>
    </Concepts>
</ConceptRoot>
```

Figure 4.9 Example ConceptRoot in an mvdXML.

```
<ConceptTemplate>
<Definitions />
<SubTemplates>
    <ConceptTemplate uuid="f7cb0a08-fee7-4cc0-85fe-43f6a6a0bce1" name="Identity" status=""
applicableSchema="IFC4" applicableEntity="IfcRoot">
        <Definitions />
        <Rules>
            <AttributeRule AttributeName="GlobalId" Cardinality="_asSchema">
                <EntityRules>
                    <EntityRule EntityName="IfcGloballyUniqueId" Cardinality="_asSchema" />
                </EntityRules>
            </AttributeRule>
            <AttributeRule AttributeName="Name" Cardinality="_asSchema">
                <EntityRules>
                    <EntityRule EntityName="IfcLabel" Cardinality="_asSchema" />
                </EntityRules>
            </AttributeRule>
            <AttributeRule AttributeName="Description" Cardinality="_asSchema">
                <EntityRules>
                    <EntityRule EntityName="IfcText" Cardinality="_asSchema" />
                </EntityRules>
            </AttributeRule>
        </Rules>
    </ConceptTemplate>
</SubTemplates>
</ConceptTemplate>
```

Figure 4.10 Example ConceptTemplate in an mvdXML.

MVDs are meant to be used in combination with IDMs and IFCs. Essentially, the main idea is that an IDM is prepared as early as possible in any AEC project. This IDM captures the overall process of the entire project. For exchanges, the IDM refers to specific MVDs, which in turn rely on IFC as they essentially capture subsets of the overall IFC schema. This entire process is also schematically depicted in Fig. 4.11. On the left is the work by the Model Support Group (MSG) focusing on the IFC specification (ISO 16739). On the top of the diagram is the IDM which is prepared by an end user in a specific project. This IDM captures the necessary Exchange Requirements (ERs) and relies on the ISO 29481 standard. Furthermore, this IDM refers to a number of Model View Definitions (MVDs). The result then needs to stream into “Software Implementation”.

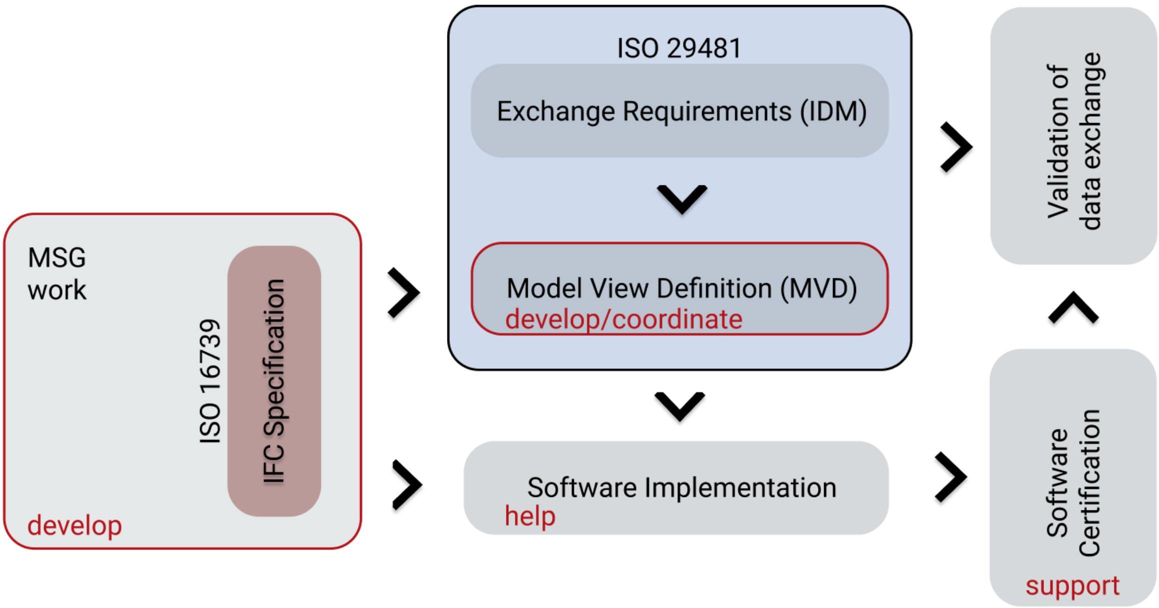


Figure 4.11 The relation between IFC, IDM, MVDs, and software certification and implementation.

Unfortunately, commonly available BIM tools are unable to automatically parse and interpret and use an mvdXML file and create custom IFC exports or imports. As a result, the custom defined mvdXML documents currently seldom to never lead to custom exporters and importers in BIM authoring tools. Only major MVDs are implemented (Design Transfer View, Coordination View, Reference View, etc.). The main resulting software implementations are done by the software vendors themselves and typically include MVDs for key handover moments, such as "Coordination View", "Reference View", "Design Transfer View", and so on. These are relatively big hand-over moments or exchange moments, and it is likely best to align an IDM directly with these main MVDs.

4.1.4 International Framework for Dictionaries (IFD)

The International Framework for Dictionaries (IFD) is one of the three pillars of standardisation in buildingSMART (data, processes, terminology). Whereas IFC focuses on data and IDM focuses on processes, IFD focuses on terminology. As indicated in ISO12006-3[20], *it specifies a language-independent information model which can be used for the development of dictionaries used to store or provide information about construction works. It enables classification systems, information models, object models and process models to be referenced from within a common framework*.

The main purpose of IFD is thus to provide a language that allows to specify and define terms and to link them with each other. One of the more commonly used examples to explain the idea, is the terminology associated to a door (see Fig. 4.12). The IFD language allows one to define the terms associated to a door. Any product vendor can then use these terms to effectively describe his door using the standard vocabulary. It is important to note here that

[20] https://www.iso.org/standard/38706.html

the IFD language only standardizes the data model that allows representing terminology, it does not standardize terminology itself.

Figure 4.12 Definition of a generic door, represented using the IFD standard (left), and the way in which it is used in the definition of a specific product (right)[21].

In a later phase, development of the buildingSMART Data Dictionary (bSDD) started, thereby relying on the IFD standard. This initiative focuses on standardisation of terminology and is thus an implementation of the IFD standard. As indicated in the buildingSMART pages, *"The bSDD is a reference library based on the IFD standard and intended to support improved interoperability in the building and construction industry. The bSDD provides a flexible and robust method of linking existing databases with construction information to a buildingSMART based Building Information Model (BIM)."*[22]

This results in an overall working as displayed in Fig. 4.13. From any possible environment (BIM authoring tool, database, website, excel, …), it is possible to link directly to a globally unique ID (GUID) that represents a specific term. This GUID or term gathers all related definitions and attributes for that entity, thus resulting in a globally standardised dictionary of terms, which can be used as a reference in any possible scenario.

[21] Image inspired by https://bips.dk/files/article_files/4c-1_2010.pdf
[22] https://www.buildingsmart.org/standards/technical-vision/open-standards/

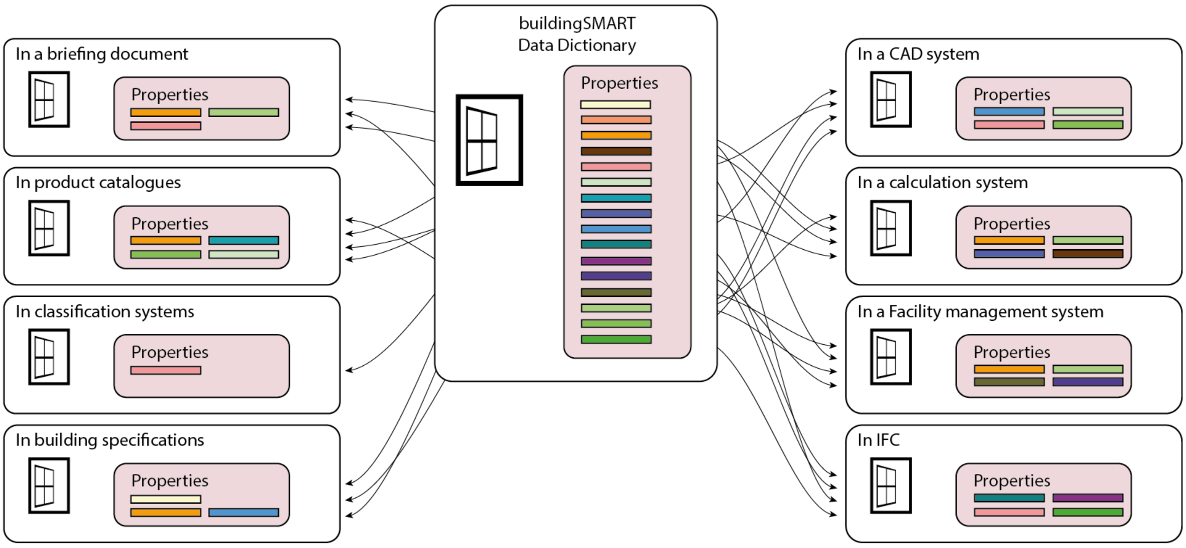


Figure 4.14 bSDD as a mapping mechanism between terms (Image adapted from Roger Grant'[23]).

The bSDD is currently available at http://bsdd.buildingsmart.org/. Behind this webpages is a fully functional web service and database which allows to search, add, and edit terminology in the bSDD. The following access mechanisms are hereby available:

- Access existing object and property relationships and definitions
  - writing calls to the web service API from another application (access the API at bsdd.buildingsmart.org)
  - requires participation as Associate or Sponsor and license when application in the market
- Add/Manage content in the Dictionary
  - using existing tools from bSI or writing own
  - requires participation as a Partner or Affiliate with Project
- Lookup content in the Dictionary
  - bsdd.buildingsmart.org, available to anyone[24]

Everyone is able to look up content through the online web platform for free. Only users without a commercial interest are able to access the API for free. Otherwise, most of the content and other functionality is shielded behind licenses and content management systems.

In order to keep the content in the bSDD of sufficient value to the entire industry, a full quality control system is set up to make sure that only qualified experts can provide the required high-value content. This quality control system is displayed in Fig. 4.14, showing how only specific Agents have write and edit access to the bSDD *through* a quality control system.

[23] http://projects.buildingsmartalliance.org/files/?artifact_id=5148
[24] http://bsdd.buildingsmart.org/

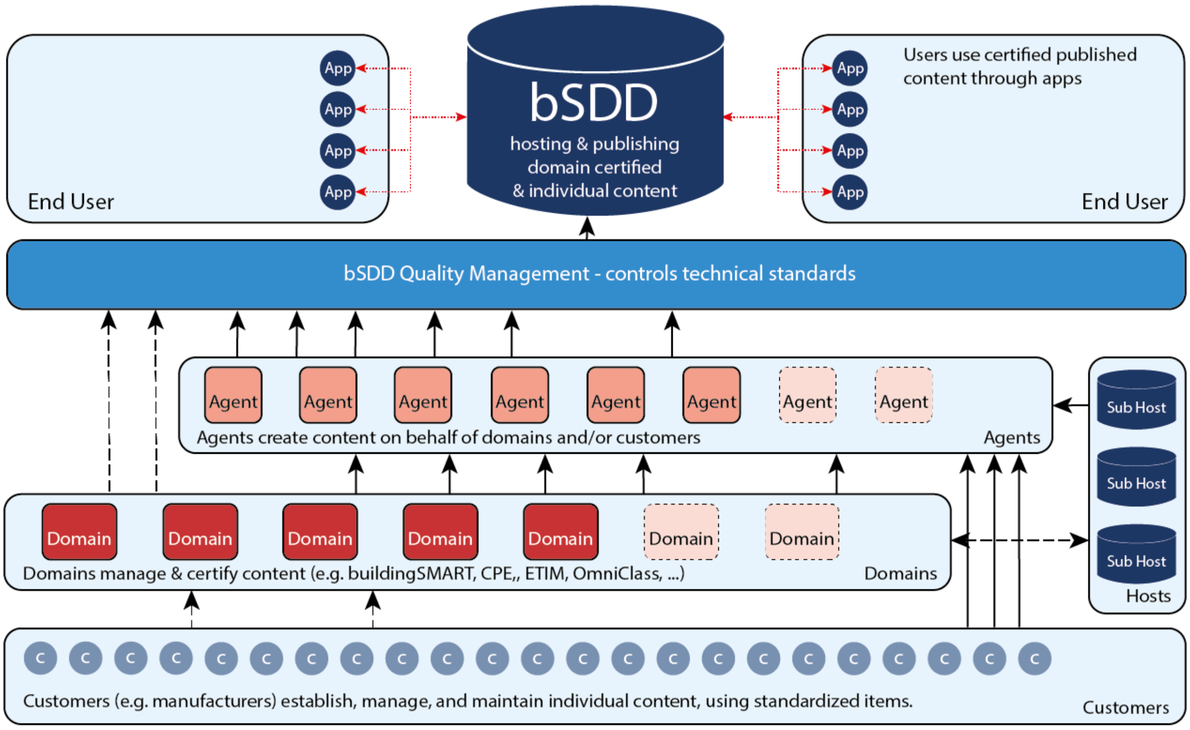


Figure 4.14 Quality control mechanism for the bSDD.

4.1.5 BIM Collaboration Format (BCF)

Somewhat standing apart from the core triangle of standards (data, terms, process) is the BIM Collaboration Format (BCF). BCF is a buildingSMART standard that supports workflow communication in BIM processes. As indicated in the BIMcollab website, *"the BCF concept was introduced by Solibri, Inc., and Tekla Corporation in 2009. They introduced the idea of using open standards enabling workflow communications between BIM software tools. An XML schema, called Building Collaboration Format (BCF), was developed. It encodes messages that inform one BIM tool of issues found by another. Separating communication from the model, enabling a powerful and open collaboration between parties in any construction project."*[25]

The BCF standard responds directly to the need for communicating issues between different BIM tools and discipline professionals. Indeed, BIM tools commonly work with diverse aspect models. Information is thus handled not in a single model, but rather in a number of applications by a number of stakeholders. Using IFC, a coordination model can be obtained, as displayed in Fig. 4.15.

[25] https://www.bimcollab.com/en/BIM/OpenBIM/BCF

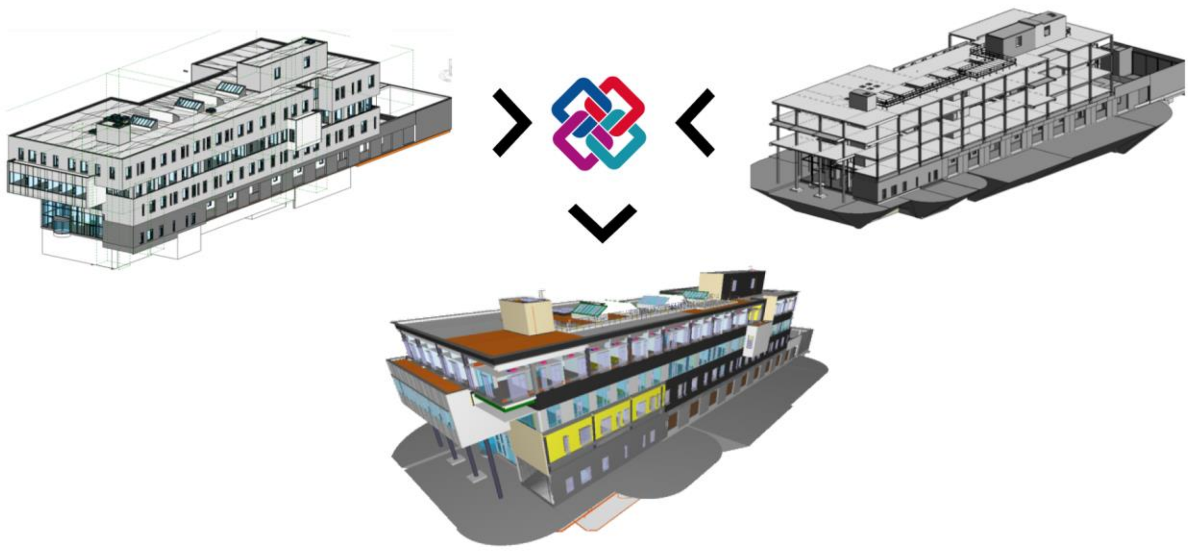


Figure 4.15 Combining different aspect models into one coordination model using IFC.

When issues are found in one application (e.g. the coordination software), they need to be passed on to other users in other applications. Passing on those issues are the core reason of BCF. Instead of having to compare large models with each other, communication can be achieved using small BCF snippets which focus directly on the issues that need to be resolved. This workflow is illustrated in Fig. 4.16. The BuildingSMART logo stands for IFC, meaning to indicate that IFC is used as a format to exchange complete models, both as reference models between BIM authoring tools, and as discipline models between BIM authoring tools and coordination tools (e.g. Solibri Model Checker in Fig. 4.16). BCF, on the other hand, is used only to communicate issues back from the coordination software to the BIM authoring tools. These are the green arrows with the BCF logo shown in Fig. 4.16. The BIM modeller in the BIM authoring tool is then responsible for implementing the necessary changes in the building model.

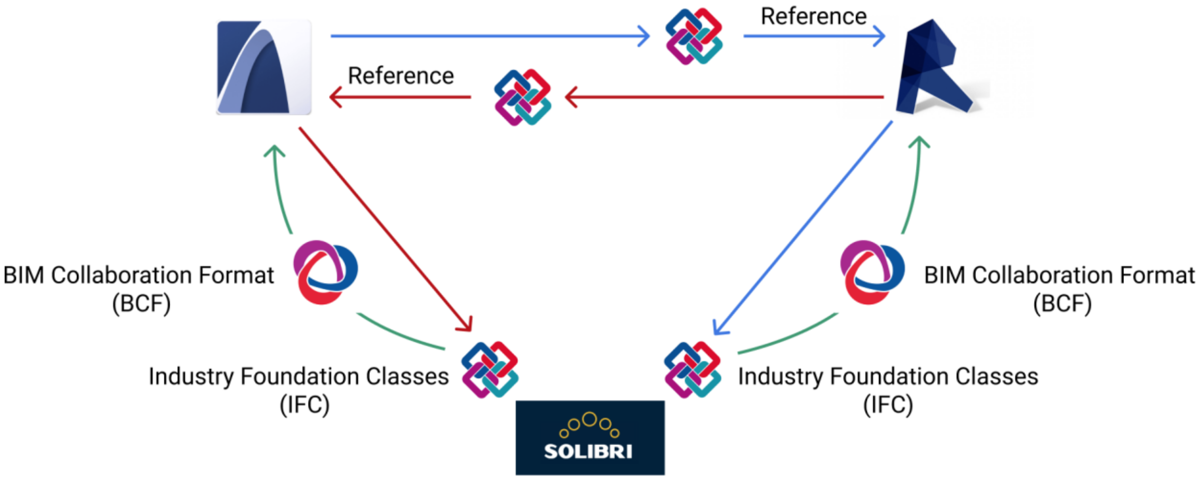


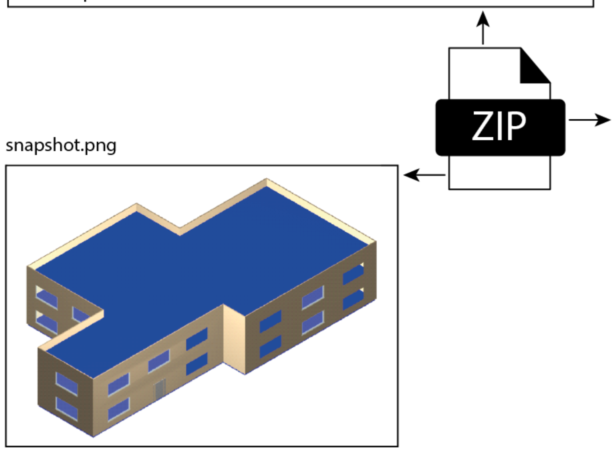
Figure 4.16 The combined use of IFC and BCF allows an appropriate collaboration and coordination process.

Technically, BCF is available as either a ZIP container or as a web service specification. We will not go in depth about the web service specification here. The ZIP container, however, contains three main files, namely markup.bcf, snapshot.png, and viewpoint.bcfv.

These three files contain the issue that is communicated in three distinct ways. The snapshot file contains a thumbnail that is used to communicate a graphical representation of the issues. The viewpoint.bcfv file is used to denote the viewpoint and camera from which the included BCF issue is taken. The markup.bcf finally is *the* actual BCF file. The BCF file relies on an XML schema for the standard textual representation of the issue. The original XML schema can be understood as *"a 'simplified' open standard XML schema that encodes messages to enable workflow communication between different BIM (Building Information Modeling) software tools."*[26] An example BCF container is given in Fig. 4.17.

markup.bcf

```
<?xml version="1.0" encoding="utf-8"?>
<Markup xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:xsd="http://www.w3.org/2001/XMLSchema">
  <Header />
  <Topic Guid="fdb92063-a353-4882-a4a9-b333fe0b2985">
    <ReferenceLink>reference 1</ReferenceLink>
    <Title>topic1</Title>
  </Topic>
</Markup>
```



viewpoint.bcfv

```
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ma-instance" xmlns:xsd="http://www.w3.org/2001/XMLSchema">
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    <Component IfcGuid="1gF16zAF1DSPP1$Ex04e4k">
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    </Component>
  </Components>
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      <Y>-1152.1249999640554</Y>
      <Z>1452.1249999640554</Z>
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    </CameraDirection>
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      <Z>0.81649658092772615</Z>
    </CameraUpVector>
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  </PerspectiveCamera>
</VisualizationInfo>
```

Figure 4.17 The three files typically contained within a BCF ZIP container.

4.2 ISO/TC59/SC13

As indicated in the start of this Chapter, BuildingSMART International is a standardisation body for the AEC industry which mainly aims at developing standards which are then proposed to an official standardisation body such as the International Organization for Standardization (ISO). The ISO was initiated in 1947 as an independent, non-governmental organization and consists of 161 members. This includes:

- Full members or 'member bodies': national bodies considered the most representative standards body in each country. These are the only members of ISO that have voting rights.

[26] https://www.buildingsmart.org/standards/technical-vision/open-standards/

- Correspondent members: countries that do not have their own standards organization. These members are informed about ISO's work, but do not participate in standards promulgation.
- Subscriber members: countries with small economies. They pay reduced membership fees, but can follow the development of standards.

The ISO follows the governance structure that is outlined in Fig. 4.18. The general assembly and the ISO council are the highest authorities in the organisation; they manage the overall working of the ISO organisation. Most of the standardisation work itself occurs in the Technical Committees, which have to report to the Technical Management Board (TMB).

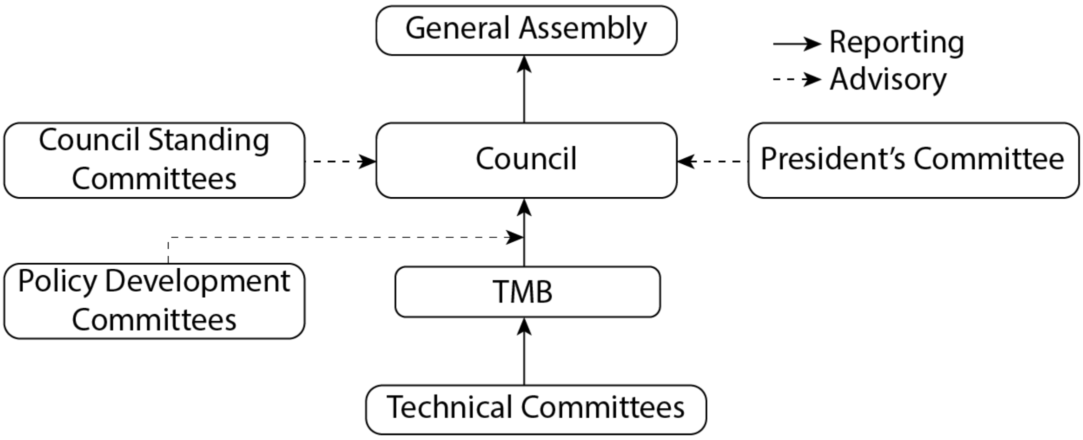

Figure 4.18 ISO governance structure[27].

The lead technical committee in ISO for the construction industry is Technical Committee 59 (TC59), which deals with "Buildings and civil engineering works"[28]. This TC has its scope set on standardization in the field of buildings and engineering works. This happens within about 18 subcommittees. Of specific importance to the topic of digitisation is subcommittee 13 (SC13), which deals with the "Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)"[29].

The ISO/TC59/SC13 is organized in a number of working groups focusing on diverse topics. Not all working groups are equally active, including a number of dormant working groups.As of December 2018, the SC13 has 7 active groups:

- ISO/TC 59/SC 13/JWG 12: Joint ISO/TC 59/SC 13 - ISO/TC 184 /SC 4 WG: Development of building data related standards
- ISO/TC 59/SC 13/JWG 14: Joint ISO/TC 59/SC 13 - ISO/TC 211 WG: GIS-BIM interoperability
- ISO/TC 59/SC 13/TF 1: Terminology
- ISO/TC 59/SC 13/TF 2: Business Planning and Strategy
- ISO/TC 59/SC 13/WG 8: Building information models – Information delivery manual
- ISO/TC 59/SC 13/WG 11: Product data for building services systems model

27 https://www.iso.org/technical-committees.html
28 https://www.iso.org/committee/49070.html
29 https://www.iso.org/committee/49180.html

- ISO/TC 59/SC 13/WG 13: Implementation of collaborative working over the asset life cycle

The ISO/TC59/SC13 currently has published 9 ISO standards, and has 11 ISO standards under development. The nine published standards from ISO/TC59/SC13:

1. ISO 12006-2:2015
   Building construction – Organization of information about construction works – Part 2: Framework for classification
2. ISO 12006-3:2007
   Building construction – Organization of information about construction works – Part 3: Framework for object-oriented information
3. ISO/TS 12911:2012
   Framework for building information modelling (BIM) guidance
4. ISO 16354:2013
   Guidelines for knowledge libraries and object libraries
5. ISO 22263:2008
   Organization of information about construction works – Framework for management of project information
6. ISO 16757-1:2015
   Data structures for electronic product catalogues for building services – Part 1: Concepts, architecture and model
7. ISO 16757-2:2016
   Data structures for electronic product catalogues for building services – Part 2: Geometry
8. ISO 29481-1:2016
   Building information models – Information delivery manual – Part 1: Methodology and format
9. ISO 29481-2:2012
   Building information models – Information delivery manual – Part 2: Interaction framework

Many of these standards are at the source originating from other standardisation efforts, most prominently buildingSMART International and the German VDI national standardisation body.

- ISO 12006: These standards are direct copies from the IFD standard elaborated and finalized within BuildingSMART.
- ISO 16757: This standard focuses on standardizing data structures for electronic product catalogues to transmit building services product data automatically into models of building services software applications. A lot of the contents of this standard originates from the VDI3805, which is a German standard with the same aim.
- ISO 29481: These standards are direct copies from the IDM standard elaborated and finalized within BuildingSMART.

Furthermore, there are 11 standards under development. A number of acronyms (WD, PRF, AWI, WD, …[30]) indicate the current status of the standard in development.

[30] Abbreviations used by ISO:

- ISO/WD 12006-3
  Building construction – Organization of information about construction works – Part 3: Framework for object-oriented information
- ISO/PRF 16739-1
  Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries – Part 1: Data schema using EXPRESS schema definitions
- ISO/PRF 19650-1
  Organization of information about construction works – Information management using building information modelling – Part 1: Concepts and principles
- ISO/PRF 19650-2
  Organization of information about construction works – Information management using building information modelling – Part 2: Delivery phase of assets
- ISO/AWI 19650-3
  Organization of information about construction works – Information management using building information modelling – Part 3: Operational phase of assets
- ISO/WD 19650-5
  Organization of information about construction works – Information management using building information modelling – Part 5: Specification for security-minded building information modelling, digital built environments and smart asset management
- ISO/DIS 21597-1
  Organization of information about construction works – Information container for data drop (icdd) – Part 1: Container
- ISO/DIS 21597-2
  Organization of information about construction works – Information container for data drop (icdd) – Part 2: Dynamic semantics
- ISO/AWI TR 23262
  GIS (Geospatial) / BIM interoperability
- ISO/WD 23386
  Building information modelling and other digital processes used in construction -- Methodology to describe, author and maintain properties in interconnected dictionaries
- ISO/AWI 23387
  Product data templates, for products and systems used in construction works, stored in a data dictionary framework -- Part 1: General concepts, relations, and general structure of product data templates, and how to link the product data templates to Industry Foundation Classes (IFC)

- PWI – Preliminary Work Item
- NP or NWIP – New Proposal / New Work Item Proposal
- AWI – Approved new Work Item
- WD – Working Draft
- CD – Committee Draft
- FCD – Final Committee Draft
- DIS – Draft International Standard
- FDIS – Final Draft International Standard
- PRF – Proof of a new International Standard
- IS – International Standard

Also this work originates for a large part from other standardisation efforts, most prominently buildingSMART International and national efforts (Netherlands, United Kingdom, Germany).

- ISO/DIS 16739: These standards are direct copies from the IFC standard elaborated and finalized in buildingSMART. The standard is revised every so many years, leading to revision of the standard within ISO as well, with some delay.
- ISO/DIS 19650: These standards are European variants based on the PAS1192 standards that were originally developed in the United Kingdom for the management of building information through the entire building life cycle.
- ISO 21597: These standards focus on standardising the mechanism for building data drop or information handover (Information Container for Data Drop - ICDD). This is particularly useful for handing over complete BIM projects from one stakeholder to the other, thereby moving from one CDE to another CDE. This initiative has its origin in the COINS initiative in the Netherlands.

4.3 CEN/TC442

4.3.1 Standardisation in Europe

Three chief standardisation organisations exist in Europe:

- CEN: European Committee for Standardisation
- CENELEC: European Committee for Electrotechnical Standardisation
- ETSI: European Telecommunications Standards Institute

These standardisation bodies produce European Norms (ENs), including for example the well-known Eurocodes. Within this European standardisation landscape, there are two important charters that define the collaboration with the international standardisation bodies, such as ISO and IEC (International Electrotechnical Commission), namely the Vienna agreement and the Frankfurt agreements. The purpose of these agreements is to provide a:

- framework for the optimal use of resources and expertise available for standardization work;
- mechanism for information exchange between international and European Standardization Organizations (ESOs) to increase the transparency of ongoing work at international and European levels.

In other words, these agreements ensure that standardisation efforts are not duplicated and that standards in Europe align with international standards. It is hereby important to note that ISO standards are not required to be implemented on a national or local level, but that European standards (EN) are required to be implemented in all participating member countries. The effect of the two kinds of standards is thus considerably different.

The Vienna Agreement (1991) is an agreement between CEN and ISO. The Frankfurt Agreement is a similar agreement, but between CENELEC and IEC (electrotechnical domain), and thus of less importance here. A number of the previously mentioned ISO standards have been elaborated within this Vienna agreement.

“The standardization activities of CEN are steered by the CEN Technical Board (BT), who has full responsibility for the execution of CEN's work programme. Standards are prepared by Technical Committees (TCs). Each TC has its own field of operation (scope) within which a work programme of identified standards is developed and executed. TCs work on the basis of national participation by the CEN Members, where delegates represent their respective national point of view. This principle allows the TCs to take balanced decisions that reflect a wide consensus.

The real standards development is undertaken by Working Groups (WGs) where experts, appointed by the CEN Members but speaking in a personal capacity, come together and develop a draft that will become the future standard. This reflects an embedded principle of 'direct participation' in the standardization activities.”[31]

4.3.2 CEN TC on Building Information Modelling

For the construction industry and any stakeholder in the built environment, the most important Technical Committee in CEN is the CEN / TC 442 on Building Information Modelling[32]. This Technical Committee was originally set up in December 2013, with the decision to create a CEN/BT/WG on “Building Information Modelling” (BIM). It was decided to set up a WG on BIM for 12 months, with the aim to deliver:

- proposal for scope,
- proposal for a work program
- a draft business plan for a future new technical committee (TC) in CEN

This eventually resulted in a new Technical Committee CEN/BT/WG 215, which has by now evolved into the CEN/TC442 Technical Committee.

The scope of this group is:

- Standardization in the field of structured semantic life cycle information for the built environment.
- The committee will develop a structured set of standards, specifications and reports which specify methodologies to define, describe, exchange, monitor, record and securely handle asset data, semantics and processes with links to geospatial and other external data.

The priorities of this group are:

- Understand existing activities and standards in use within the European market
- Adopt suitable standards and technical specifications from ISO and then extend to cover new areas including infrastructure as well as records management
- Develop new standards to support process management and associated guidance, as well as standards to enable the representation of European sustainability standards in BIM.

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31 https://standards.cen.eu/

32 https://standards.cen.eu/dyn/www/f?p=204:7:0::::FSP_ORG_ID:1991542&cs=16AAC0F2C377A541DCA571910561FC17F

- Develop relationships with key stakeholders including the European Commission.

The aim of this group is to help the construction sector to be more (cost) efficient and sustainable by enabling a smooth data exchange and sharing between partners in the value chain.

4.3.3 Standards

CEN/TC442 works around the three pillars of standardisation (data model, process, and data dictionary), and, as such, has many resemblances with the work done in ISO and buildingSMART. Essentially, the structure of the CEN/TC442 Working Groups can be clarified using the diagram shown in Fig. 4.19, with working groups focusing on (1) data, (2) processes, and (3) terminology.

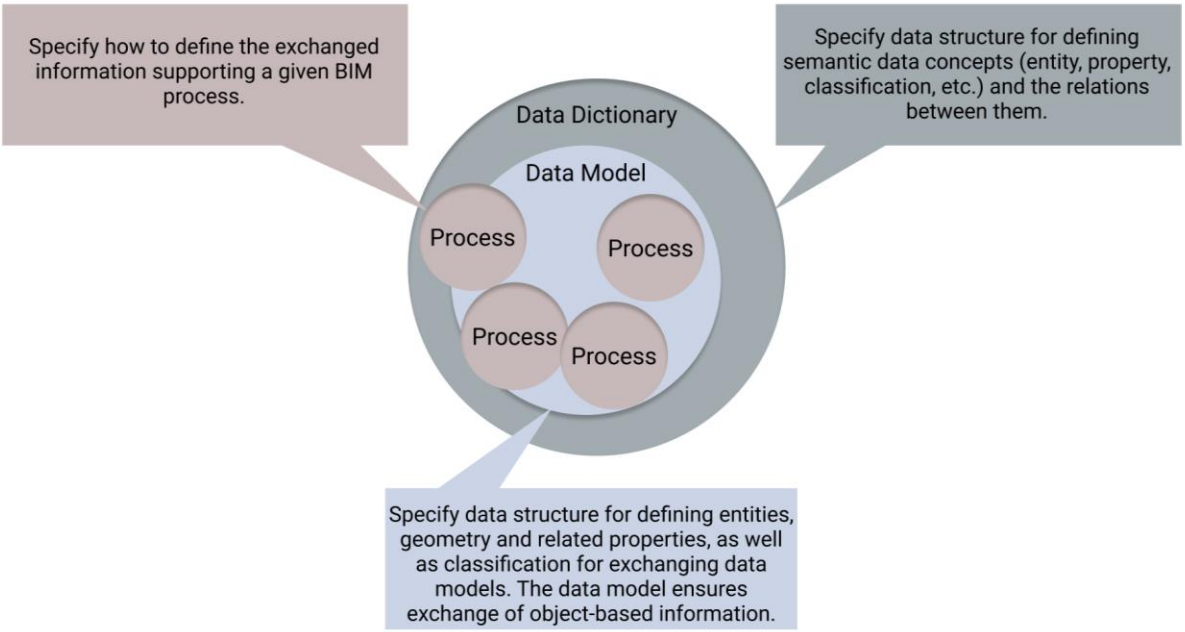

Figure 4.19 Three pillars of standards for the CEN/TC442: data, processes, terminology.

As a result, the Technical Committee is currently organised around 5 working groups:

- WG1: Terminology
- WG2: Exchange information
- WG3: Information Delivery Specification
- WG4: Support Data Dictionaries
- WG5: Chairperson's Advisory Group

The first WG is a WG focusing solely on terminology. The fifth WG is a horizontal WG spanning the other 4 working groups and thus contributing to consistency and joint strategic planning between the work done by the individual other WGs.

The following standards have been produced by CEN. They are all stemming from corresponding standards in buildingSMART and ISO.

- EN ISO 12006-3:2016
  Building construction - Organization of information about construction works - Part 3: Framework for object-oriented information (ISO 12006-3:2007)
- EN ISO 16739:2016
  Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries (ISO 16739:2013)
- EN ISO 29481-1:2017
  Building information models - Information delivery manual - Part 1: Methodology and format (ISO 29481-1:2016)
- EN ISO 29482-1:2016
  Building information models - Information delivery manual - Part 2: Interaction framework (ISO 29481-2:2012)

The following standards are a work in progress:

- prEN ISO 19650-1
  Organization of information about construction works - Information management using building information modelling - Part 1: Concepts and principles (ISO/DIS 19650-1:2018)
- prEN ISO 19650-2
  Organization of information about construction works - Information management using building information modelling - Part 2: Delivery phase of the assets (ISO/DIS 19650-2:2018)
- prEN ISO 16757-1
  Data structures for electronic product catalogues for building services - Part 1: Concepts, architecture and model (ISO 16757-1:2015)
- prEN ISO 16757-2
  Data structures for electronic product catalogues for building services - Part 2: Geometry (ISO 16757-2:2016)
- prEN ISO 21597-1
  Information container for data drop - Exchange specification - Part 1: Container (ISO/DIS 21597-1:2018)
- prEN ISO 21597-2
  Information container for data drop - Exchange specification - Part 2: Dynamic semantics (ISO/DIS 21597-2:2018)
- prEN ISO
  Building Information Modeling - Level of Information Need - Part 1: Concepts and principles
- prEN ISO
  Product data templates, for products and systems used in construction works, stored in a data dictionary framework - Part 2: Specification of Product data templates based on harmonised technical specifications under the Construction Products Regulation (CPR), and how to link the product data templates to Industry Foundation Classes (IFC)

- prEN ISO 23387
  Product data templates, for products and systems used in construction works, stored in a data dictionary framework - Part 1: General concepts, relations, and general structure of product data templates, and how to link the product data templates to Industry Foundation Classes (IFC)
- prEN ISO 23386
  Building information modelling and other digital processes used in Construction – Methodology to describe, author and maintain properties in interconnected dictionaries
- prEN ISO 19650-3
  Organization of information about construction works -- Information management using building information modelling -- Part 3:Operational phase of assets
- prEN ISO 19650-5
  Organization of information about construction works -- Information management using building information modelling -- Part 5: Specification for security-minded building information modelling, digital built environments and smart asset management
- prEN ISO 12006-3 rev
  Building construction -- Organization of information about construction works -- Part 3: Framework for object-oriented information

5. BIM Reference Guides

The implementation of BIM always happens within a national or international framework. In most cases, national standardization committees and communities are committed to providing guidance documents and BIM reference guides for all people and companies aiming to implement BIM. These guidance documents have many names, but we will refer to them here as BIM reference guides, as they are typically used in practices as such: reference guides that contain advice and recommendations that should be implemented by a company with a certain degree of freedom. These BIM reference guides must be used as a reference.

Below are the BIM reference guides that will be briefly documented in this chapter, thereby giving an indication of the advice that are typically given in the diverse countries in the world aiming for wider and standardized BIM implementation approaches. More BIM Reference Guides exist, but will not be taken into account here. Many of these BIM Reference Guides have a basis in the concepts and standards sent out by BuildingSMART, ISO, and CEN (see Chapter 4). Most prominently, the three pillars of interoperability are prominently present in all of them: data, process, and terms.

In this chapter, we will look into the following BIM Reference Guides:

- Finland: COBIM Common BIM Requirements
- Denmark: Digital Construction
- United Kingdom: UK Government BIM Strategy
- Belgium: The Guide to BIM
- Australasia: NATSPEC National BIM Guide

5.1 Finland: COBIM - Common BIM Requirements

As already indicated before, buildingSMART International houses a number of national chapters, which gather local communities. One of those chapters is the buildingSMART Finland chapter. In order to help the AEC firms on the national market, this local chapter published a series of publications, under the term "Common BIM Requirements 2012" (COBIM 2012[33]).

This publication series is the result of a broad-based development project entitled COBIM. The need for these requirements arises from the rapidly growing use of building information modeling in the construction industry. During all phases of a construction project, the parties to the project have a need to define more precisely than before what is being modeled and how the modeling is done. "Common BIM Requirements 2012" is based on the previous instructions of the owner organizations and the user experiences derived from them, along with the thorough experience the writers of the instructions possess on model-based operations.

[33] https://buildingsmart.fi/en/common-bim-requirements-2012/

The Common BIM Requirements 2012, COBIM, is based on the BIM requirements published by Senate Properties. The project was funded by Senate Properties, as well as several real estate owners and other developers, construction companies and software providers.

The COBIM series consists of 13 parts, namely:

- Series 1: General part
- Series 2: Modeling of the starting situation
- Series 3: Architectural design
- Series 4: MEP design
- Series 5: Structural design
- Series 6: Quality assurance
- Series 7: Quantity take-off
- Series 8: Use of models for visualization
- Series 9: Use of models in MEP analyses
- Series 10: Energy analysis
- Series 11: Management of a BIM project
- Series 12: Use of models in facility management
- Series 13: Use of models in construction

Most important in the context of a BIM implementation plan are series 1 and 11. They set out (1) general settings for taking on BIM projects; and (2) overall management guidelines.

5.1.1 COBIM General Part

The introductory part of the COBIM guide lists a number of overall general reasons why one may want to do BIM in a company. This one page of requirements aligns well with the incentives that were listed in Chapter 2 of this book. Furthermore, they are requirements and reasons that one may typically want to include in a company-wide implementation plan (see Section 3.2.1). We will look into the more specific guidelines here.

The general part of the COBIM guide elaborates on the general technical requirements for doing BIM. Additionally, the COBIM guide devotes a large part of the section to the generation and utilization of models at different project stages. In other words, there is a strong focus on the technical approach in general (focus on product modelling), and on the overall flow of the process in diverse stages of a BIM design and construction lifecycle (focus on process modelling). In terms of the technical requirements, the following advice is given by the COBIM guide.

- Software: Clear choices need to be made regarding the specific software tools that are used, including versions of software and data exchange formats (IFC vs. proprietary formats). Changes in any of these choices need to be communicated as soon as possible and agree upon within a project team.
- Release of the BIM: Whenever BIM models or information is released, in any stage of the project, a clear method and approach needs to be followed regarding data formats, liability, intended use of the released documents and models, tracking data, and so forth.
- Coordinates and Units: A single reference point is set for the entire project team, including the coordinate system and the unit system used.

- BIM Accuracy: A specification needs to be made within a project of what levels of detail are maintained at each stage of a project.
- Modeling Tools: Modeling agreements are made. In this case, it is argued that modelers are meant to model information using the types and properties provided by the software application used (i.e. walls, slabs, and so forth), instead of using generic geometry that gets labelled afterwards.
- The Buildings, Floor Levels and Divisions: A BIM model is here required to be modelled into floor levels. This is suggested as the default approach for modelling buildings. Alternative modelling approaches and exceptions to this rule are possible, but they then need to be communicated among project partners.
- Naming and Archiving of the BIM: A naming and archiving convention is set up and maintained.
- BIM Specification: An indication is maintained by all individual stakeholders of what they are modelling. This happens in a Model Description Document.

> Each discipline has to maintain a Model Description Document. The document is a description of the contents of the model and it explains the purpose for which the model has been published and what the degree of precision is. The description document contains information about the modeling software used, the different versions created from the original model, and exceptions to these requirements. In addition, all naming conventions used, the maturity of the content and any restrictions on its use are documented in the description.
>
> COBIM Guide, 2012

- Role of the BIM Coordinator: A BIM Coordinator is assigned for each project. This is here proposed to be done by the head of design, which places this responsibility with the architect. This is a good position, yet, one needs to consider impartiality for this person, when deciding on a BIM coordinator. A BIM coordinator needs to communicate among all stakeholders, aiming for the best result for the design and building, not of the stakeholder position he belongs to.
- Publishing of Models: At very specific publication moments in the timeline of a project, such as the building permit application and construction cost estimation, the BIM model should be readily available (as it follows the design and construction process), and it should therefore be widely published simultaneously with reaching such publication deadlines.
- Working Models: Besides the formally published models and exchanged hand-overs, a number of working models need to be maintained throughout a project. A clear strategy for this purpose needs to be set out and agreed upon by project partners. Working models are supposed to be a flexible and rapid method to exchange design information and to represent the intended design solutions, space reservations, specific details, etc.
- Quality Assurance: Each stakeholder is responsible for the quality of his deliveries, hence, he should assure that quality on his own.

In addition to the focus on technical requirements for BIM (above), the COBIM guide furthermore focuses on the generation and utilization of models at different project stages. The following subchapters are given:

- needs and objectives
- design of alternatives
- early design
- detailed design
- contract tendering stage
- construction
- commissioning

For each of these phases, the deployment of BIM has an impact. The precise details of that impact will not be documented here, but they are in the COBIM reference guide. Yet, it is very important to note that, in whichever stage or phase one is in the design and construction process, one always should list the data requirements and the goals as precisely as possible in light of the task at hand, and then specify in a positive and goal-oriented manner how they can be feasibly implemented over time.

5.1.2 COBIM Management of a BIM project

In terms of the management of a BIM project (Series 11 of the COBIM guide), again overall goals and objectives are outlined in an introductory section. Indeed, in the context of implementing BIM, a clear definition of those objectives is imperative. When looking only on a managerial level, these objectives will be rather generic, abstract, and company-oriented. Such objectives should be part of a company-wide implementation plan. Ideally, they include statistics and key tangible criteria for evaluation of the success of the BIM implementation plan. As a result, a company-wide BIM implementation plan not only includes a general business value section on product modelling and technical goals, but it also includes a general business value section on coordination targets (process).

Besides the general overall introductory section, Series 11 of the COBIM guide outlines (1) a number of key principles regarding information management, as well as (2) an outline of information management and coordination tasks from stage to stage. As such, the outline of this Series 11 is nearly identical to the outline of Series 1.

In terms of key principles regarding information management, the following elements are included that are of clear relevance to any BIM implementation plan nowadays:

1. BIM Execution Plan: For any project to be successful, there needs to be a plan specifying how the BIM approach for the project is concretized. This is in this COBIM document done by the specification of a “Design Program”, which is meant to be specified as early as the design preparation stage. Such a document is currently more commonly known to be a BIM Execution Plan (BEP). This document captures the objectives aimed for by using BIM. Furthermore, the schedule and technical choices are set and procedures are specified.

2. BIM Role Model: The COBIM guide argues for the implementation of two specific roles in a project, namely a BIM coordinator and discipline-specific managers. The

discipline-specific managers are in charge of the BIM models that they manage specifically. They are reference points in communications, quality assurance and responsibility. In addition, the BIM coordinator coordinates and mediates among these discipline-specific managers.

5.2 Denmark: BIPS and Digital Construction (Det Digitale Byggeri)

In 2007, the Danish government decided that data in public building projects must be digitally managed and exchanged based on a set of requirements regarding digital communication and tendering through a web-based document management system, use of 3D building models, and digital handover of operation and maintenance related information to the client. As such, the Danish government was much in advance to the European procurement directive that was formulated in 2014 regarding the use of specific electronic tools, such as BIM for public works contracts and design contests.

To prepare both the industry and the public clients for the implementation of the new requirements, the government launched a development project called Digital Construction (Det Digitale Byggeri), which was carried out between 2003 and 2006. Digital Construction is a government initiative, which states that state, regional and municipal building owners must state a number of requirements towards consultants and executives concerning the use of Information and Communication Technologies (ICT).

The development project was divided into six major work packages, including foundation for digital construction, client demands on electronic tender, client demands on 3D models, client demands on project web (web based document management systems), client demands on electronic hand-over and best practice. Details of the rules and requirements were first given in an executive order from the National Agency for Enterprise and Construction in the form of a regulation concerning the use of information and communication technology (ICT) in public construction. The latter was further updated in 2011 (and entered into force in April 2013) and includes the following main categories:

1. *Area of application*: Any construction with the Danish State as the client for an estimated total contract sum of minimum DKK 5 million excluding VAT.

2. *ICT coordination*: The client must ensure that the overall use of ICT throughout the construction project is coordinated between all of the parties involved.

3. *Handling of digital construction objects*: The client must require that digital construction objects are structured, classified, named, coded and identified in a uniform way and to a specific degree of detail. The client must also require that the construction objects are provided with the relevant information and characteristics necessary for management, operation and maintenance.

4. *Digital communication and project web, etc.:* The client must require the use of a system for digital communication and archiving of all relevant information during the construction project.

5. *Use of digital construction models*: The client must require that all proposals include digital, object-based construction models, as well as visualisations made on the basis of these models. The received construction models and visualisations must document the project proposals' architectural, functional and technical conditions at a specified information level. Included here is that object-based construction models should be provided in IFC format.

   During design and execution, the client must require the use of object-based construction modelling and must ensure that: 1) agreement is reached concerning which discipline and shared models are to be prepared; 2) each of the responsible stakeholders prepares the necessary discipline models; 3) discipline models are coordinated via one or several shared models for the purpose of simulation, clash detection, bill of quantities, drawings and specifications; and 4) the models are made available in IFC format.

6. *Digital invitations to tender and bids:* The client must require that the use of digital systems are applied to invitations to tender and bids (e.g. digital invitation to tender and digital bids). The tender documents must be drawn in a way that allows them to be used digitally by the bidders in conjunction with their submission of bids, and so that bids are structured in accordance with the structure otherwise used in the construction project.

7. *Digital delivery on handing over the construction project:* In consultation with the contractor, the client must set requirements concerning the digital submission of the information that is deemed relevant for 1) documentation of the construction work; 2) documentation of the construction project; 3) operation and maintenance; and 4) the future management of the property. The client must also ensure that: 1) digital delivery on the handover of the construction project is included in the agreements with advisers, contractors and suppliers; 2) the agreements include the hand-over's extent, structure, classification, identification and formats; and 3) object-based construction models are provided in IFC format.

8. *Digital information concerning defects:* The client must ensure the use of digital lists that describe the registered defects in accordance with the project structure.

Based on the above, BIPS Denmark[34] adopted the results from the Digital Construction project and started promoting the new working methods to the construction industry stakeholders by developing "The building's ICT specifications". Bips was a non-profit membership organisation of construction industry companies represented by building owners, designers, contractors, manufacturers, dealers, trade organisations, and institutions of research, education and information. The ICT specifications were meant as tools to support public owners in complying with the ICT order and a standard agreement that the developer and advisors use to agree on matters such as the project web, digital tender procedure, object-based building models and so on.

[34] https://bips.dk/

As of 2016, the bips organisation merged with the Byggecentrum. This organisation is now known as Molio[35], but the purpose is the same as the original: to help strengthen construction companies' competitiveness for the benefit of both industry and society, by providing products and tools that promote development, digitization and streamlining. That also includes the latest editions of the offered tools and specifications, including A102 ICT-specifications, A104 Document handling, A106 Checklist for requirement specification for Facilities Management tools, A305 ICT project roles, A402 ICT process manual, C402 Consistency control of building models, and so forth (internal web content).

Currently, Molio acts as the Danish partner in the buildingSMART Nordic Chapter. As such, Molio is the key organisation to both communicate buildingSMART standards to the market, and represents Denmark in the creation and management of international standards.

5.3 United Kingdom: BIM Implementation in Levels

5.3.1 Government BIM Strategy

BIM implementation in the United Kingdom (UK) is highly influenced by the stimulus made by the UK Government. This stimulus started earlier, but picked up speed in 2011, when the Government Construction Strategy[36] was initiated by the Cabinet Office. The Government Construction Strategy is a framework aimed at reducing the cost of government construction projects by 15-20% by the end of the term of the Parliament. This strategy was part of the Government's Plan for Growth, which highlighted the critical importance of an efficient construction industry to the UK economy.

It was highlighted that the construction sector is a major part of the UK economy, representing about 7% of the GDP or £110bn per annum of expenditure - some 40% of this being in the public sector, with central Government being the industry's biggest customer. Furthermore, there was a wide consensus, supported by several studies, that the UK does not get full value from public sector construction; and that it has failed to exploit the potential for public procurement of construction and infrastructure projects to drive growth. The Government Construction Strategy was aimed to change that.

One of the key goals of the strategy was a procurement reform: "*The principal barrier to reduced cost and increased growth is the lack of integration in the industry, compounded by a lack of standardisation and repetition in the product (e.g. fragmented and unpredictable demand), and by relative protection from overseas competition. In parallel, a procurement process has been shaped that has reinforced those barriers. Addressing them calls both for reform of the procurement process and for greater efficiency in the operation of that process.*"

The plan clearly includes a stimulus to adopt BIM in the construction industry. It is indicated that there are companies with the capability of working in a fully collaborative 3D environment, so that all of those involved in a project are working on a shared platform with reduced

[35] https://www.molio.com/
[36] https://www.gov.uk/government/publications/government-construction-strategy

transaction costs and less opportunity for error; but construction has generally lagged behind other industries in the adoption of the full potential offered by digital technology. Furthermore, a lack of standards, systems and protocols is found.

Therefore, the plan aims at driving the development of standards, to then also enable all members of the entire building life cycle to work collaboratively through Building Information Modelling (BIM). Three key elements are in place here:

1. *Change of procurement forms:* by changing procurement forms, the UK Government aims to include all partners of a building life cycle throughout the entire life cycle, from early design to demolition.
2. *Development of standards:* by developing standards and protocols, the adoption of technologies and effective collaboration will be enhanced and stimulated.
3. *Support for innovative technology:* by demanding the use of BIM tools, the industry is aimed to innovate its methods, thereby improving efficiency and reducing failure cost.

Effectively, the plan demanded that *"Government will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016"*. One year later, in July 2012, the One Year On report and Action Plan Update[37] was published, providing an overview of overall progress. In terms of BIM, it was indicated that four pilot projects were being executed and everything was on track. Furthermore, work had been done regarding the construction of standardized protocols. Namely:

> The legal, commercial and insurance protocols for BIM are nearing completion; the structured digital data exchange format known as COBie UK 2012 has been prepared and a number of institutions including RIBA have been working with the Construction Industry Council (CIC) to develop BIM-enabled plans of work. A Publicly Available Standard (PAS), 1192-2:2012, which documents the delivery of BIM-enabled design and construction information, is undergoing public consultation with an operational version covering asset management and operation due for the end of 2012. Work on a comprehensive training strategy is underway along with general supply chain guidance.
>
> One Year On report and Action Plan Update, 2012

Links to other organisations had been set up, in particular with buildingSMART International, thus aligning with an international standardization context. In other words, from 2012 onwards, the UK Government has undertaken with the industry a four-year program for the modernization of the sector with the key objective of: reducing the cost and carbon footprint in the process of construction and exploitation of the built environment by 20%. Central to these ambitions is the adoption of Building Information Modeling (BIM), which are considered to be

37 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/61151/GCS-One-Year-On-Report-and-Action-Plan-Update-FINAL_0.pdf

collaborative processes and behaviors that will open new and more efficient ways of working at all stages of the life cycle of the project.

The government hereby gives a strong opportunity to the industry, to which the industry then also responds. A lot of the work is undertaken by a UK BIM Task Group. The overall UK aim then became to achieve “BIM Level 2” by 2016 for public projects.

By 2016, a number of achievements has been reached. These achievements are communicated in the 2016-2020 Government Construction Strategy[38]. The overall strategy and plan by the UK Government achieved a better relationship between government and construction industry, and the Government has as a result become a better client that clearly communicates its requirements to industry about its programme of work. This improved client behaviour and positive response from industry delivered £3 billion of efficiency savings over 2011-15.

Key enablers for this achievement were found to be:

- *improving client intelligence with the annual publication of cross-government data to benchmark construction costs, enabling the market to focus on delivery capability and client outcomes*
- *developing digital capability in design and construction, with all departments on target to procure assets using Building Information Modelling (BIM) Level 2 by 2016*
- *improving transparency for industry by publishing the Government Construction Pipeline every six months, with the latest iteration identifying projects worth £163 billion*
- *developing new models and approaches to procurement, which focus on collaboration and early contractor involvement*
- *facilitating fair payment in the supply chain, with over £10 billion cumulative committed spend on projects using Project Bank Accounts since 2011.*

After the 2011-2016 Government Construction Strategy plan, a new 2016-2020 plan was initiated, aiming now to further increase productivity in government construction to deliver £1.7 billion efficiencies and support 20,000 apprenticeships over the course of 2016-2020. The strategy sets out ambitions for smarter procurement, fairer payment, improving digital skills, reducing carbon emissions, and increasing client capability. By doing so, the government aligned with the wider ambitions for industry in Construction 2025 delivered by industry and government through the Construction Leadership Council. BIM is considered to be a key enabler in this strategy. Main aims in this regard are the move towards BIM Level 3, although no specific date is set, and the further adoption of PAS1192 standards that provide the required protocols and standards for the UK market.

A more long-term plan has also been provided, namely the Construction 2025 Strategy[39]. This is a joint strategy from government and industry for the future of the UK construction industry. This document contains clear aims and goals, showing that lower costs, faster delivery, lower emissions, and improvements in exports are aimed at.

[38] https://www.gov.uk/government/publications/government-construction-strategy-2016-2020
[39] https://www.gov.uk/government/publications/construction-2025-strategy

Progress in terms of BIM implementation in the UK market is furthermore documented in the annual NBS National BIM Surveys and corresponding Reports. These reports go back to 2011. The latest 2017 report[40] is marked as the first one after BIM Level 2 was mandated by the UK Government. The Report is therefore also marked with positive news:

> BIM Level 2 looks to be well established; the normal way for most practices to carry out design work. Over 60% now use BIM, and 95% expect to within three years. To change a relatively static industry like construction in such a short period is nothing short of astonishing and is best in class at a global level.
>
> NBS National BIM Report, 2017

Although it is clearly indicated that further growth is expected, a number of work items is also listed. Some elements in the adoption of BIM are not working yet as desired. The following things are listed:

- Information and training: confidence in BIM skills is improving, but it can still be improved a lot with the appropriate information and training.
- Awareness: Many clients need further support and careful explanation of the BIM process and its benefits.
- Standards: UK standards and protocols are found to be underused, potentially because they seem too complex.
- Small-scale SME adoption: BIM adoption is lower among smaller practices, although even here, it is getting close to a majority.

The NBS National BIM Survey went to more than 1,000 participants, ranging in profession and practice types, and coming from all nations and regions of the UK. The report gives a clear indication of the BIM maturity levels and skills in the UK. For example, it illustrates that far from everyone is very confident about their BIM skills, and it confirms that the majority of the industry considers themselves to be achieving BIM Level 2, and only a very small minority already claims to be at BIM Level 3. Furthermore, a number of other key findings are made, as listed in the NBS BIM Report homepage[41]:

- *A majority of respondents (51%) think that the Government is on the right track with BIM and awareness is near-universal and adoption is up (62% of practices use BIM on some projects - up 8% year on year). Indeed, the year just gone has seen the most rapid BIM growth since 2014. 78% see BIM as the future of project information. There is, however, work to do - 65% said BIM can bring real benefit beyond the design stages but 72% believed clients don't understand these benefits.*
- *Government hopes that BIM will help in delivering projects for lower cost, more rapidly, with fewer greenhouse emissions and a better trade balance for construction projects. Our survey showed that 60% of respondents think that BIM will help bring time*

[40] https://www.thenbs.com/knowledge/nbs-national-bim-report-2017
[41] https://www.thenbs.com/knowledge/nbs-national-bim-report-2017

efficiencies, reducing time from inception to completion, 70% believe cost reduction in the design/build/maintain life cycle will be realised. Those who responded were, however, less convinced on BIM's ability to reduce greenhouse gas emissions (44% agreed) or improve the trade gap (32% agreed).

- *A majority thought the Government was failing to enforce the mandate. A third of respondents stated they were not clear on what they had to do to comply with the BIM mandate. Many cited a lack of client education limiting the effect of the BIM mandate to fully reap the fullest rewards. Across the board nearly 18% of respondents said they used BIM on every project - 29% said they used BIM on more than 75% of projects. Our survey shows that once BIM is adopted it usually becomes the design methodology of choice.*
- *For the first time a majority describe themselves as confident in BIM (55% - compared to 35% back in 2012) but 90% said BIM adoption requires changes in workflow, practices and procedures. Learning from colleagues (75%) and fellow professionals (62%) were cited as key ways people keep skills sharp. Professional bodies and expert organisations, such as NBS, the BIM Task Group, BSI and RIBA, were also deemed significant.*
- *Thinking about BIM maturity most respondents said that Level 2 was the highest level reached on a project (70%). 7% said they were at BIM Level 3, 22% at Level 1. Our survey shows more than three quarters of organisations who have adopted BIM are at or beyond the level required by the BIM mandate.*
- *Respondents were clear in their demand for manufacturers to provide BIM objects and well-structured generic objects. 45% said they use a BIM object library - 66% create objects as needed and a similar number create objects in-house and re-use them across multiple projects. Placing standards and specifications squarely in the BIM environment via BIM software tools was also seen as key.*
- *41% of respondents use Autodesk Revit, just 14% AutoCAD. Indeed, Autodesk dominates the UK market with 66% using an Autodesk product, that said Graphisoft, Nemetschek and Bentley have a significant user base. 35% manage specification references digitally using a free plug-in from NBS.*

5.3.2 BS/PAS 1192 Series

A very important part in the adoption of BIM in the UK market, are the protocols, standards and agreements. These are already mentioned above to be captured in the BS/BAS 1192 Series[42]. This is a series of Publicly Available Standards (PAS), set out for achieving BIM Level 2 by establishing a framework for collaborative working and information requirements. The following PAS 1192 standards have by now been prepared:

- *PAS 1192-2: 2013 [CAPEX]*, which deals with the construction (CAPEX) phase, and specifies the requirements for Level 2 maturity; sets out the framework, roles and responsibilities for collaborative BIM working; builds on the existing standard of BS 1192, and expands the scope of the Common Data Environment (CDE).
- *PAS 1192-3: 2014 [OPEX]*, which deals with the operational (OPEX) phase, focusing on use and maintenance of the Asset Information Model, for Facilities Management.

[42] https://www.thenbs.com/knowledge/what-is-the-pas-1192-framework

- *BS 1192-4: 2014 [COBie]*, technically a code of practice rather than a specification standard, which documents best practice for the implementation of COBie.
- *PAS 1192-5: 2015 [Security],* a specification for security-minded building information modelling, digital built environments and smart asset management.
- *PAS 1192-6 [Health and Safety]*, a specification for collaborative sharing and use of structured health and safety information using BIM.

One other PAS standard is now in development, namely:

- *PAS 1192-7 [Product data]* - Construction product information - Specification for defining, sharing and maintaining structured digital construction product information.

These protocols have a high impact on the rest of the world, including Europe. These standards are meant to be applicable also to non-public projects, and they furthermore form the basis of the ISO 19650 international standard.

Central to these PAS standards are the BIM maturity levels, which have already been mentioned before in Section 3.1 (BIM Level 0, 1, 2, 3). These levels are typically documented in the wedge diagram shown in Figure 5.2. These BIM Maturity Levels indicate a need to progress from traditional CAD-based practice (level 0) to level 3 BIM (ideal, ultimate goal of complete web-based data integration). Many current projects reach BIM Level 2, and innovative companies and projects aim at achieving BIM Level 3.

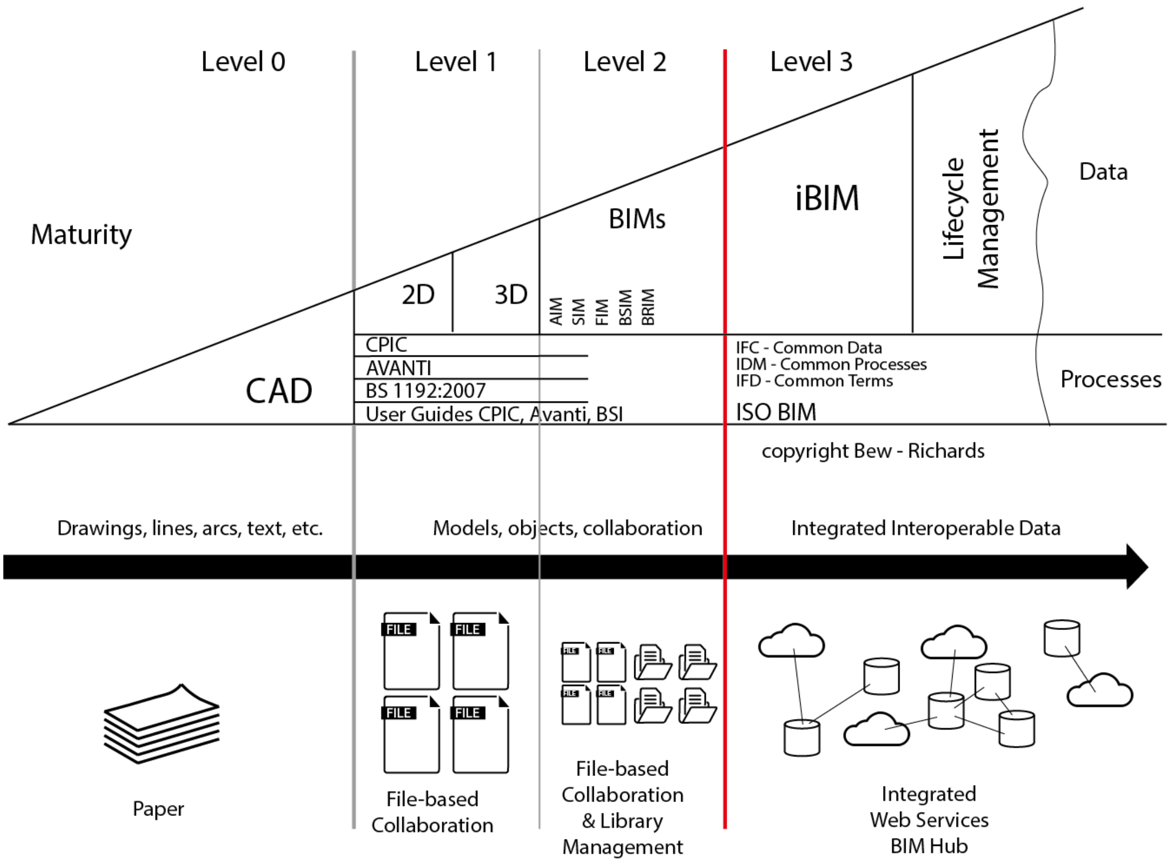

Figure 5.2 The BIM wedge displaying the BIM maturity levels and what they mean.

The standards furthermore rely heavily on the diagram shown in Figure 5.3: the information delivery and project management cycle. This graph documents how processes go through the life cycle of a building, thereby building up information that is then finally delivered to the owner of the building. As such, the graph captures how the BIM process generates information models and their associated information that are used throughout the lifecycle of building/infrastructure facilities or assets. The blue cycle in Figure 5.3 shows the generic process of identifying a project need, procuring, awarding a contract, mobilizing a supplier, and generating production information and asset information relevant to the need.

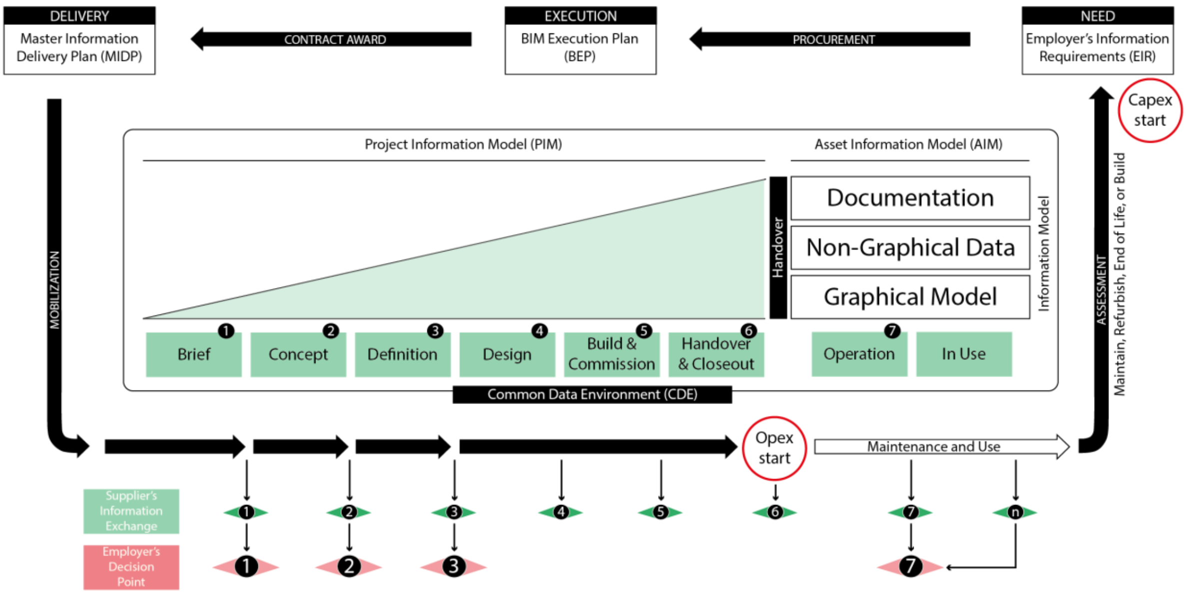

Figure 5.3 The information delivery cycle, as included in the PAS 1192-2.

Central in Figure 5.3, seven project stages are outlined in green that indicate how design information is built up and refined over time. These stages include brief, concept, definition, design, build & commission, handover & closeout, and operation. This build-up of information during the design and construction project is meant to take place in a common data environment or CDE (Fig. 5.3).

The PAS 1192-2 standard focuses on the CAPEX phases shown in Figure 5.3, which includes all the following steps:

- Need: setup of Employer's Information Requirements (EIRs)
- Procurement: setup of BIM Execution Plan (BEP)
- Contract award: setup of Master Information Delivery Plan (MIDP)
- Mobilization: build-up of information in accordance to plans.

The PAS 1192-2 standard thus focuses specifically on project delivery, where the majority of graphical data, non-graphical data and documents, known collectively as the project information model (PIM), are accumulated from design and construction activities. The bottom of the graph in Figure 5.3 then shows a number of important moments for information exchange and client decisions.

The PAS 1192-3 standard focuses entirely on the OPEX phase of the building, happening after the hand-over of the project to a client. In other words, focus lies more on the use and maintenance of the asset information model (AIM – right in Fig. 5.3) to support the planned preventative maintenance programme and the portfolio management activity for the life of the asset. In this regard, the standard provides guidance on how the Project Information Model can be used to feed the Asset Information Model (= as-built). The following phases are hereby distinguished (see Figure 5.4):

- Inherit asset
- Minor Works
- Maintenance
- Major Works
- Transfer Ownership
- Breakdown
- End of Life

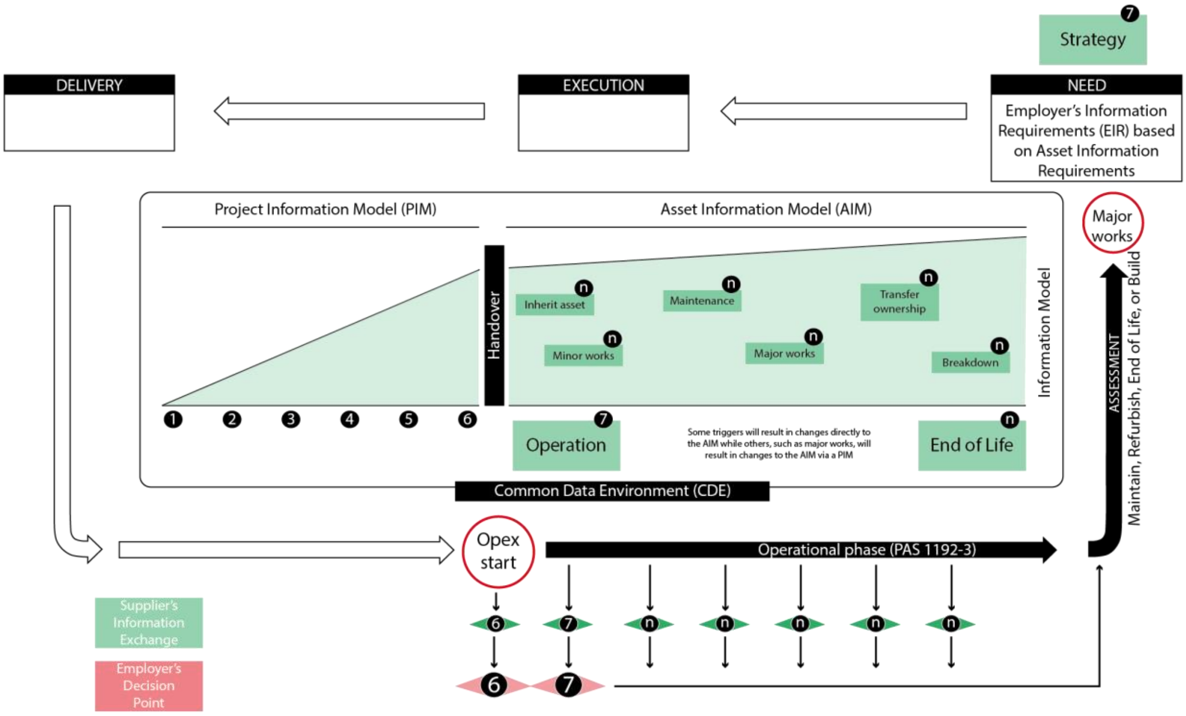

Figure 5.4 The information delivery cycle amended for asset management (OPEX).

An important part of PAS 1192-3 focuses on the process of how the Project Information Model (PIM) evolves and feeds into the Asset Information Model (AIM). At handover, it is defined that a set of data is available that contains the aggregated, coordinated BIM Model, all linked data sets and all linked documents. The standard thereby indicates that, for an appropriate AIM to be achieved, the building model needs to be cleaned from any deprecated information, and all elements describing design intent need to be fully replaced with as-built content.

Note that not all information on a project will be originated, exchanged or managed in a BIM format. This information will also need to be managed in a consistent and structured way to enable efficient and accurate information exchange. The BS 1192:2007 provides details of the standards and processes that should be adopted to deliver these outcomes, whereas the PAS standards focus exclusively on the BIM data that is to be exchanged.

Of further relevance here is the BS 1192-4:2014 standard, which aims at "Fulfilling employer's information exchange requirements using COBie". This standard defines expectations for the exchange of information throughout the lifecycle of a facility. The use of COBie ensures that information can be prepared and used without the need for knowledge of the sending and receiving applications or databases. It ensures that the information exchange can be reviewed and validated for compliance, continuity and completeness.

COBie can hereby be understood as a format for the exchange of information, a performance-based specification for facility asset information delivery. COBie defines HOW information should be handed over, not WHAT information nor by WHOM this should happen. In other words, COBie specifies which data is to be transferred from model to operation. COBie can hereby be understood as a data model, often represented as a spreadsheet and accompanied by an IFC model.

In conclusion, we can state that the Series of BS/PAS 1192 standards focuses on processes and workflows, in line with many of the BIM Guides referenced in this section. It does not focus on the tools or the software. In particular, the overall diagram shown in Figure 5.5 indicates the key focus of the BS/PAS 1192 standards, namely defining and standardizing the interplay between requirements –Organizational Information Requirements (OIR), Asset Information Requirements (AIR), and Employer's Information Requirements (EIR)– and models –Asset Information Model (AIM), and Project Information Model (PIM).

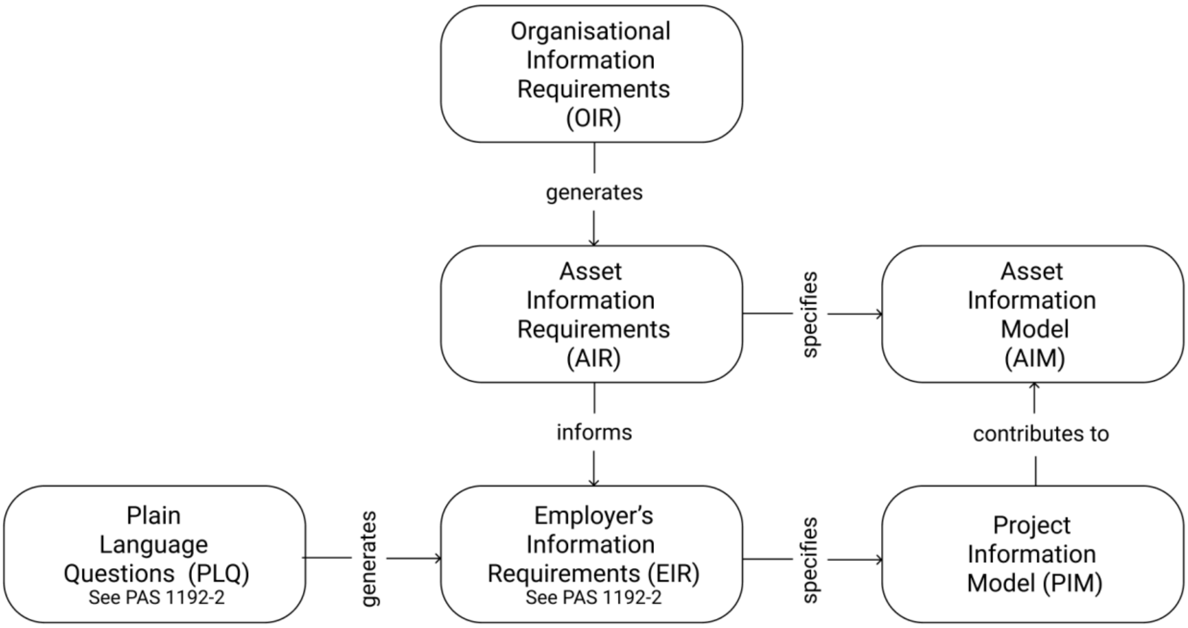

Figure 5.5 BS/PAS 1192 defines the interplay between models and requirements.

5.4 Belgium: The Guide to BIM

BIM is not mandated in Belgium, yet, a national BIM reference guide is available since the end of 2017, and it includes a national BIM Protocol and BIM Execution Plan[43], both available in Dutch. The BIM Protocol is briefly summarized here, and provides a reference framework that helps anyone in the Belgian AEC industry in adopting and implementing BIM. The BIM Protocol and Execution Guide have been written in 2016 and 2017, and thus relies heavily on the content and lessons learned in the other BIM guides.

5.4.1 BIM Reference documents: vision, protocol, and plan

First and foremost, the BIM protocol consists of two parts. Namely, a reference guide document is provided, as well as a template file that can be used for specifying the project-specific agreements of a BIM project.

The main BIM Protocol consists of the following structure:

PART 1 – Guidelines Belgian BIM Protocol

1. Background and purpose
2. Documents and appendices
3. During the construction process
4. Reading manual

PART 2 – Belgian BIM Protocol

1. Terms and Definitions
2. Situating the BIM Protocol
3. Project information
4. Objectives
5. Information to be exchanged
6. BIM Process and Information Management
7. Overview of BIM-related tasks and responsibilities
8. Signature

For this entire second part, a fillable template is provided that can be used to specify project- and company-specific agreements.

The Guideline document specifies that a BIM Protocol needs to be set up at project start: the BIM Protocol. This BIM Protocol is a contractual document that lists agreements and expectations regarding BIM, and it is ideally signed by all already known project stakeholders at the outset of a project. It is recommended that a BIM Execution Plan (BEP) is defined as well, in addendum to the BIM Protocol. This BEP defines how the BIM Protocol agreements need to be carried out in practice. This BEP is an evolving document that is amenable for changes throughout the entire project.

Besides the Protocol and the BEP, it is advised for a client or owner to set up a BIM Vision document. This document is expected to contain a BIM Information Delivery Specification

[43] https://www.bimportal.be/nl/projecten/tc/publicaties-resultaten/belgisch-bim-protocol/

(ILS), in response to the same idea and term having been coined earlier in the Netherlands. If a BIM Information Delivery Specification is unavailable, BIM modelling requirements should at least be set. A set of national modelling requirements and national LOD tables are defined, aiming to support the AEC experts with a set of initial reference guidelines.

The Belgian BIM guideline, similarly to all other guideline documents, makes reference to known procurement forms, hereby distinguishing in particular 'traditional' (DB) and 'integrated' procurement forms (IPD). The different documents provided (BIM Vision, BIM Protocol, and BIM Execution Plan) have a different value and use depending on the procurement form that is used (traditional, integrated), which is displayed in Figure 5.6.

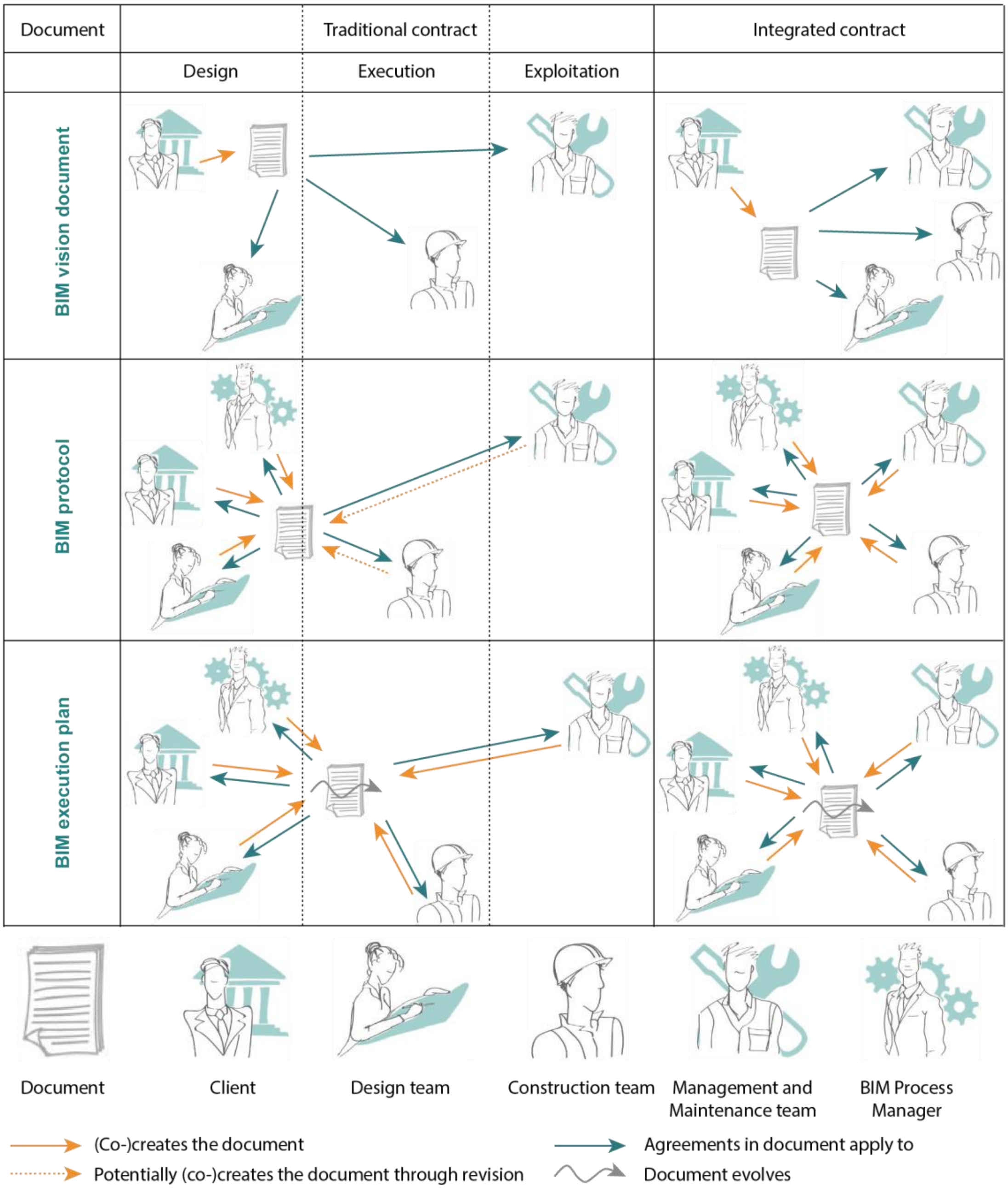

Figure 5.6 Schema of the diverse BIM documents (Y-axis left) in function of the procurement form (X-axis top).

Figure 5.6 shows the different BIM documents provided by the Belgian BIM guide on its y-axis (left): BIM Vision, BIM Protocol, and BIM Execution Plan. The x-axis (top) lists the traditional procurement form and the integrated procurement form. The traditional procurement column furthermore includes the Design, Execution, and Operational project phases. For each cell in the matrix, the diverse stakeholders are listed (bottom of Fig. 5.6): Client, Design team, Construction team, Management and Maintenance team, and BIM Process manager. The diagram then finally indicates the way in which content is initially set (orange arrows) and enforced (green-blue arrows). The curly arrow indicates that the document can still change over time. As such, a clear indication is given of who creates which documents and to which stakeholders they apply in what procurement forms.

5.4.2 BIM Protocol

The BIM Protocol itself consists of 8 sections, as already indicated above. Many of these sections contain reference material and definitions, such as the section on terms and definitions. Also in this BIM Guide, the selection of the right objectives for the BIM process is stressed significantly (Section 4 of the BIM protocol). First of all, the BIM Protocol needs to align objectives to the BIM Vision document that is provided by the owner / client. This can include global objectives and requirements, but also specific BIM methods and techniques. Additional objectives can be added as well. The following objectives are named in the Belgian BIM reference guide:

- Improved collaboration and communication
- Modelling and documenting
- Usage of the model to derive 2D drawings
- Usage of the model to derive quantities (quantity takeoff)
- Coordination and model checking
- Analyses and simulations
- 4D BIM (time planning)
- 5D BIM (cost planning over time)

In the section on the information to be exchanged, it is advised to define a number of aspect models that needs to be delivered, a number of phases in which these models need to be delivered, and a specific indication of the Level of Development to which these need to be delivered in each of these phases. This can be done using an indicative table, as included in the online template. All the deliverables need to be described in detail, indicating who needs to deliver them, with what software, what content is included, which naming conventions are used, what they can be used for, and so forth. The Belgian BIM guide indicates as a guideline that native files (and formats) are to be used in case every stakeholder works with the same software. In all other cases, the IFC file format should be chosen as a primary reference.

Regarding information exchange, the guide advises to construct a general BIM process schema. Two sample BIM process schemes are given as a guideline, namely one for a traditional and one for an integrated procurement form. The exchange of aspect models is meant to take place using a Common Data Environment (CDE), using a Document Management System. Coordination of models needs to be assigned to specific partners, both during the design and construction phase. The way in which this coordination takes place is specified in the BIM Execution Plan (BEP). Information exchange is furthermore recommended to take place in meetings, including BIM startup meetings, BIM coordination meetings, and BIM review meetings, and construction technical meetings.

In the Common Data Environment (CDE), a number of management systems is advised:

- A Document Management System (DMS): The DMS contains all digital documents, such as reports, figures, scans, administrative forms, and so forth, including a copy of all published models and their extracts (2D drawings and schedules).
- A Model Management System (MMS): All models used for coordination are made available in an MMS, which is managed by one specific partner.
- A Change Management System (CMS): All requests for changes and effective execution of changes is managed in the CMS, allowing full traceability of changes.
- An Issue Management System (IMS): All issues are remarks related to models are managed and communicated in a structured manner, which needs to be compatible with BCF.
- An Asset Management System (AMS): This system contains all the as-built models.

Finally, a number of roles and responsibilities needs to be set. More particularly, the following roles are recommended, in alignment with previously documented BIM Guides in other countries:

- BIM Process manager
- Client / Owner
- Individual Project partners

Role play within individual project partner teams is defined in the BIM Execution Plan.

5.5 Australasia: NATSPEC National BIM Guide

5.5.1 BuildingSMART Australasia

BuildingSMART is also active in Australasia through the buildingSMART Australasia Chapter[44]. Hence, also for this region, specific guidelines have been produced to guide the implementation of BIM in the industry and further encourage BIM adoption in this area of the world. A national BIM initiative (NBI) was set forward in 2012[45], explaining the main strategy of buildingSMART Australasia. This initiative resulted in an NBI Report, which consists of a Strategy and an Implementation volume. These documents start from the finding that accelerating the adoption of building information modelling (BIM) in the Australian built environment sector could improve productivity by between six to nine percent (overall financial incentive). It also found that concerted government support for the use of BIM by architects, engineers, builders, contractors, owners and facility managers involved in a building's life-cycle would increase BIM adoption in 2025 by six to sixteen percent and produce an economic

[44] http://buildingsmart.org.au/
[45] http://buildingsmart.org.au/wp-content/uploads/2014/03/NationalBIMIniativeReport_6June2012.pdf

benefit equivalent to $5 billion added to Australia's Gross Domestic Product (GDP). Hence the need for a government-led initiative in support of the use of BIM.

As reported on their website[46], the BuildingSMART Australasia vision is to have an Australasian building and construction industry that collaboratively shares and maintains information about facilities and infrastructure in a manner that optimizes the quality and economy of regulatory approval, design, construction and operation of the built environment. The mission of buildingSMART Australasia is to work with key Australian and New Zealand government and industry leaders, to proactively facilitate the use of open standards, collaborative processes and integrated practices that will:

- improve all built facilities and infrastructure projects throughout their life cycle,
- increase the value achievable from investments in the built environment, and
- enhance opportunities for economic growth.

BuildingSMART Australasia drives industry uptake of technologies to facilitate these goals, providing promotion, implementation and education programs, while also contributing to the technical standards development work of buildingSMART International.

One of the main tools used in Australasia to achieve the above goals, is the national BIM initiative. This initiative aimed at the following targets:

1. Procurement: Manage risk, intellectual property, insurance and warranty requirements for clients, consultants and constructors through new forms of procurement contracts that support collaborative, model-based procurement processes.
2. BIM Guidelines: Provide industry and government clients, consultants and constructors with a set of Australian BIM Guidelines based on collaborative working, open standards and alignment with global best practice.
3. Education: Deliver a broad industry awareness and retraining program through a national BIM education taskforce based on core multidisciplinary BIM curriculum, vocational training and professional development.
4. Product Data and BIM Libraries: Enable easy access to building product manufacturers' certified information for use in all types of model-based applications through an Australian on-line BIM Products Library.
5. Process and Data Exchange: Establish open standard data exchange protocols that will support collaboration and facilitate the integration of the briefing, design, construction, manufacturing and maintenance supply chain throughout the entire life of a built facility.
6. Regulatory Framework: Establish a mechanism for planners, local government and government regulatory bodies with integrated data of building and service system elements, land, geospatial and definition of human and related activities to measure and analyze the performance of built form.

[46] http://buildingsmart.org.au/about-us/our-goals/#.WsNpU4hua70

5.5.2 NATSPEC

Within Australia, this overall push has been aligned most prominently with the NATSPEC efforts, most notably the NATSPEC National BIM Guide and BIM Management Plan. Founded in 1975, NATSPEC[47] is a national not-for-profit organization, owned by government and industry, whose objective is to improve the construction quality and productivity of the built environment through leadership of information. It is impartial and is not involved in advocacy or policy development. The main service of NATSPEC is the national, comprehensive construction specification system endorsed by government and professional bodies and used throughout the Australian industry.

An important part of NATSPEC is the NATSPEC BIM Portal[48]. This portal gathers resources for industry stakeholders to be able to implement BIM and guide people through the usage of BIM in a nationally coordinated manner. As such, it resembles other BIM reference guides. It is also a repository of documents and tools that will assist the implementation of BIM in the construction industry. This portal serves as a mediator for the Australasian BIM Advisory Board (ABAB) and the ACIF-APCC Project team integration (PTI) and BIM initiative. The BIM Advisory Board[49] was established by the Australasian Procurement and Construction Council (APCC) and the Australian Construction Industry Forum (ACIF), together with key standard-setting bodies, NATSPEC, buildingSMART, and Standards Australia. It provides a coordinated approach across government, industry, and academia to the development of BIM practices, standards, and requirements. New technologies and processes in BIM can lead to increased productivity and improved asset management in the built environment across Australasia through collaboration, education, innovation, and simplification.

The ABAB focuses on three key elements:

1. Exchange Information Requirements (EIR): will provide an essential foundation to assistance to the Australasian construction industry by creating a common framework and language for everyone involved in the construction process.
2. Intellectual Property Framework: will assist with education and collaboration across Australia by demystifying and simplifying what is required.
3. BIM Process Consistency: will identify and promote which BIM elements should be consistent across Australasia to ensure the optimisation of BIM benefits and therefore eliminate waste in construction practices.

One of the most important documents produced by NATSPEC, and then also by ABAB and BuildingSMART Australasia, is the NATSPEC National BIM Guide. This guide has from the start been well received and increasingly adopted across the industry, providing a sound basis for further work. This work has been based on adapting (with permission) the U.S. Veteran Affairs' BIM Guidelines and is a role model for international cooperation and alignment. The NATSPEC National BIM Guide is a suite of documents that can be used to implement BIM on a project. To work effectively, the documents should be compiled in a coordinated way and read in conjunction with each other. The following documents are available:

47 https://www.natspec.com.au/
48 http://bim.natspec.org/
49 http://www.abab.net.au/

- *NATSPEC National BIM Guide* is the central reference document that defines roles and responsibilities, collaboration procedures, approved software, modelling requirements, digital deliverables and documentation standards for projects in general.
- *Project BIM Brief Template* provides a means of documenting client requirements regarding BIM for individual projects.
- *NATSPEC BIM Reference Schedule:* A list of documents and standards provided for consideration as references that can be cited in the National BIM Guide. The specific documents chosen to be applicable to a project are recorded in the Project BIM Brief.
- *NATSPEC BIM Object/Element Matrix:* A series of Microsoft Excel (.xls) worksheets that defines a large number of objects and elements and their properties by Uniformat/OmniClass classification and Level of Development (LOD) at different stages in the building's life-cycle.

The first two are the most important documents and should in fact be used in conjunction. The intent of the Guide's structure is to allow each edition of the National BIM Guide to function as a core reference document and to confine all editing to the Project BIM Brief. This allows the National BIM Guide to be tailored to individual projects while allowing it to be progressively upgraded in response to users' needs from edition to edition within a consistent, recognisable framework. The other two documents, namely the NATSPEC BIM Reference Schedule and the Object/Element Matrix are documents to which is referred from the main Guide.

5.5.3 NATSPEC Project BIM Brief template

The Project BIM Brief template consists of a 6-page Word template, which can be filled in for individual projects. As such, it forms a project-specific addendum to the core BIM Guide, aiming specifically to define the client's requirements for the use of Building Information Modelling (BIM) on the project. This document lists a number of sections that need to be covered:

1. Project team members
2. Project goals
3. Procurement strategy
4. Project Schedule
5. Client-specified BIM uses (e.g. modelling existing conditions, site analysis, space and equipment validation, …)
6. Client-specified BIM deliverables
7. Client-specified software file formats
8. Client-specified Reference documents

An excerpt of the template is provided in Figure 5.7. As such, a very brief overview can be documented of how a project will take place. This leaves freedom to the project team, yet, a number of elements are more generally specified in the core BIM Guide.

1.3 Project team members

The contact details for key stakeholders who will be involved in planning for BIM on this project are:

Role	Discipline	Name	Company/ Organisation	E-mail
Client representative				
Project Manager				
Lead consultant				
Design BIM manager				
Construction BIM manager				

1.4 Project goals

The Client's goals for the project are:

Priority	Goal description	BIM uses

1.5 Procurement strategy

Proposed project procurement strategy	
Contractor engagement: indicative date:	

1.6 Project schedule

The estimated dates for major project milestones are:

Project phase or milestone	Estimated start date	Estimated completion date
Project planning		
Conceptual Design		
Schematic Design		
Design Development		
Contract Documentation		

Figure 5.7 Excerpt from the Project BIM Brief Template by NATSPEC.

Most particularly, this template does not provide the room and place for documenting the exact process diagram that is aimed at in the project. As a result, handover and exchange moments and means can be captured only to a minor extent. This content resides more prominently in the BIM Guide, which serves as a general reference.

5.5.4 NATSPEC BIM Guide

The NATSPEC BIM Guide consists of 12 sections, including:

1. Introduction
2. Implementation
3. BIM Management Plan (BMP)
4. BIM Roles and Responsibilities
5. Model Sharing
6. Collaboration Procedures
7. Requirements for using BIM
8. 3D Models, Formats, and Model Structures
9. Technology Platform and Software
10. Modelling requirements
11. File Storage and Security
12. Requirements for 2D drawings

As such, the guide covers much of the content that is otherwise covered in many of the already documented BIM reference guides.

Regarding implementation, it is indicated that a number of important features and recommendations need to be taken into account in order to make the implementation of BIM a success, namely the procurement strategy followed, the responsibilities to be taken when using BIM methods, the way in which data is made re-usable throughout the project (data creation, management and stewardship), the terms of use defining duty and risk management, and the use of open standards (e.g. IFC and MVD).

Section 3 outlines the need for a BIM management plan (BMP), which is a formal document that defines how the project will be executed, monitored, and controlled with regard to BIM. This BMP is equivalent to the diverse project plans and process maps outlined earlier.

> It is required that a BMP be developed to provide a master information/data management plan and assignment of roles and responsibilities for model creation and data integration at project initiation. The BMP shall align the project procurement strategy needs and requirements with the PFD, client technical standards, team member skills, construction industry capability, and technology maturity. Through this process, the team members and the project management shall jointly agree on how, when, why, to what level, and for which project outcomes BIM will be used.
>
> NATSPEC National BIM Guide

These BMPs are meant to be different depending on the procurement form. Whenever a procurement form is chosen in which construction information is already present in the design phase (e.g. IPD), the BMP includes both the design and construction phases. In other forms (e.g. DBB), the definition of two separate BMPs is advised, one for design, one for construction. These BMPs include project scope, exchange considerations, modelling considerations.

The NATSPEC BIM Guide outlines furthermore a number of BIM roles, namely:

- *Project Manager:* Manages and coordinates project execution and BIM to meet procurement strategy and cost containment.
- *Design Team Project Manager:* Team manager and coordinator.
- *BIM Manager:* Coordinate BIM use on project, determine schedule of use, sharing activities, quality control, modelling responsibilities and documentation in BMP.
- *Lead BIM Coordinator:* Assist BIM Manager.
- *Architecture Team:* Design Execution – formulate with BIM Manager. Map BIM use for architectural design.
- *Structural Team:* Engineering – formulate with BIM Manager. Map BIM use for structural design – determine BIM use for structural simulations, analysis and documentation. Identify tools.
- *MEP Team:* Engineering – formulate with BIM Manager. Map BIM use for MEP design – determine BIM use for simulations, analysis and documentation. Identify tools.
- *Interior Design Team:* Interior Design Execution – formulate with BIM Manager and Architect. Map BIM use for interior design.
- *Sustainability and Energy Team:* Engineering – formulate with BIM Manager. Map BIM use for sustainability, 3rd Party Rating Systems – Determine BIM use for simulations, analysis and documentation. Identify tools
- *Building Users Group*: Determine facility functionality issues to be modelled and tested.
- *Commissioning Agent*: Support. Provide architectural, engineering, equipment compliance reports produced in the specified exchange format.
- *BIM Modelling Application Expert*: Support BIM Manager on application specific content, issues.
- *Quantity Surveyor / Cost Planner*: Support alignment of project procurement to BIM development and cost containment strategies.
- *Contractor*: Receive or help create BIM for constructability and handover for field use. Determine interference checking responsibility.
- *Subcontractor and / or Fabricator*: Off-site fabrication – formulate with BIM Manager and designer. Map BIM use for fabrication and shop drawing design. Determine BIM use for simulations of maintenance space analysis and documentation. Identify tools.

Setting the BMP and the diverse roles and responsibilities is an important core part of the NATSPEC BIM Guide. From this start, a large number of more detailed requirements are set and proposed by NATSPEC, referenced in the diverse following sections of the BIM Guide. This includes:

- *Model sharing in the diverse stages of a BIM project:* who is responsible of sharing what models when
- *Collaboration procedures:* which standards are used for collaboration
- *BIM Uses and requirements:* for which purposes is the 3D BIM model going to be built (cfr. List of Client-specified BIM uses in BIM Project Brief Template)
- *3D Models, formats and model structures:* what structure should BIM models have (e.g. floor elevation protocol, granularity of elements, cleaning of models, …)

- *Technology platform and software:* which software will be used, for what purpose, and how
- *Modelling requirements:* which general modelling rules are followed, which types of model elements can be used (manufacturer models vs. custom models), where is the geographical location of the building defined, what grid reference system is used, how spaces are modelled, what metadata are added, what naming and coding conventions are used, and what the final BIM deliverables are
- File storage and security: which folder structure is used, and how data security is ensured.
- Requirements for 2D drawings: what the role and purpose of 2D drawings should be.

The glossary towards the end of the BIM Guide contains a lot of important references with definitions of key terms. This includes for example the legal status that can be applied to the design model on the moment of handover to construction teams, the definitions for the diverse Levels of Development, and so forth.

6. Software market overview

6.1 AEC vendors and beyond

A select number of software vendors currently aim at supplying the AEC industry with software applications. There are five big vendors governing the market, and a number of smaller vendors. Because these vendors change strategy quite often, and because the number and kinds of tools they provide, changes even more often, we will not go in full detail in presenting what software tools they provide and how they fit in a BIM workflow and BIM tools landscape. We do give a short overview of the main vendors, and the main tools that they provide at the time of writing.

It is important to note that each vendor has its own profile and character, and they brand products accordingly. Based on their product strategy, they also target different parts of the AEC market, in all possible ways. For example, where one vendor may be very strong in one continent or country, it could very well be a runner-up in another continent or country. Furthermore, different software packages are used for different purposes (steel structure design versus road engineering versus architectural conceptual design versus construction site control). This chapter is by no means exhaustive or complete in listing different features and characteristics of software tools and vendors; and this chapter is also by default outdated, as the software market changes incredibly fast, and almost subjective, as this review is written predominantly based on the feedback received by the authors of this book from AEC industry.

6.1.1 Autodesk

Autodesk has always been a key market leader in many countries. Especially in Europe, Autodesk is typically the market leader for CAD software and BIM software. Leading software tools are **AutoCAD** and **Revit**. Both tools are available in the AEC Collections software package, which also includes many other tools, including Autodesk 3ds max, BIM360, Navisworks, and a number of other tools that could be useful for an AEC expert. Therefore, this AEC Collections is acquired by many AEC companies.

Besides the main 3D modelling and authoring tools (AutoCAD, Revit, Inventor), a number of additional tools are available (not exhaustive):

- **3ds Max and Maya**: these tools are typically used for animations and 3D visualisations, and focus a lot more on detailed mesh-based geometry, textures, lighting, and animations.
- **A360, BIM360**: BIM360 is known to be the Common Data Environment (CDE) offered by Autodesk. This tool allows to collect all sorts of files and documents related to a building project in a web-based interactive directory structure. As such, BIM360 allows all partners in a project to collaborate within the boundaries of one collective project CDE.
- **Navisworks**: It is possible to perform clash detection and 4D modelling (time planning) for AEC projects using Navisworks. The tool provides a 3D view of the project; a project browser; and a timeline that allows to do project and construction site management

over time. Navisworks allows loading or importing multiple files of many file types in the project, yet does not provide export functionality for those files. As such, this tool is excellent for BIM coordination purposes (clash detection and issue management over multiple models and files).
- **InfraWorks** and **Civil3D** are the references tool for modelling infrastructure and geospatial data (roads, bridges, construction sites, etc.).
- **Robot**, **CFD**, **Ecotect**, **Nastran**, and a number of other tools are dedicated tools for calculations and simulations (structural analysis, environmental analysis, energy performance simulations, CFD-based simulations, etc.).

Typical to the Autodesk strategy is the unified branding of the software products. All software tools are clearly “Autodesk-branded”: the name ‘Autodesk’ is used everywhere, and all software tools have a similar branding (logo, layout, etc.). As soon as Autodesk acquires a new product (e.g. Revit, Ecotect, Green Building Studio, Dynamo, etc.), it typically rebrands the product so that it integrates quite well in the Autodesk product suite. Beyond the similarity in logo’s, features of one software (e.g. the 3ds max render engine) are combined in other software (e.g. AutoCAD, Revit); and several interoperability mechanisms are targeted at (e.g. FBX for exchange of geometry for visualization and animation – Revit to 3ds max; DXF; Dynamo – Revit integration, and so forth).

6.1.2 Trimble

Trimble as a company exists for a long while, yet it has appeared only recently in the AEC market (since around 2012). Trimble has always been highly active in GPS and scanning technologies. A couple of years ago, it has acquired: (1) Gehry Tech, which included for example Trimble Connect and Digital Project, (2) Tekla, which included for example Tekla Structures and Tekla BIMSight, (3) VICO, (4) and Google SketchUp. With these acquisitions, Trimble took a strong position in the AEC market.

Key modelling and authoring tools offered by Trimble are:
- **Sketchup**: easy to use and intuitive surface-based modeler that is often used for fast conceptual design and visualization (architectural design offices)
- **Tekla Structures**: specialized structural design software that is typically used for detailed steel structure design.
- **Digital Project**: the key 3D modelling software built in support of Frank Gehry’s modelling requirements allows advanced free-form modelling and detailing of buildings, thereby taking a lot of inspiration from automotive and aerospace industry (detailed modelling of cars and planes).

Besides these modelling and authoring tools, the following tools are additionally useful for AEC experts:

- **VICO**: The VICO software (Virtual Construction) allows 4D modelling of construction project and hence shows similarities with Autodesk Navisworks in its timeline and coordination functionalities.
- **Trimble Connect** and **Tekla BIMSight** are very similar tools which allow gathering all reference documents and models for a project in a web-based platform, allowing

retrieval and viewing of the project by all project stakeholders, not only in design and engineering offices, but also on site.

Unlike Autodesk, software tools tend to keep their own special focus and features after acquisition. Furthermore, tools are provided that aim at very specific and complementary areas in the AEC market (structural steel design, conceptual architectural design, GPS and total station hardware, and coordination).

6.1.3 Nemetschek

A third vendor company is the Nemetchek Group, which in fact consists of a number of smaller companies, namely AllPlan, Solibri, DDS, Graphisoft, Scia, dRofus, and so forth, each offering their own software tool. Each of these companies has its own structure, market, branding and strategy. As such, the Nemetschek group is very different from Autodesk.

Reference authoring and modelling software offered by Nemetschek are:

- **Graphisoft ArchiCAD**: This software allows to build a 3D model of a building since the 1980's, and is therefore considered to be the first and most long-standing BIM tool on the market. In comparison to Revit, this tool typically focuses more on architectural design, and provides less support for advanced MEP and structural design.
- **AllPlan**: This software is typically used for concrete-based structural design, which includes a lot of infrastructure works.
- **Vectorworks**: This software has always been an alternative for AutoCAD, and has been most popular with Mac users. It currently also has a version that allows BIM modelling.

Other than these authoring and modelling tools, Nemetschek has a number of other key tools among their products:

- **Maxon** and **Cinema4D**: These tools are used for visualization and animation, and thereby compete with Autodesk 3ds Max and Maya.
- **Solibri Model Checker**: This tool is the reference tool for BIM coordination, as it provides model checking (clash detection), information take-off, and issue tracking in one comprehensive tool. Furthermore, this is one of the only commercial tools that allows rule-checking on BIM models.
- **BIMx** and **BIMcloud**: These tools allow collecting documents and models in a web-based interactive project-based viewer and management environment. As such, they are typically used as CDE's for specific projects, providing access to information for many stakeholders and from many places (office and construction site).
- **Frilo**, **SCIA Engineer**, **Nevaris**, **dRofus**, and **Data Design System** are more specialized tools that allow specific kinds of simulations and analysis in the AEC industry, such as facility management, structural analysis, and so forth.

6.1.4 Dassault Systèmes

Dassault Systèmes has a smaller market share and originated from the aerospace industry in France (Dassault). Its main 3D modeling tool is CATIA, which has a long-standing history, and which was originally used in design and modelling of airplanes. Of course, CATIA therefore has very specialized 3D modelling features, which are much more complicated than mainstream AEC modelling features found in tools like AutoCAD, Sketchup, Archicad, and others.

Apart from **CATIA**, Dassault Systèmes also offers several other tools, which includes:
- **3DVia**: This visualization tool of Dassault Systèmes mainly aims at providing cloud-based applications for interior room design, kitchen layout and in-store user experiences. Such tools provide retailers a shorter sales cycle by enabling to visualize the end result more realistically.
- **Simulia**: This simulation tool aims at simulating solutions before they are bought / sold.
- **Enovia**: This Product Lifecycle Management (PLM) solution provides stakeholders with a platform and tools to address business, product, and process complexity challenges over the product lifecycle.

6.1.5 Bentley

A fifth and last vendor discussed in this chapter is Bentley Systems. Bentley's market share is relatively small in Europe, and focuses more on the American market. Its flagship 3D modelling tool is **MicroStation**, which has been around for decades, much like Tekla Structures, CATIA, Digital Project and ArchiCAD.

Apart from this main authoring tool, Bentley Systems also offers:
- **Generative Components:** a tool that allows to perform complex, script-based and visual programming-based 3D geometrical design, much like Dynamo and Grasshopper/Rhino.
- **OpenBuildings:** The former product AecoSIM was rebranded to OpenBuildings. This application aims to integrate multiple disciplines to successfully design, analyze, construct, and manage buildings of all types and scales. The focus of this software is on the delivery of sustainable, high-performance buildings quickly and easily.
- **STAAD:** The STAAD branch of Bentley (including STAAD.PRO) aims specifically at structural analysis software. It supports the analysis and calculation for steel, concrete, timber, aluminum, and cold-formed steel projects. It furthermore supports over 90 building codes.

6.1.6 Other vendors

Besides these five main vendors, a number of other software tools of smaller companies can be mentioned:

- **IntelliCAD:** This software platform emulates the interface and functions of AutoCAD mainly. It is meant to stick to core functionality, be affordable, and of use to core development users. IntelliCAD is available for members supporting the IntelliCAD Technology Consortium (ITC). With extensive APIs in various programming languages, the software focuses a lot on custom CAD development, instead of providing a standard generic solution.
- **IES VE Integrated Environmental Solutions Virtual Environment:** IES focuses strongly on building performance analysis and on integrated environmental analysis. IES VE in particular is a suite of building performance analysis applications, mainly aimed

to be used by designers to assess their impact on the environment (CO2 footprint, energy use, renewable technologies, etc.).

- **BricsCAD BIM:** BricsCAD BIM has been built on the DWG file format, allowing to handle 2D and 3D geometry as one is able to do so in AutoCAD. Even with the emergence of Revit, BricsCAD has kept its focus on freeform 3D modelling according to the DWG format and functionality. This tool has by now evolved into a complete BIM modelling environment.
- **BuildSoft Diamonds:** The Diamonds tool by BuildSoft as a structural analysis package for steel, concrete and timber structures. With BIM Expert, exchange is enabled with Tekla and a number of other software tools, thereby aiming at direct interoperability.

6.2 No ring to rule them all, no holy grail

As can be seen from the software market overview, a grand myriad of software applications is available, each of them covering very specific fields and providing very specific functionality. Functionality provided includes modelling, simulation, animation, online collaboration, coordination, analysis and many other functionalities. These tools are used throughout the building life-cycle (Fig. 6.1). The concept of Building Information Modelling (BIM) allows to gather information in a central source of truth, so that it can be re-used throughout the building lifecycle.

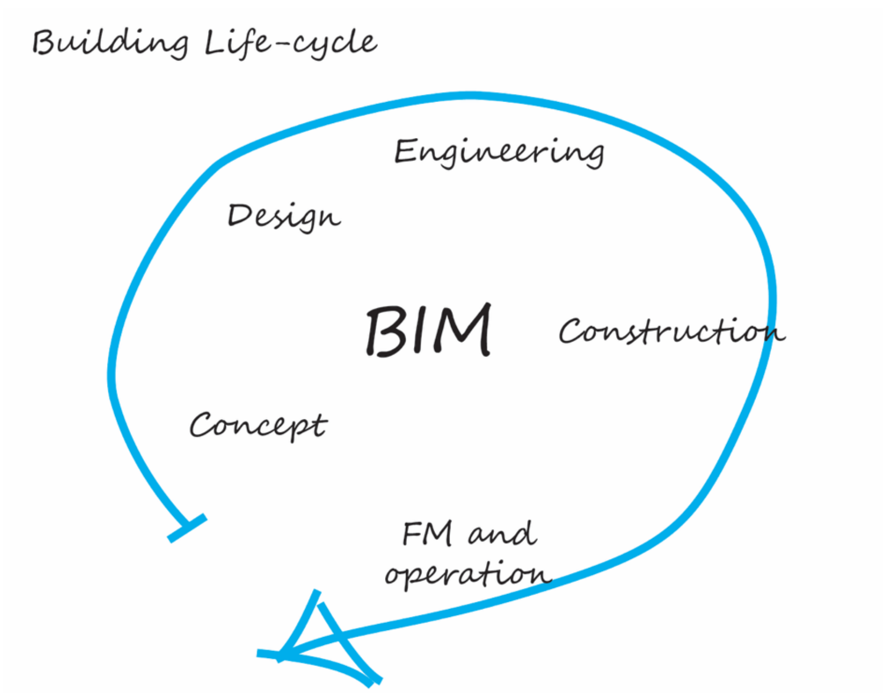

Figure 6.1 The building life cycle includes many stages, in which diverse tools are of use. As all tools include 'information', the concept of Building Information Modelling is to supply all such tools with information from a central reference.

In such an environment, according to the concept of BIM, information can best be gathered in a central source of reference (right in Fig. 6.2), instead of keeping all information at the edges (left in Fig. 6.2). Decentral management of information brings a big risk of uncoordinated and therefore inconsistent information exchange, leading to ineffective information exchange and failure costs.

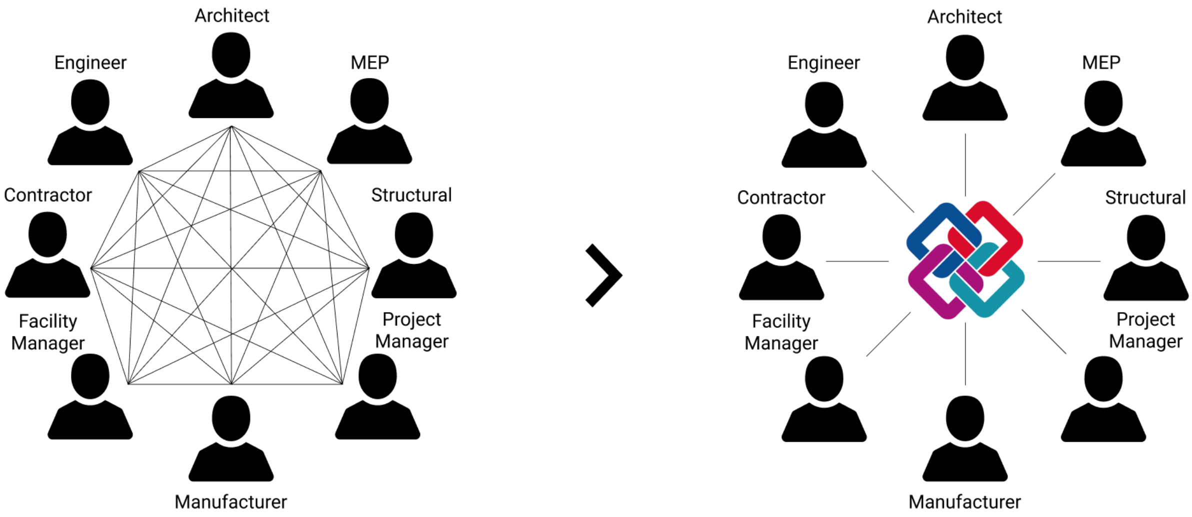

Figure 6.2 Traditional decentralized exchange of information (left) versus centralized exchange of information (right).

Starting from Fig. 6.1 and 6.2, the traditional BIM concept thus aims at a centralized single source of truth, which can be actively used by all project stakeholders according to a common process plan. BuildingSMART, or originally the International Alliance for Interoperability (IAI), has additionally aimed at providing a neutral data model, namely the Industry Foundation Classes (IFC), which can ideally be used as a data model that can represent that single central source of truth. This central and neutral data model serves then as a language that can be used by all software tools to communicate. Hence, it can be compared to a Babylonian language (Fig. 6.3), a common language that is understood by all in construction the Tower of Babel.

Figure 6.3 The Industry Foundation Classes as a Babylonian language.
Image: The Tower of Babel by Pieter Bruegel the Elder (1563). Source: PUBLIC DOMAIN

Alternatively, IFC may be considered to be the holy grail for AEC industry (Fig. 6.4). If this common language or common data model is found, all miscommunication between all tools on the market may be resolved, and collaboration may run more efficient as ever.

Figure 6.4 The Industry Foundation Classes as the holy grail of the AEC industry.

Image: Depiction of King Arthur's knights seeing a vision of the Holy Grail gathered at the Round Table. Source: EVRARD D'ESPINQUES/PUBLIC DOMAIN

Unfortunately, similar to how it has been impossible to complete Babylon, find one Babylonian language, or find the holy grail, it has proved to be impossible to find one data model that can be used throughout the AEC industry as a single reference data model. Over the last ten years, focus has been put a lot more on the process of information exchange on a project basis. Whenever a project is started, stakeholders are not just required to choose a common data model, they are, more importantly, required to define a process of information exchange, which typically includes Business Process Model (BPM) diagrams and Exchange Requirements. Such project-based process is agreed upon by all stakeholders in a project and then serves as “the rules of the game” used by all stakeholders in common agreement. As an effect of this evolution, BIM projects have shifted focus from “defining a common data model” to “defining a common process”, in which multiple data models or languages may be used (more decentralized in terms of data; more centralized in terms of coordination).

6.3 Specifics of software (kernel, purpose, scale)

As was indicated in Section 6.1, diverse kinds of software exist. And each software tools has its specifics. Figure 6.5 shows some example views in diverse software, indicating here the difference between a BIM model, a mesh model and an analytical model.

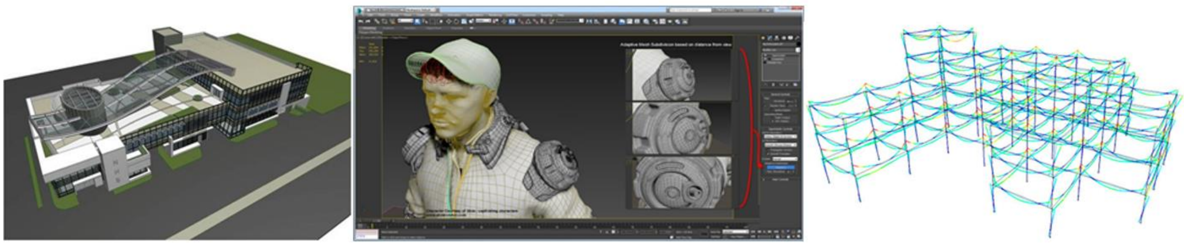

Figure 6.5 Specifics of software: BIM software versus 3ds max mesh modelling versus an analytical model for structural analysis.

Every software tool has its specific characteristics. In the case of tools for the AEC industry, the following three features are what define the specific characteristics of a certain software application:

1. Kernel
2. Purpose
3. Scope

And then there are still file formats, which are external to any application and thus inhibit a translation step with loss of information. In addition to kernel, purpose, and scale, file formats play also a very important role in defining what can be done in which application. Fig. 6.6 gives an indication of what geometry can be described using which file format or modelling kernel[50].

[50] Source: P. Pauwels et al. Three-dimensional information exchange over the semantic web for the domain of architecture, engineering, and construction. Artificial Intelligence for Engineering Design, Analysis and Manufacturing (2011), 25, 317-332.

		DXF	DWG	FBX	OBJ	STL	DAE	VRML	X3D	U3D	3DS	STEP	IFC	GBXML	ACIS	PARASOLID	OPEN CASCADE
Mesh geometry	Mesh geometry	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Face normals			Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N		Y	Y
	Texture mapping vertices			Y	Y	N	Y	Y	Y	Y	Y		Y	N	N	N	Y
Freeform 3D	NURBS curve	Y	Y		Y	N	Y	N	Y	Y	N	Y	Y	N	Y	Y	Y
	NURBS surface	*	*		Y	N	Y	N	Y	Y	N			N	Y	Y	Y
	Parameter space vertices	*	*		Y	N	Y	N	Y	Y	N			N	Y	Y	Y
	Trimming loops / holes	*	*		Y	N	N	N	Y	Y	N			N	Y	Y	Y
2D Primitives	Point	Y	Y		N	N	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y
	Arc2D	Y	Y		N	N	N	N	Y	N	N		N	N		N	Y
	ArcClose2D	N	N		N	N	N	N	Y	N	N		N	N		N	N
	Circle2D	Y	Y		N	N	Y	N	Y	N	N		Y	N		Y	Y
	Disk2D	N	N		N	N	N	N	Y	N	N		N	N		N	N
	Ellipse2D	Y	Y		N	N	Y	N	N	N	N		Y	N		N	Y
	Polyline2D	Y	Y		N	N	N	N	Y	N	N		Y	N		N	Y
	Polypoint2D	N	N		N	N	N	N	Y	N	N		N	N		N	Y
	Rectangle2D	N	N		N	N	N	N	Y	N	N		Y	N		N	Y
	Triangleset2D	N	N		N	N	N	N	Y	N	N		N	N		N	Y
	Hyperbola	N	N		N	N	Y	N	N	N	N		Y	N		N	Y
	Parabola	N	N		N	N	Y	N	N	N	N		Y	N		N	Y
3D Primitives	Box	*	*		N	N	N	Y	Y	N	N		N	N		N	Y
	Cone	*	*		N	N	Y	Y	Y	N	N		Y	N	Y	Y	Y
	Cylinder	*	*		N	N	Y	Y	Y	N	N		Y	N	Y	Y	Y
	Sphere	*	*		N	N	Y	Y	Y	N	N		Y	N		Y	Y
	Torus	*	*		N	N	Y	N	N	N	N		N	N		Y	Y
	Polyline3D	Y	Y		N	N	N	Y	Y	N	N		Y	N		N	N
	Helix	Y	Y		N	N	N	N	N	N	N		N	N		N	N
Geometric features	Basic feature transformations (scale, rotate, etc.)	*	*		N	N	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y
	Surface modelling (sweep, revolve, etc.)	*	*		N	N	Y	N	Y	N	N	Y	Y	N	Y	Y	Y
	Boolean operations	*	*		N	N	N	N	N	N	N	Y	Y	N	Y	Y	Y

Figure 6.6 Diverse file formats and 3D modelling kernels, indicating what functionality each one of them supports.

In conclusion, these specifics of software (kernel, purpose, scale), complemented by a diversity in file format, constitute the complete diversity of languages in the AEC software world, leading to Babylonian misinterpretations and translations. The next few sections will shed some light over these three main specifics of software.

6.3.1 Kernel

What is a 3D kernel?

A 'kernel' is the core of any system. In the case of computers, parallels can be drawn with the kernel of a computer: the Operating System (OS – Fig. 6.7). The kernel acts as the link between software applications and the hardware (CPU, memory, devices). As such, it defines a number of key structures that define the nature of the software application. For example, the Apple OS allows very different things compared to the Linux or Windows kernels. Hence, applications have a different look and feel, and very different connections are made to different hardware.

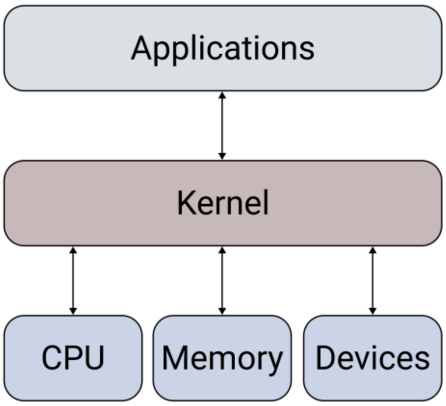

Figure 6.7 The Operating System (OS) is the kernel between hardware (bottom) and the application layer software (top).

In the case of 3D geometry, the geometric modeling kernel is a 3D solid modeling software component used in 3D modelling packages. Similar to an OS, this kernel defines all possible geometric operations that can be made in a 3D model or 3D modelling environment. Consequently, it defines the way in which one can model geometry, as is displayed in Fig. 6.8[51].

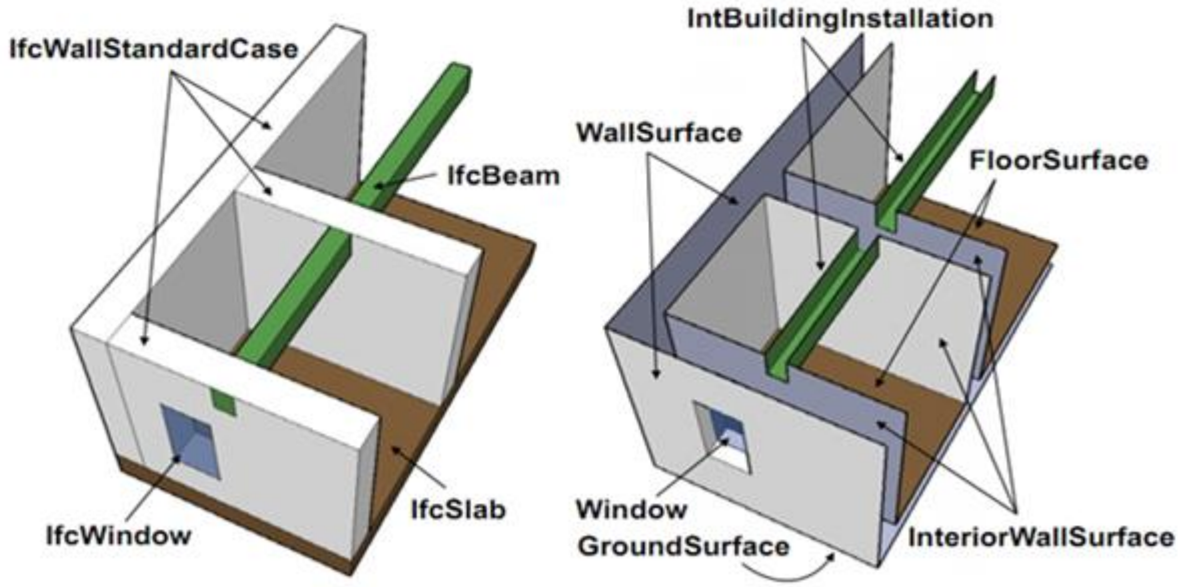

Figure 6.8 The 3D modelling kernel defines which kinds of geometric modelling operations can be performed in a 3D modelling environment (e.g. solid modelling on the left versus mesh modelling on the right).

Some key existing kernels are:
- Convergence Geometric Modeler (CGM) – Dassault Systèmes
- Romulus – Shape Data
- Parasolid – Shape Data, Siemens

[51] Source: Claus, N., Alexandra, S. & Thomas, K. H. (2009). Conceptual requirements for the automatic reconstruction of building information models from uninterpreted 3d models.

- ACIS – Spatial Corporation (Dassault Systèmes)
- ShapeManager (branched from ACIS) – Autodesk
- Granite – Parametric Technology Corporation
- Open CASCADE – open
- C3D kernel – C3D Labs (ASCON Group)
- SMLib – Solid Modeling Solutions
- SOLIDS++ – McNeel

Among these example kernels, one can for example see the CGM modeller, which lies at the core of CATIA, and the modelling kernel of McNeel (SOLIDS++), which lies at the core of Rhino(ceros). CATIA and Rhinoceros have very different 3D modelling functionality, which is a direct effect of the difference in modelling kernel. The two most well-known kernels in AEC industry are ACIS and Parasolid.

History of 3D modelling kernels

The first kernel dates back to 1974, with the formation of the company Shape Data, which later became Three-Shape Ltd. This company was formed by Ian Braid, Alan Grayer, and Charles Lang. These three, as part of Shape Data created ROMULUS, which was the first commercial solid modeling kernel. This was a BREP solid modeler, released in 1978, and immediately licensed by Siemens, HP and several other CAD software vendors.

The ROMULUS kernel became the foundation of the ACIS and Parasolid kernels. As can be seen in Fig. 6.9, Romulus was bought in 1981 by Evans and Sutherland, where it became the basis of Parasolid. Much later, Parasolid was bought by Siemens PLM, which is still the owner of this kernel.

In a second, alternative branch, Ian Braid, Alan Grayer, and Charles Lang created the company Three-Shape, which produced the ACIS kernel. After acquisition by Spatial Corporation, the ACIS kernel was bought by Dassault Systèmes. Autodesk’s ShapeManager has been inspired by the ACIS kernel. Up until now, ParaSolid and ACIS are key modelling kernels used in 3D authoring tools for the AEC industry.

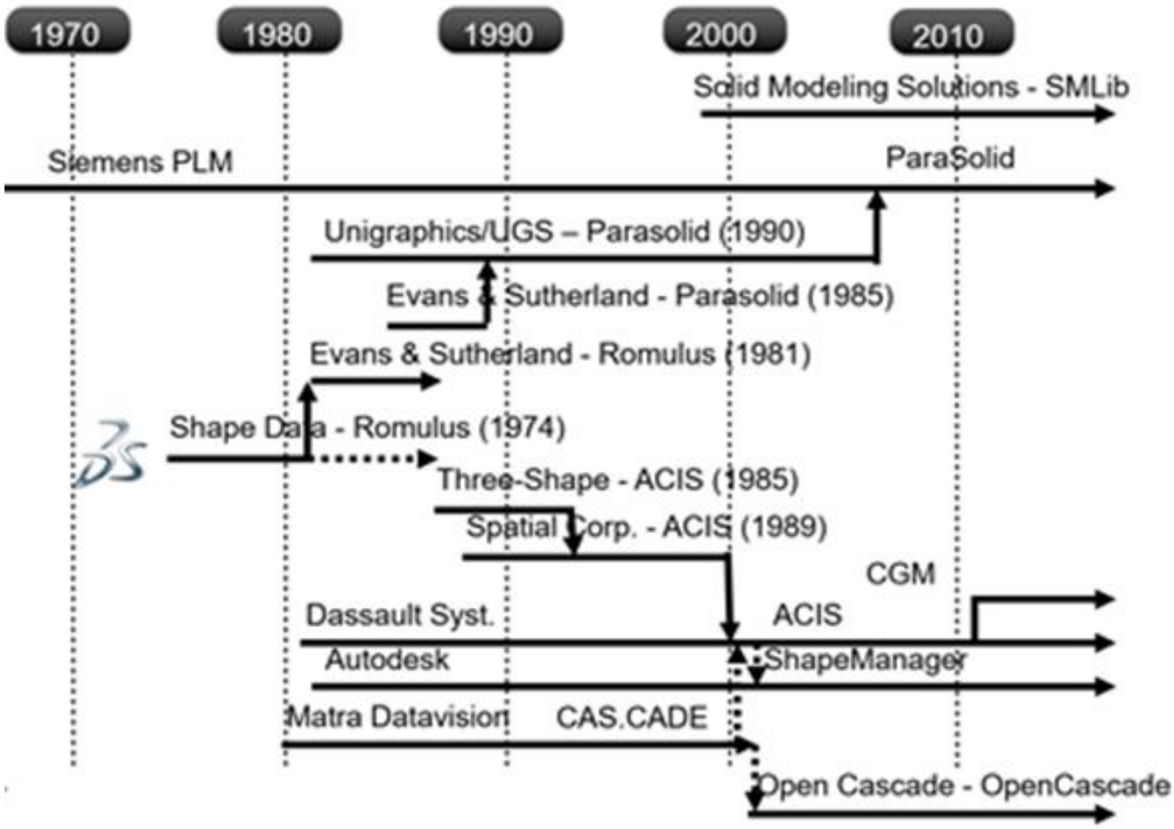

Figure 6.9 Historical development of diverse 3D modelling kernels.

Kernels in the AEC industry

The two most commonly known and most important kernels nowadays are ACIS and Parasolid. They inhibit the following operations:

ACIS:

- C++ architecture
- wireframe model, surface, and solid modeling functionality
- both manifold and non-manifold topology
- rich set of geometric operations:
    - Extrude/revolve/sweep sets of 2D curves into complex surfaces or solids.
    - Fillet and chamfer between faces and along edges in surface and solid models.
    - Fit surfaces to a closed network of curves.
    - Hollow solids and thicken surfaces.
    - Interactively bend, twist, stretch, and warp combinations of curves, surfaces, and solids.
    - Intersect/subtract/unite any combination of curves, surfaces, and solids.
    - Taper/offset/move surfaces in a model.
    - Attach user-defined data to any level of a model.
    - Track geometry and topology changes
    - Unlimited undo/redo with independent history streams.
    - Tessellate surface geometry into polygonal mesh representation.

        ○ …

Parasolid:

* model creation and editing utilities:
    * Boolean modeling operators
    * feature modeling support
    * advanced surfacing
    * thickening and hollowing
    * blending and filleting and sheet modeling
* Direct model editing
    * tapering, offsetting, geometry replacement and removal of feature details with automated regeneration of surrounding data.
* graphical and rendering support
    * including hidden-line
    * wireframe
    * drafting
    * Tessellation
    * model data inquiries

Similar to the way in which it is difficult to exchange information across diverse operating systems, it is equally difficult to exchange information across different geometry kernels. Transferring ACIS geometry to the SOLIDS++ kernel is likely possible, but both kernels provide very different functionality. As geometry is changed in one kernel, it will not be directly interoperable with the other kernel.

This can be illustrated with the simple example of a circle. In one kernel, a circle may be defined by a point and a radius, which allows to enlarge the circle by enlarging the radius. If this circle is transferred to a kernel which only allows a circle to be described by three points on its boundary, a computation will need to happen to calculate those three points from the point and radius data. Three points will be obtained, yet, certain rounding off will occur. Enlarging the circle in the other software can happen by dragging one of those points. If transferring back to the first kernel, an origin point and a radius will need to be calculated. Because of the rounding errors in recalculating origin and radius, even if the circle was not enlarged, the new circle will likely be different from the original one.

6.3.2 Purpose

The second feature by which software defines itself, is the application layer that is built on top of the kernel. This application layer defines the functionality that is built with the basic commands that are available through the kernel. In the case of the operating system example, the application layer makes the difference between Microsoft Word and Microsoft Excel. Both are built on top of the Windows OS (kernel), yet, both provide very different functionality. Similarly, AEC software can be built using the same 3D modelling kernel, but providing very different functionality. For example, using the same kernel, one may build a BIM authoring tool or a structural analysis tool (Fig. 6.10). Similar to the difficulties of transferring Excel data into Word and back, conversion errors typically occur in the transfer of BIM data to a structural analysis tool (or other).

Figure 6.10 Historical development of diverse 3D modelling kernels.

A typical example in which different functionality may be provided using the same kernel, can be found in the distinction between 3D BIM modelling tools (left of Fig. 6.11) and energy modelling or geospatial modelling tools (right of Fig. 6.11). Where BIM software focuses more directly on element-based models (walls, windows, doors, slabs, etc.), geospatial models and energy models typically focus on surfaces, spaces, boundaries and faces. Even if it is possible to transfer data from one to the other (both directions), this typically requires algorithms to compute the 3D geometry and semantic annotations. Information is lost when transferring data in either direction, thus resulting in limited interoperability.

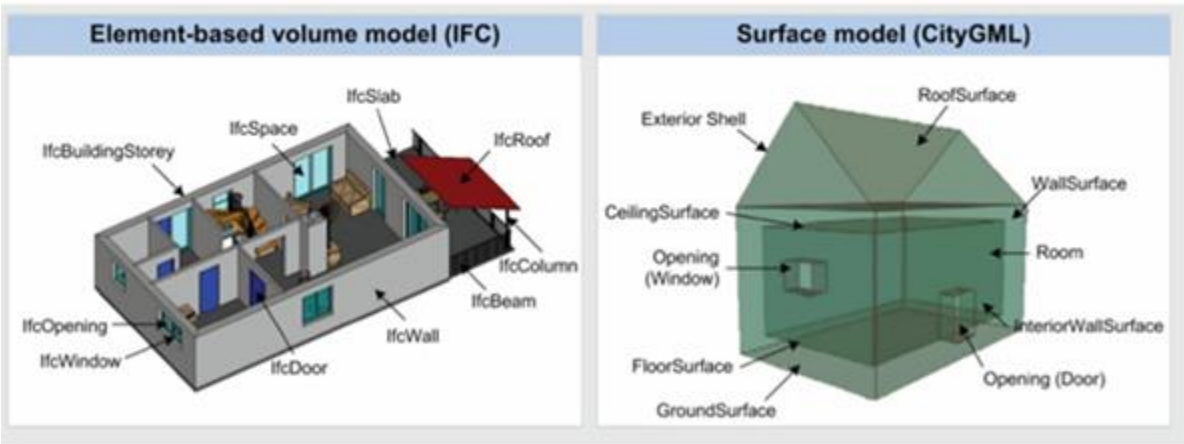

Figure 6.11 Applications have different purposes, making information harder to exchange. This is illustrated here in the difference between the element-based models used for BIM and the surface models used for geospatial and energy modelling[52].

6.3.3 Scale

A third and last feature by which software distinguishes itself from other software, thereby making interoperability difficult to achieve, is in the scale of its content. The world is very big, and when modelling it in a machine-interpretable version, certain approximations are made. The model is never identical to the real-world version, and a certain scope and scale is maintained (see Fig. 6.12).

[52] Image source: Claus, N., Alexandra, S. & Thomas, K. H. (2009). Conceptual requirements for the automatic reconstruction of building information models from uninterpreted 3d models.

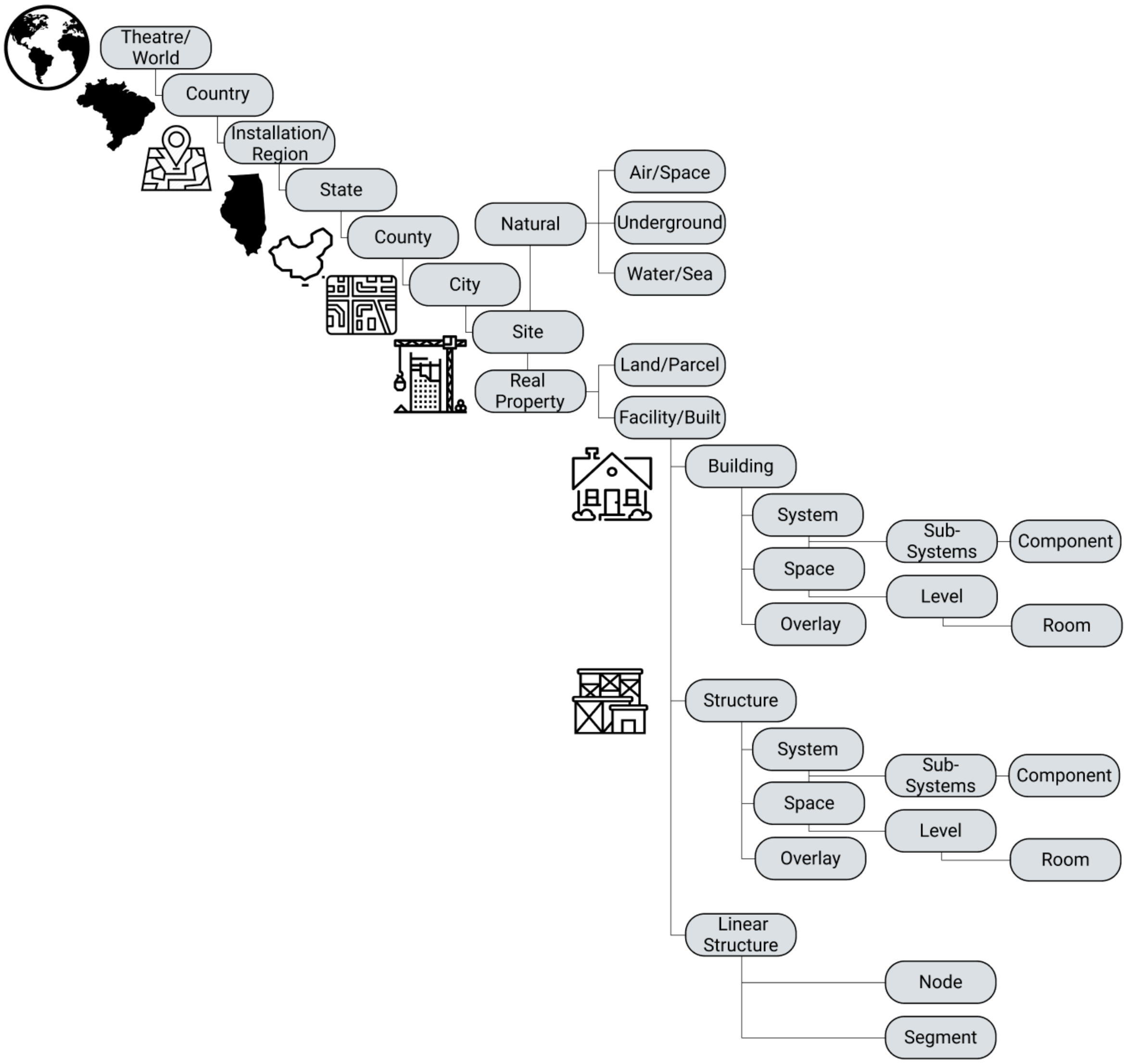

Figure 6.12 Different scales in modelling the world: from a global perspective (geo-coordinates) to city modelling, building modelling (BIM), and finally product modelling[53].

In the case of the built environment, a model could scope to the entire world, including models of countries, regions, states, provinces, and cities. This scope is typically targeted within the geospatial domain (geographic information systems – GIS). Within this scope or domain, a certain granularity or scale is maintained to ensure that the information is manageable. In this domain, scale does not focus on millimeters and complex 3D features and objects. Instead, it focuses on latitude and longitude, a diversity of coordinate systems (global and local), differences in curvature of the earth, and complex 2D mapping techniques.

Alternatively, a model could scope to built infrastructure (roads, tunnels, bridges, railway networks, etc.). In such case, a more narrow scope and scale is maintained. Curvature of the earth and global coordinate systems become less important, and there is more focus on 3D

[53] NIBS (Alan Edgar), Introduction to National BIM Standard Version 1 Part 1 – Overview, principles, & Methodologies, 2007.

geometry, object geometry and object semantics (beams, rails, columns, bridge decks, etc.). Urban and national networks can be modelled in topological networks. Additionally, the elements in those networks (roads, rails, waterways, etc.) can often be modelled using a 2D cut-through model swept along a path to constitute the model of the infrastructure (Fig. 6.13). Those models can be modelled using tools that are on the edge of the traditional set of BIM software, such as InfraWorks, AllPlan and Civil3D. As such, a combination of 2D models, network models and local geospatial models prevails. The scale of these models is not on a millimeter dimension, but it is more specific than the scale and level of detail at a global geospatial level.

Figure 6.13 Infrastructure networks modelled as 2D cut-through sections that are swept along paths.

Very local elements that often occur at the nodes of the network, such as bridges, tunnels, and other intersections, can typically be modelled using local 3D models with semantic annotations and classifications. Such models can be built using BIM software, including Revit, Tekla, AllPlan and so forth.

More detailed or smaller scale models are typically produced for buildings (Fig. 6.14), which are the prime targets for BIM software, such as Revit, ArchiCAD, BricsCAD, IntelliCAD, Tekla, Vectorworks, and so forth. These models have a more fine-grained geometry and semantics. They typically lack any notion of geospatial coordinates, besides the base point or reference point, simply because a different scale or level of detail is used for building these models. All geometry is represented using a local reference coordinate system.

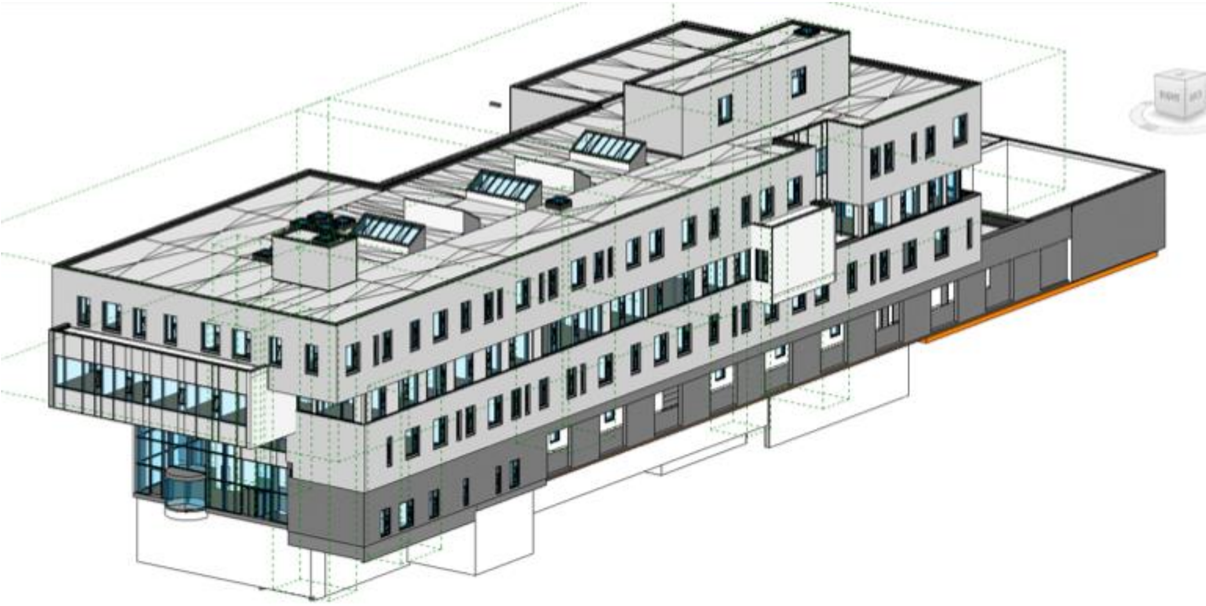

Figure 6.14 Building Information Models with a medium level of detail and a focus on approximate 3D geometry and information.

Furthermore, all elements in such building models have a certain level of approximation. They do not go in full detail. Each building element is modelled using geometric primitives (boxes, spheres, sweeps, extrusions, and so forth), typically resulting in a solid model that includes flat walls, straight roofs, flat slabs, and so forth, even though nothing in reality is really flat or straight. The same applies to product classifications and properties. No BIM model has full detail in terms of element classifications (dome, vault, column, pilaster, etc) or element properties (thermal transmittance, acoustic performance, etc.). When modelling BIM models for existing buildings, such approximations need to be considered, taken into account, and respected. If more detailed geometry, object classifications, or object properties are needed, alternative software is available, including point cloud modelling software and product modelling software (e.g. Inventor).

A last, more fine-grained kind of object models is available in the product modelling domain (Fig. 6.15). Product (information) models are typically modelled using very precise and complex geometry, leading to a product definition that details how a complete product consists of individual parts. In such software, millimeter accuracy is absolutely required, including geometric tolerances everywhere in the product definition. Also in terms of properties, a lot more detail is required, to be able to simulate exact performance of the product.

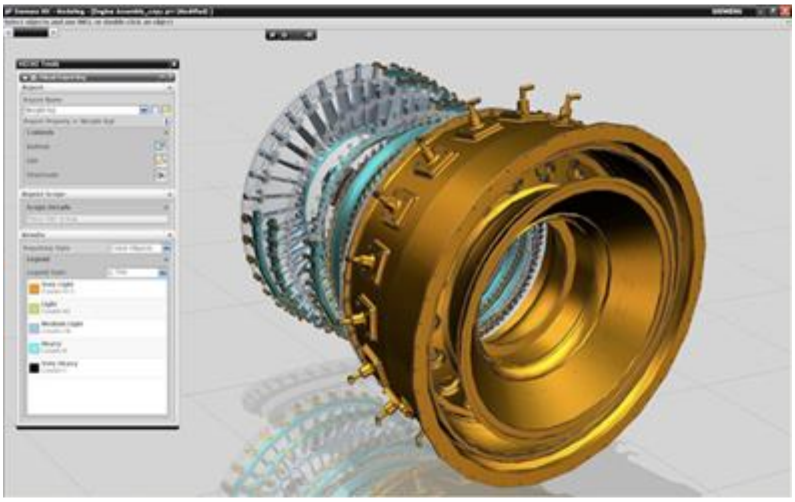

Figure 6.15 Product (Information) Models with a fine-grained and full level of detail.

As such, product information models and software are very different from building information models (medium scale), infrastructure models and geospatial models (wide scale). This difference in scale is a third, very important feature of software that makes it extremely difficult to exchange data between these software applications in an interoperable manner: detailed product information is simply not of use in GIS or BIM applications, and geospatial data is of no use in BIM models or product models.