International BIM implementation guide

RICS guidance note, global

1st edition

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International standards

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This is a guidance note. Where recommendations are made for specific professional tasks, these are intended to represent 'best practice', i.e. recommendations which in the opinion of RICS meet a high standard of professional competence.

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Document status defined

RICS produces a range of standards products. These have been defined in the table below. This document is a guidance note.

Type of document	Definition	Status
Standard		
International standard	An international high level principle based standard developed in collaboration with other relevant bodies	Mandatory
Practice statement		
RICS practice statement	Document that provides members with mandatory requirements under Rule 4 of the Rules of Conduct for members	Mandatory
Guidance		
RICS code of practice	Document approved by RICS, and endorsed by another professional body/stakeholder, that provides users with recommendations for accepted good practice as followed by conscientious practitioners	Mandatory or recommended good practice (will be confirmed in the document itself)
RICS guidance note (GN)	Document that provides users with recommendations for accepted good practice as followed by competent and conscientious practitioners	Recommended good practice
RICS information paper (IP)	Practice based information that provides users with the latest information and/or research	Information and/or explanatory commentary

Foreword

This second decade of the third millennium will witness our built environment switching from a relatively analogue-based Victorian-era process to one which is fully digitised, with computer-readable data powering or informing our decision-making processes during the entire asset life cycle. Key to unlocking this global transference in industry working is building information modelling (BIM), not just from a digital technology perspective but also through changing processes and culture, enabling better collaboration and ultimately an integrated construction and asset management modus operandi.

Economists have noted an ever-growing demand for BIM-related services and have, for example, estimated that the UK market for this will be an annual £30 billion by 2020. Developing BIM capabilities and new ways to manage asset knowledge will become key to organisational and export growth.

BIM is fundamentally game changing for the construction sector. Along with a number of foresighted countries, the UK is taking the lead in a global race to develop both open standards and supporting tools for adopting BIM. Together they are putting substantial effort into the development of new requirements to harmonise ways of managing information in which 3D geometry and data is stored and shared between parties throughout the creation and care of both buildings and infrastructure in the built environment.

BIM will by design disrupt current ways of procuring and operating our assets, helping industry become more industrialised and efficient. It has the potential to revolutionise the relationship between supply chain partners, create new business models, reduce both capital and operational costs, speed up delivery times, increase efficiency, cut waste and deliver assets that are 'right first time' through soft landings and predictive data that flow across the life cycle.

As industry takes hold of this new future it is essential that organisations and individuals are not flying blind but have information to plot out a change plan and BIM implementation trajectory both for now and indeed a 'future wise' longer term digital strategy. BIM is a broad subject with many perspectives across the globe both in terms of what it means and how it should be applied. This guidance note explores the concepts and often complex dynamics that need to be travelled to intelligently invent your future in the background of a new data-rich built environment.

David Philp, MSC BSC FRICS FCIOB, RICS BIM Manager

Head of BIM Mace and UK BIM Task Group

1 Introduction and background

The built environment sector is inundated with debate on the what, why and how of building information modelling (BIM). BIM reiterates the importance of the information-intensive nature of the sector and highlights the links between technology, people and processes in every aspect. Pundits are predicting a revolutionary transformation of the sector, governments are implementing national programmes in the hope of reaping major benefits, and individuals and organisations are adjusting rapidly to these developments, with some aggressively moving forward and some waiting for a time when clarity emerges.

In these times it is crucial to be clear on the current and future state of BIM. This can be achieved through a concise document that provides a holistic view of the current state and, using forces on the ground, lays out some strategic guidelines for individuals and organisations involved in the creation and operation of our built environment.

1.1 Purpose of this guidance note

This guidance note highlights international high-level principles around how to implement and use BIM in the design, construction and operation of our built environment, including facets of procurement management and asset management. It is intended that these principles are used as an overarching framework for potential national standards or regional guidelines on BIM, and also by individuals and organisations. Therefore, this guidance note is designed for any firm or professional using BIM or considering using BIM in the foreseeable future.

Given this background, this guidance note focuses on how BIM stands to transform and complement current practice to create and sustain better levels of performance in the provision and operation of our built environment. The literature clearly demonstrates that the focus of the industry has surrounded the 'what' and the 'why' of BIM. Studies show the context in which BIM has been applied in the industry, thereby answering the 'what'. Similarly, the benefits of and reasons for adopting BIM on building projects have been studied to answer the 'why' question. However, there is a gap in understanding **how** an organisation (and the professionals that constitute that organisation) adjusts and adapts to the diffusion of BIM. An organisation's transformation, including the transformation of the project delivery networks they participate in, induced by adopting BIM needs further and careful scrutiny.

This guidance note attempts to answer the 'how' question. The inter- and intra-organisational implications of BIM are discussed in the form of process maps, with inputs and outputs identified. The following major dimensions, apart from the technological issues, are covered:

1. people, process and organisational issues across the entire life cycle of a project
2. the world view of major stakeholders of a project
3. guidance at the individual level as well as at the company level; and
4. inter-organisational aspects are given specific attention. The organisational transformation and changes to inter-organisational interactions induced by digital technologies in the context of the design, construction and operation of the built environment are considered.

This guidance note focuses on implementation strategies for all types of built environment projects, ranging from small and medium to large and complex projects. Section 1 provides an introduction and background to BIM in the sector as a whole. Broader sector-wide issues such as asset management, procurement management and links to smart cities are discussed. In section 2 technological aspects of BIM are described. Process- and practice-related issues of BIM are discussed in section 3, while organisational issues are described in section 4. Section 5 provides a summary of future developments in relation to BIM.

1.2 Overview of BIM

A quick online search for the terms 'building information modelling' and 'BIM' yields over 1.5 million results (even using a less than one per cent relevance factor will lead to results that are not humanly possible to process). Obviously there is no dearth of information on BIM. The real challenge is sifting through the plethora of information to gain prudent insight into the what, why and how of BIM. Nevertheless, any discourse on BIM cannot begin without providing a generic and focused overview and definition.

There is no universally accepted definition of BIM, but most sources provide a more or less similar answer to the question of 'what is BIM?'. The reason there is no accepted definition could be that BIM is ever-evolving: new areas and frontiers are creeping into the boundaries of what it could be defined as. However, there have been some exemplary definitions, some of which are provided here.

'BIM is one of the most promising developments that allows the creation of one or more accurate virtual digitally-constructed models of a **building** to support design, construction, fabrication, and procurement activities through which the building is realized.'

(*BIM handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors*, Chuck Eastman et al, 2011, emphasis added).[1]

'Building Information Modelling is a digital representation of physical and functional characteristics of a **facility** creating a shared knowledge resource for information about it and forming a reliable basis for decisions during its life cycle, from earliest conception to demolition.'

(*National BIM standard: version 2 - FAQs*, US National BIM Standards Committee (NBIMS), 2014, emphasis added).[2]

'BIM is essentially value creating collaboration through the entire life-cycle of an **asset**, underpinned by the creation, collation and exchange of shared three-dimensional (3D) models and intelligent, structured data attached to them.'

(*What is BIM?*, UK Building Information Modelling Task Group, 2013, emphasis added).[3]

'Building Information Model – Product: An object-based digital representation of the physical and functional characteristics of a **facility**. [It] serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward.

Building Information Modeling – Process: A collection of defined model uses, workflows, and modeling methods used to achieve specific, repeatable, and reliable information results from the model. Modeling methods affect the quality of the information generated from the model. When and why a model is used and shared impacts the effective and efficient use of BIM for desired **project** outcomes and decision support.

Building Information Management – Data Definition: Building Information Management supports the data standards and data requirements for BIM use. Data continuity allows for the reliable exchange of information in a context where both sender and receiver understand the information.'

(*The VA BIM guide*, US Department of Veteran Affairs, 2010, emphasis added).[4]

'BIM: building construction information model is a shared digital representation of physical and functional characteristics of any **built object** (including buildings, bridges, roads, etc.) which forms a reliable basis for decisions.'

(*ISO 29481-1:2010(E) Building information modelling - Information delivery manual: Part 1: Methodology and format*, BSI, 2010, emphasis added).[5]

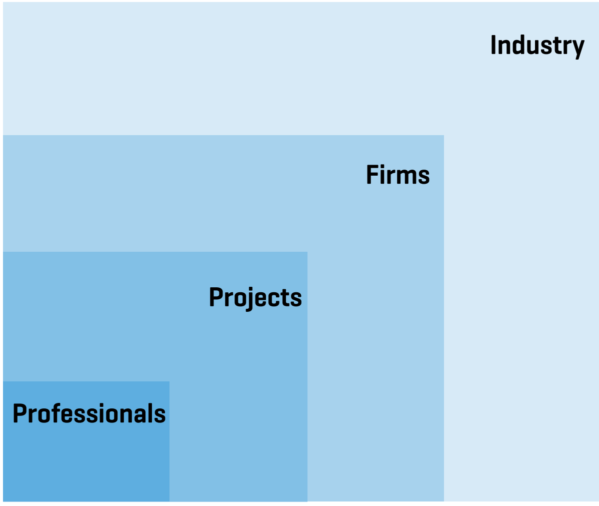
Inherent in these definitions, and also in the recent debate on BIM, are some undercurrents that need to be clearly highlighted:

- Use of the terms 'building', 'facility' or 'asset' and 'project' shows the dilemma caused by the term 'building' in building information modelling. To steer clear of confusion between 'building' as a verb and 'building' as a noun, many organisations have replaced this in their definitions with terms such as 'facility', 'project' or 'asset'.
- It is plausible that more attention is given to the term 'model' or 'modelling' rather than the term 'information'. Most discussions relating to BIM highlight that it is the information captured by the model that is more important than the model or task of modelling (while this guidance note argues that the information is dependent on the quality of the model that is developed). Some experts aptly define BIM as the 'the management of information through the whole life cycle of a built asset'.[6]
- Often the term 'model' is used interchangeably with 'modelling'. BIM is clearly about the model and process of modelling but in the end it is more than this: it is really the effective and efficient use of the model (and the information stored in the model) through an efficient modelling process. Is the model important, is the modelling process important or is the use of the model most important?
- Is it only about buildings? BIM also applies to all components of the built environment (both new and existing). BIM in the infrastructure domain is becoming common, and its use in industrial construction predates the use of BIM in buildings.
- Is BIM about information communication technology (ICT) or software technology? Has the technology matured to the extent that we can now only focus on the process- and people-related issues? Or will the technology remain intertwined with these issues?
- It is important to emphasise the shared aspect of BIM. BIM can only become a 'must have' rather than a 'nice to have' when the entire value chain embraces BIM. This can take place when technology, workflows and practices are in place to support collaborative and shared BIM.

It is clear that a holistic definition of BIM encompasses three interconnected aspects:

- **the model itself** (a computable representation of the physical and functional characteristics of the project)[7]
- **the process of developing the model** (the hardware and software used for developing

Figure 1: Broad implications of BIM



the model, electronic data interchange and interoperability, collaborative workflows and definition of roles and responsibilities of project team members in relation to BIM and a common data environment); and

- **the use of the model** (business models, collaborative practices, standards and semantics, producing real deliverables during the project life cycle).

BIM cannot be dealt with at the technology level alone as it has far-reaching implications – albeit to varying degrees – for all aspects of the built environment sector. The following major dimensions are impacted:

1. the continuum of people, projects, firms and the entire sector (as shown in Figure 1)
2. the entire life cycle of the project and world view of major stakeholders (as shown in Figure 2)
3. linkages of BIM to the underlying 'operating system'[8] of the built environment (as shown in Figure 3); and
4. the way the project is delivered, by affecting all the project processes.

Technical characteristics of a model and the process of developing a model have matured over the years. Propitiously, BuildingSMART International (BSI), a global alliance, has made significant progress in defining the computational schema needed for:

- model representation, including graphical features, properties and the behaviour of model components and content
- interoperability standards, including data representation and interchange
- agreeing to common terminology and creating unique identification codes for products, components and content
- developing an 'open' file format for storing data

Figure 2: Life cycle stages and stakeholder perspectives

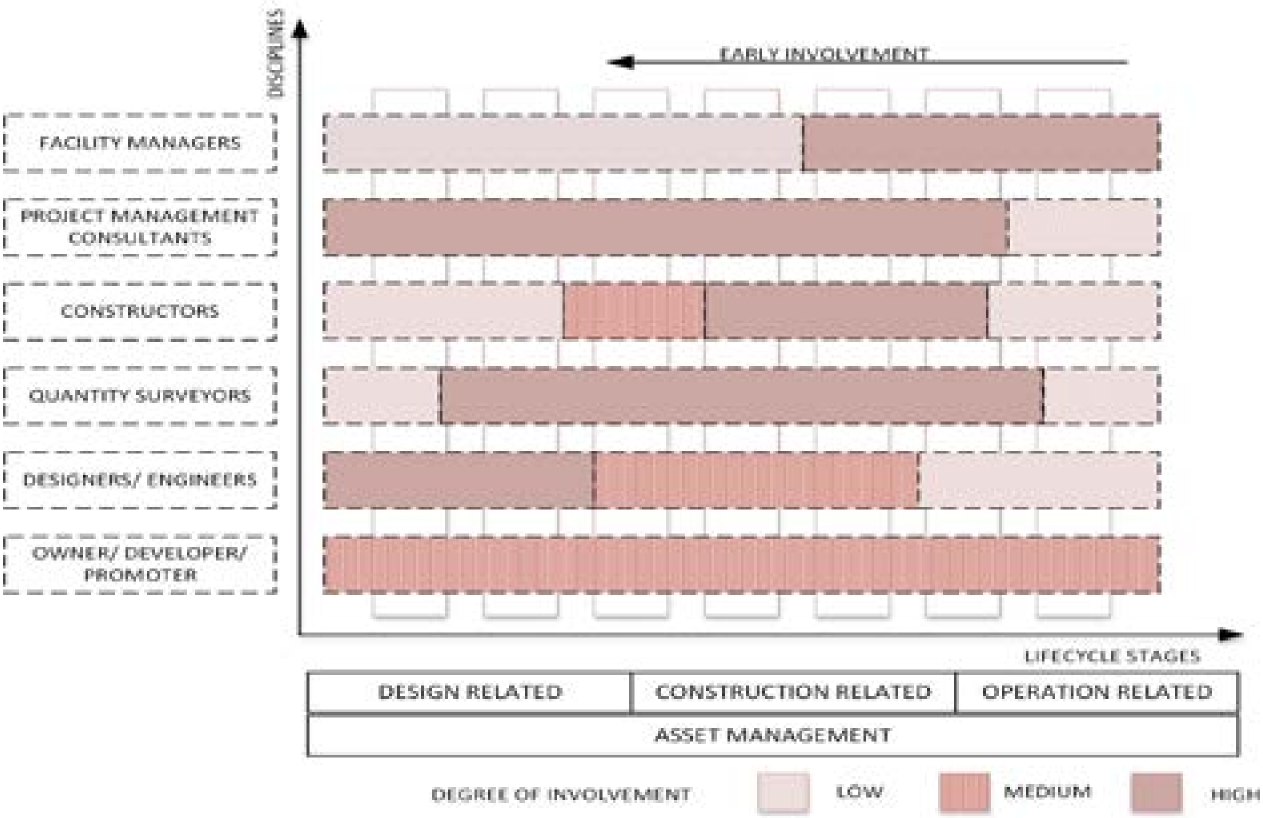
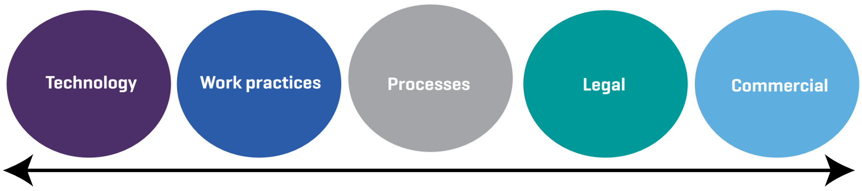


Figure 3: Impact of BIM on the operating system of projects



- creating protocols for sharing information; and
- providing a certification service for compliant software applications.[9]

1.3 Why is BIM important?

BIM is a remarkable development that has recently engulfed the built environment sector across the globe. It has provided a catalytic means for rethinking how we design, construct and operate our built environment.[10] Fundamentally a technology-driven concept, BIM, when combined with issues pertaining to people, processes and organisations, has the potential to significantly impact the industry. It has to be understood as a mechanism that allows the creation, storage and sharing of project information by a project team that is far superior to current methods of information generation, sharing and use. A quote from Chuck Eastman summarises the way BIM is viewed:

> 'The process of BIM is revolutionary because it provides the opportunity to migrate from practices that are centred around human craftsmanship to a more augmented and modern machine craftsmanship – and all that this might imply.'
>
> (*What is BIM?*, C. Eastman, 2009).[11]

Theoretically, BIM can change all that is 'wrong' with the industry, and can achieve all the lofty goals the industry has set for itself. For example, BIM can:

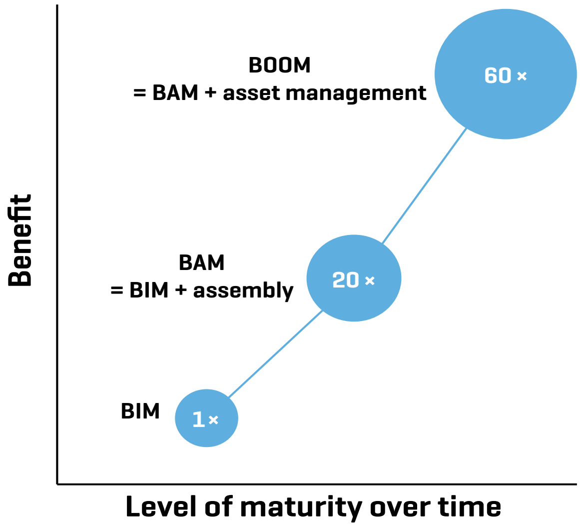
- enhance design and engineering creativity and ensure tight coupling between the design, construction and operation of the built environment
- provide analytic power to enhance project-level and organisation-level functions such as risk management, procurement management and asset management
- benefit society by reducing waste and optimising resource use and produce a greener and more sustainable built environment
- enable project-delivery networks to be more integrated by enhancing collaboration, coordination and communication
- enable project information to be more pervasive, attaining the mantra of 'information anywhere, anytime'
- enable the built environment sector to be a more knowledge-driven than skill-driven sector, allowing product orientation
- enhance the operational efficiency of the built environment by integrating and automating the facility management processes
- optimise procurement and contractual paradigms
- standardise processes and systems to attain greater profitability
- become a facilitator for the built environment sector to tap into up-and-coming technologies such as digital fabrication, cloud computing, big data and so on
- allow the built environment sector to contribute to broader societal issues such as sustainable and smart cities
- increment the intellectual and reputational capital of the industry; and
- create new business opportunities for existing and new players.

So is BIM the panacea that the industry has been looking for? This is certainly not the case. All the aforementioned revolutionary shifts that BIM theoretically allows rest on the ability of a project team to produce and use high-fidelity models that are information rich. While BIM by its very nature is less prone to mistakes, any inefficiencies that creep into the models will obviously make use of the model to yield other benefits less plausible.

From an optimist's point of view one could look at BIM as a force that allows the industry and its constituents to attain the lofty goals listed earlier. But a pessimist could look at these very same goals as impediments for BIM adoption in the industry. As a realist, it seems the industry is at a crossroads and that BIM can be used as a vehicle to steer in the right direction. A bright future is being predicted for BIM uptake. Therefore, it is crucial to carefully plan its sector-wide implementation, especially for small and medium enterprises (SMEs).

If deployed correctly, BIM could allow the built environment sector to attain the same kinds of productivity gains that have been seen in other sectors, such as manufacturing. Patrick MacLeamy, Chairman and CEO of HOK, has produced a graphical illustration of how BIM maturity level can grow and impact the industry in a significant way. As shown in Figure 4, MacLeamy predicts a 20-fold to 60-fold

Figure 4: Future of BIM



Adapted from The future of the building industry: BIM-BAM-BOOM! Presentation by Patrick MacLeamy.[12]

increase in benefits if deployed in a holistic fashion. From current levels, a 20-fold increase is possible by using BIM along with digital fabrication and assembly. An increase to a 60-fold benefit is possible when BIM and digital fabrication and assembly are coupled with a BIM-driven asset management worldview.

1.4 Status of BIM adoption globally

At the time of writing, the built environment sector was inundated with information and initiatives relating to BIM.

BIM as a technology is not new. The key shift happened around 15 years ago when researchers and practitioners realised that technology alone would not be sufficient for attaining success and that interrelationships between people and processes must also evolve with technology in order to produce a feasible implementation scenario. In recent years this amalgamation of technology, people and processes that BIM allows has taken root in both research and practice.[13]

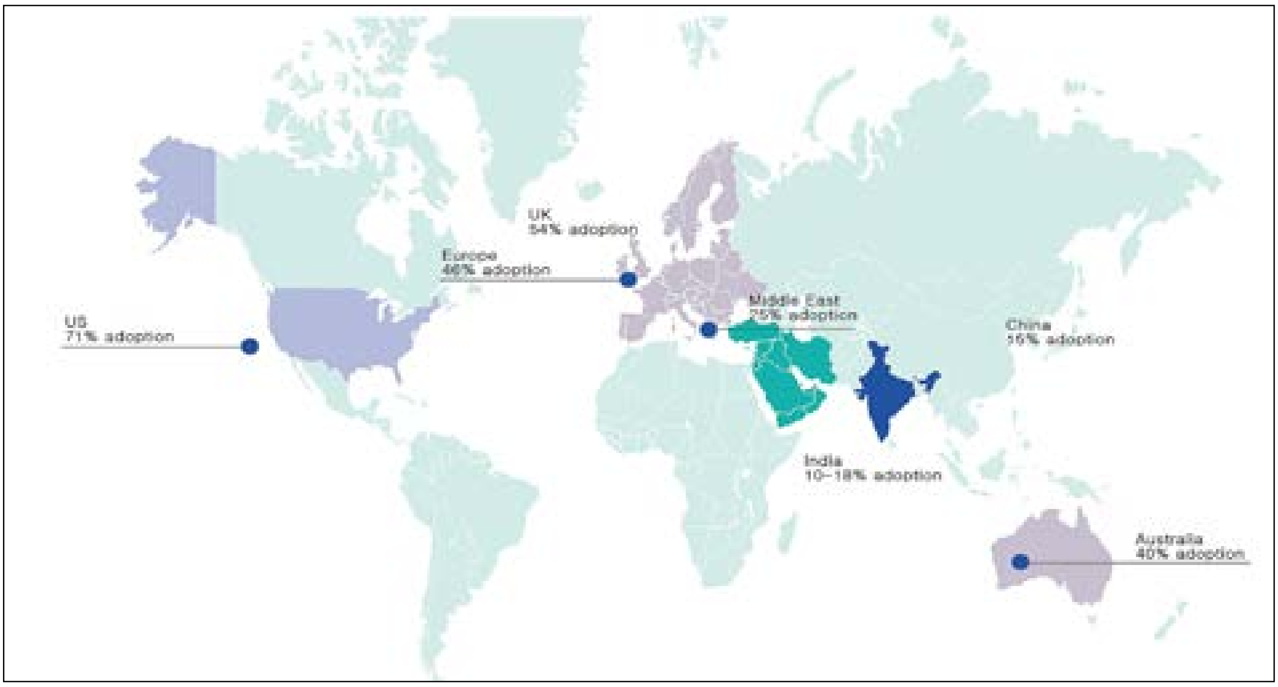
While the idea of BIM as a technology has been around for over a decade, it is only recently that, via discussion of people and process issues, it has become popular in the industry and among researchers. This shift is less than a decade old with many researchers and practitioners reporting the beginning of the 'BIM age' between 2005 and 2008.[14, 15] A flurry of activity surrounding BIM is evident in the industry and in academia in the USA and the UK.[16, 17, 18]

BIM is now widespread around the globe, with many nations reporting that BIM is affecting their respective industries at various levels. The construction industry in the developed world is rushing to embrace BIM as a catalyst for gaining operational efficiencies, with BIM adoption increasing tremendously in the last three to five years. Annual surveys are being conducted to document the state of affairs, and national-level initiatives are in place to produce BIM standards and guidelines.

Research activity focusing on BIM has also increased. Most of the information available in the research literature and industry publications is therefore primarily focused on a select few countries, mostly from the developed world.

Developing countries have not yet arrived on the scene. This may seem contradictory: the volume of

Figure 5: Status of BIM adoption globally

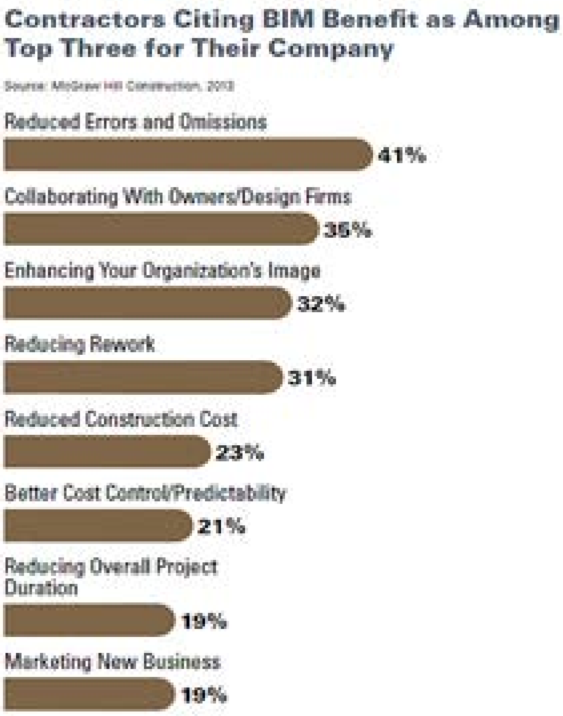


construction is poised to increase, and the gains that can be achieved from using BIM in developing countries could be enormous.[19] The state of research, education and practice pertaining to BIM in the rest of the world, especially the emerging markets, remains largely undocumented. With a significant shift in construction output expected towards emerging markets, it is prudent to explore the topic of BIM from their perspective.

A recent McGraw Hill report entitled *The business value of BIM for construction in major global markets*[20] provides a very broad and updated view of the status of BIM in important markets around the globe (see Figure 5). It summarises the status of BIM adoption over the last three to five years in Canada, France, Germany, the UK and the USA, which are considered to be mature markets. New market areas such as Australia, Brazil, Japan, New Zealand and South Korea are also covered, and some preliminary information on BIM adoption in China and India is also presented. Overall the report suggests a robust uptake of BIM globally, with the USA and Scandinavian countries taking the lead. The UK has also made significant strides, although it was a late starter. The report highlights the imminent positive changes in the industry, especially led by contractors globally.[21] The key findings of this study are:

- construction companies have reported a positive return on investment with more savings expected in the future
- the volume of construction companies' work using BIM will increase by 50 per cent by 2016

Figure 6: Benefits of BIM



Courtesy of McGraw Hill Construction, *The business value of BIM for construction in major global markets*. New York, NY, 2014.

- experience, skill level and commitment are crucial to successful BIM implementation; and
- increased investment in BIM is expected.

At the project level numerous benefits can be attained by using BIM. Project team members report that BIM allows improved visualisation, better coordination (including clash detection and resolution) and reduced rework. The study captures the top benefits of BIM adoption by companies globally, as shown in Figure 6.

1.5 National initiatives on BIM

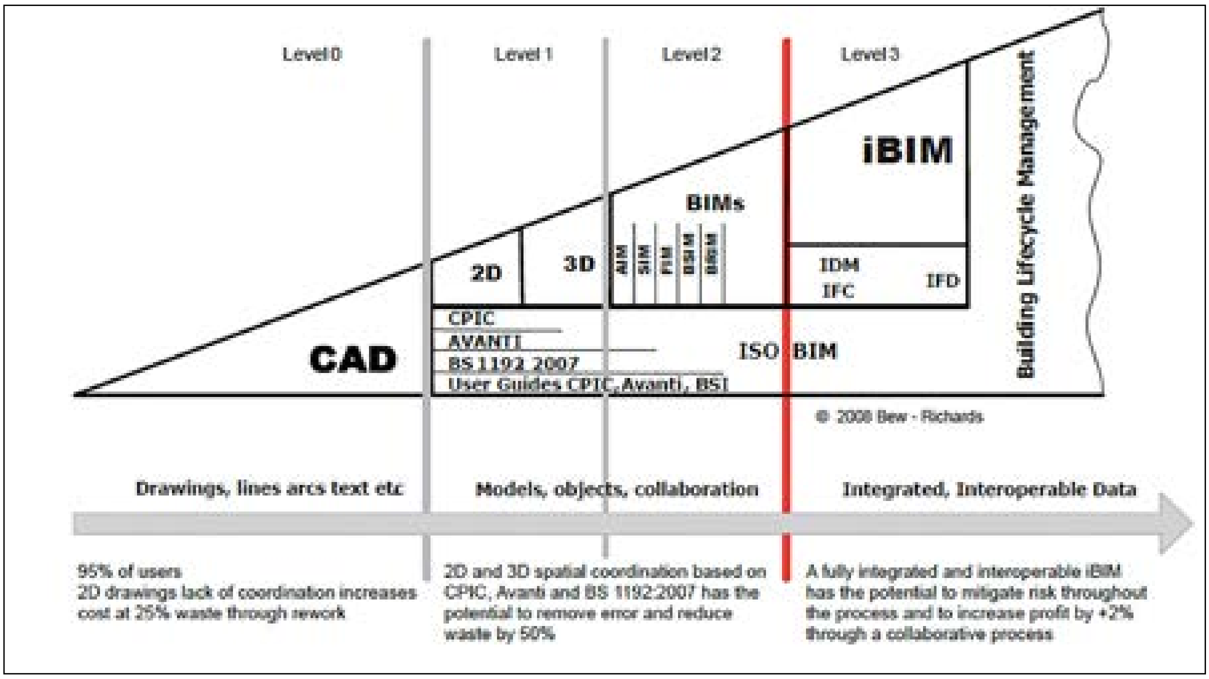
One of the significant drivers of BIM adoption and use is government intervention and support (though this is debatable, as some experts are not keen to see too much government intervention). Numerous efforts have been reported in the literature that show national-level, concentrated effort to reap the benefits of BIM. The USA, the UK and Scandinavian countries are at the forefront of these national initiatives.

In the USA the National Institute of Building Sciences (NIBS) began looking at BIM through its Facility Information Council in 1998. In 2007 the National BIM Standard (NBIMS)-US Project Committee (a project committee of the buildingSMART alliance of NIBS) prepared the National BIM Standard, and currently version 2 of this standard is available. This is probably the first known national effort, similar to the development of a national computer-aided design (CAD) standard, which was primarily led by a government at the national level. More or less simultaneously, the US General Services Administration (GSA) also launched its National 3D-4D-BIM Program in 2003.

In the UK BIM progressed fairly slowly until the UK government's BIM Task Group released its BIM Policy in May 2011. This has been called the BIM 'light bulb moment'[22] for the UK construction sector. Now the UK is considered to be leading the way, influencing global BIM initiatives.[23]

One of the key contributions of UK BIM activities is the BIM maturity model (known as the Bew-Richards BIM maturity model; see Figure 7).[24] This ramp model demonstrates a systematic transition of BIM maturity levels in the industry. At level 0 the delivery and operation of projects/assets relies on two-dimensional (2D) information that is primarily paper-based, leading to inefficiencies. Level 1 is a transition level between a paper-based environment and a 2D and 3D environment, with a shifting focus on collaboration and information sharing. At level 2 a common method of producing, exchanging, publishing and archiving information is used. Consistently along the level 2 ramp, added intelligence and metadata begins to be included in the model. However, models are discipline-centric and proprietary and as such this level is sometimes referred to as 'pBIM'. Model integration takes place on the basis of a common data environment (CDE). Level 3 achieves a fully integrated 'iBIM', marked by the use of a single model that is accessible to all the team members.[25]

Figure 7: Bew-Richards BIM maturity model[27]



Reproduced with permission from Mark Bew and Mervyn Richards.

Attaining level 3 is envisaged as an open-ended level of maturity, leaving room for further advancing BIM and information technology.

Alongside the maturity model, the UK government has introduced the concept of government soft landings (GSL), to be mandated in 2016 in alignment to BIM level 2.[26] Through GSL the government is facilitating closer alignment of design and construction with operation and asset management. GSL will ensure that a focus on the asset purpose is maintained from design and construction through to delivery and operation. It ensures early engagement of the end user. Design and construction teams assist the end user after completion of the operation of the asset, along with post-occupancy evaluation and feedback.

In other parts of the world similar activity is reported. Table 1 summarises these initiatives in major parts of the world.

1.6 Why BIM is important for industry professionals

BIM is an important concern for industry professionals. It is evident that most professional bodies in the built environment domain around the world are helping their members to develop a deeper understanding of BIM, with enhancements and embellishments in areas that connect with their members (the most notable being the Royal Institute of British Architects (RIBA; which revised and issued a RIBA Plan of Work 2013 with a BIM overlay), the Institution of Civil Engineers (ICE) and RICS).

The message is loud and clear: BIM is here to stay – it is not a case of if, but when. BIM allows built environment professionals do their jobs better, with greater collaborative input. Through guidance and training, RICS plans to empower these professionals, allowing them to seize the opportunities that BIM provides. This guidance note forms part of that initiative.

1.7 BIM and its links to other paradigms in the industry

The built environment sector is striving to be a highly efficient, quality-centred, socially responsible and bullish industry capable of successfully delivering the requirements of current and future generations.[38] BIM can play a strategic role in this transformation, but it is naïve to assume that BIM alone (if at all) can make such sweeping changes. But it is clear that BIM, along with other complementary paradigms such as lean principles, off-site construction, integrated project delivery, sustainability and smart cities,[39] can provide the necessary impetus.

As shown in Figure 8, BIM is a core activity that acts as a gear, turning other paradigms into motion. For example, a 2013 report by the UK Commission for Employment and Skills stated that:

> 'Offsite is an opportunity to more tightly control costs, respond to government targets for Building Information Modelling (BIM) and energy efficiency, increase efficiency in the build process and improve quality (including site health and safety).'
>
> (*Technology and skills in the construction industry: Evidence report 74*, Vokes et al, 2013).[40]

Table 1: Summary of select national BIM initiatives[28]

Australia

BIM adoption in Australia is increasing. Proponents are pushing for stronger cooperation between government and industry to increase the adoption and resultant benefits of its use. The Sydney Opera House is often cited as an exemplar BIM project that captures the benefits of using BIM in the management of existing buildings.

According to the *National building information modelling initiative* (BuildingSMART Australasia, 2012), over the next three years the Australian government plans to:

- By 1 July 2014:
  - a) develop national BIM contracts.
  - b) encourage BIM training to be included in tertiary-sector education (both professional and vocational).
  - c) develop protocols for information exchange to enable reliable communication between sectors.
  - d) facilitate integrated access to land, geospatial and building information by coordinating activities between relevant sectors.
- By 1 July 2015:
  - a) develop national technical codes and standards, and align these with international counterparts.
  - b) develop a model-based building regulatory compliance process demonstrator.
  - c) plan the transition of national regulatory codes and compliance mechanisms to model-based performance systems.
- By 1 July 2016:
  - a) the Australian government will require BIM for its built environment projects.
  - b) state/territory governments and the private sector will also be encouraged to require BIM for all built environment projects.[29, 30]

Singapore

By 2014:

- It will be mandatory for all new building projects of at least 20,000m^2 to have engineering BIM e-submissions.

By 2015:

- It will be mandatory for all new building projects of at least 5,000m^2 to have engineering BIM e-submissions.
- A general target is for BIM to be used widely in the Singapore construction industry.
- The Singaporean government is mandating BIM, offering incentives to early adopters; the goal is increased industry adoption, and ultimately full BIM submissions by 2015.

By 2020:

- Achieve a highly integrated and technologically advanced construction industry, with cutting-edge firms and a skilled and proficient workforce.[31, 32, 33, 34]

China

China is witnessing a strong uptake of BIM and most entities engaged in the built environment sector seem well positioned to adopt BIM quickly. Large investments in infrastructure propelled by strong overall economic growth are providing a good platform for BIM adoption. There is strong government support for increasing BIM adoption. BIM was included in the National 12th Five Year Plan (2011–2015). A BIM framework is being formulated.[35]

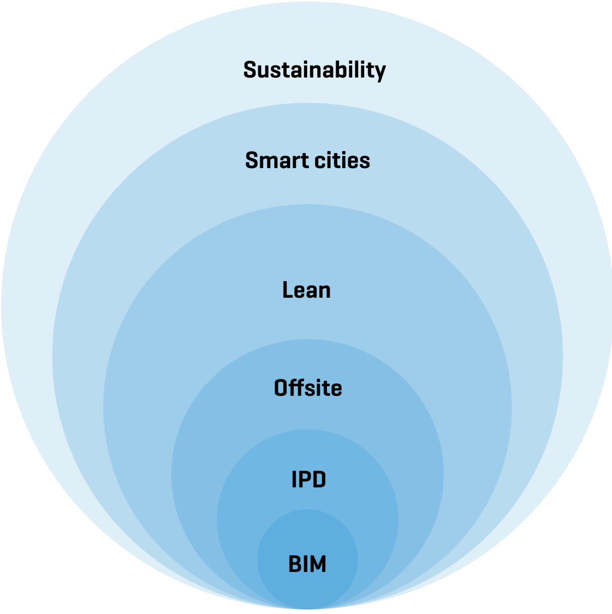
Hong Kong

Hong Kong Housing Authority has set a target to apply BIM in all new projects by 2014. A BIM Academy is planned in the first quarter of 2014, to provide education, assessment and certification for BIM professionals in the country.[36]

Finland

Finland provides a strong innovation culture for companies engaged in the built environment sector. Research and development in the area of BIM have been most notable in Finland. BIM maturity level is more advanced here than anywhere else in the world. Finland has an agile construction industry with a long history of trust and open standards, making BIM adoption easier. No official government mandate on the use of BIM but it is being used as a response to the need of architecture, engineering and construction firms for a more advanced technology than CAD.[37]

Figure 8: BIM and other complementary paradigms



The interconnections between paradigms are clearly evident. But many professionals and firms are looking at these in a disjointed manner; that is, with a 'take it one at a time' strategy.[41] It is important that a holistic view is considered to ensure that suboptimal solutions are not attained. In subsections 1.7.1 to 1.7.5, descriptions of these interconnections are explained in order to help professionals and organisations attempting to embrace improvements look at BIM in a more holistic fashion.

1.7.1 BIM and lean

Lean thinking, with its roots in the Toyota Production System (TPS), revolves around the bedrock principles of continuous improvement (*kaizen*) and respect for people. Using the 'challenge everything' and 'embrace change' mindset, an organisation or even an entire industry can systematically adopt lean principles in their core business processes.[42] Waste elimination and waste elimination tools can be viewed as a shallower interpretation of lean, as lean principles run much deeper. Understanding the importance of these principles, the construction industry is embracing them by reincarnating them as 'lean construction'. Aptly stated, lean construction is:

> 'the pursuit of concurrent and continuous improvements in design, procurement, construction, operations and maintenance processes to deliver value to all the stakeholders'.
>
> (*The Construction Industry Research and Education Center (CIREC)*, Michigan State University, 2006).[43]

Proponents of lean construction feel that BIM is a lean tool and claim that there are four major links between lean and BIM:[44, 45]

1. BIM contributes directly to lean principles by reducing waste[46]
2. BIM-based methods and tools can be developed and used for realising lean principles
3. lean principles and methods can be supported/ facilitated through BIM; and
4. lean principles facilitate the introduction of BIM.

A strategic, tactical and operational effort is required to combine lean and BIM.

1.7.2 BIM and off-site construction

As demand on the construction sector increases, especially in emerging economies, off-site construction techniques will be increasingly relied on. Off-site or industrialised construction offers benefits such as faster construction, better quality, lower costs and fewer workers needed on-site.[47, 48] These technologies are proving to effectively address all three dimensions of sustainability: environment, economic and social. Although mainstream acceptance of off-site construction is still problematic, supporters contend that it drives operational efficiencies and reduces waste:

> 'not just on site, but throughout the design and manufacturing processes, which are optimized through computer aided design and manufacturing and fully or semi-automated production lines'.
>
> (*Sustainable steel construction*, Burgan and Sansom, 2006).[49]

It is suggested that BIM will play a crucial role in mainstreaming off-site construction, which will reap the many benefits of this technology. By allowing experimentation of off-site technologies in the design process, BIM can act as a catalyst. There is a significant overlap between BIM and off-site construction that organisations and professionals need to look at.

1.7.3 Integrated project delivery

The American Institute of Architects (AIA) defines integrated project delivery (IPD) as:

> 'A project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction'.
>
> (*Integrated project delivery: A guide: Version 1*, AIA, 2007).[50]

BIM is one of the most powerful tools/processes supporting IPD.[51] IPD processes work hand in hand with BIM and leverage its capabilities. Generally it is felt that BIM facilitates IPD by allowing better coordination, collaboration[52] and communication within the project team.

1.7.4 Sustainability

BIM allows the project team easier access to model-driven analysis that is otherwise quite cumbersome or sometimes impossible to perform. Through this type of analysis the design, construction, commissioning and operation of the built environment with lower environmental impacts is now possible. With the help of BIM improvements in energy efficiency, reduction in carbon footprint and effective use of materials can be achieved.[53, 54]

Selection of design alternatives becomes more robust in a BIM environment. Early in the project life cycle analysis-based design decisions can be performed by the design and engineering teams. Sharing of data and information in a model-centric environment drives the project team to look for sustainable design solutions. The information-rich environment allows rapid access to metrics such as embodied energy, early cost estimates and other quantifiable parameters.[55]

1.7.5 Smart cities

BIM is not limited to a single asset: it can also be used to develop an information-rich model at the district, precinct or city level. These models can become the foundation or digital 'DNA' of smart cities.[56] Smart cities have spatial, physical, digital, commercial and social dimensions.[57] Built environment professionals can contribute through information-rich 3D modelling to the ultimate realisation of the smart city concept.

BIM for a smart city framework requires use of data standards such as CityGML, LandXML and Industry Foundation Classes (IFC). BIM provides one of the key pieces of information for the smart city concept, but it alone cannot deliver everything. The city model needs to be linked to a variety of other data sources such as geospatial data, sensor data, transactional data from citizens, and statistical data.

2 BIM as a technology

At its core, BIM is an ICT that is driven by the fundamental principles of CAD. It uses the technological advances made in the area of 3D modelling, especially from the product development and manufacturing sector. In order to understand BIM it is crucial to have a basic understanding of the core technology that drives it. In this section the technological aspects of BIM are described from an end-user perspective.

2.1 Technology behind BIM

A building information model is a centralised electronic repository of information pertaining to the physical and functional aspects of a project. The repository of this computable information evolves over the project life cycle. The information is used in many ways in the BIM process, some directly and some derived, calculated and analysed. For example, a 3D representation of a project is the most common visual extraction of this information. Similarly, a schedule of doors and windows in the building being designed is another incarnation of the information from the central repository. The way this information is collected, stored, edited, managed, retrieved and handled is important for the success of the BIM process.[58] For this, a built environment project can be considered as a large collection of interconnected objects (e.g. walls, doors, girders, ducts, pumps, etc.). The underlying ICT technology that supports BIM also uses object-orientation in performing the aforementioned tasks. Essentially BIM can be considered as a collection of 'smart' objects stored in an 'intelligent' database.

Traditionally, CAD software internally represents data using geometric entities such as points, lines, rectangles, planes and so on (as shown in Figure 9).[59] The drawback of this approach is that, while the system can accurately describe geometry in any domain, it cannot capture domain-specific information about objects (e.g. properties of a column, hosting of a door or window in a wall, location of the pipe rack etc.). This can be

Figure 9: Object representation in BIM[61]

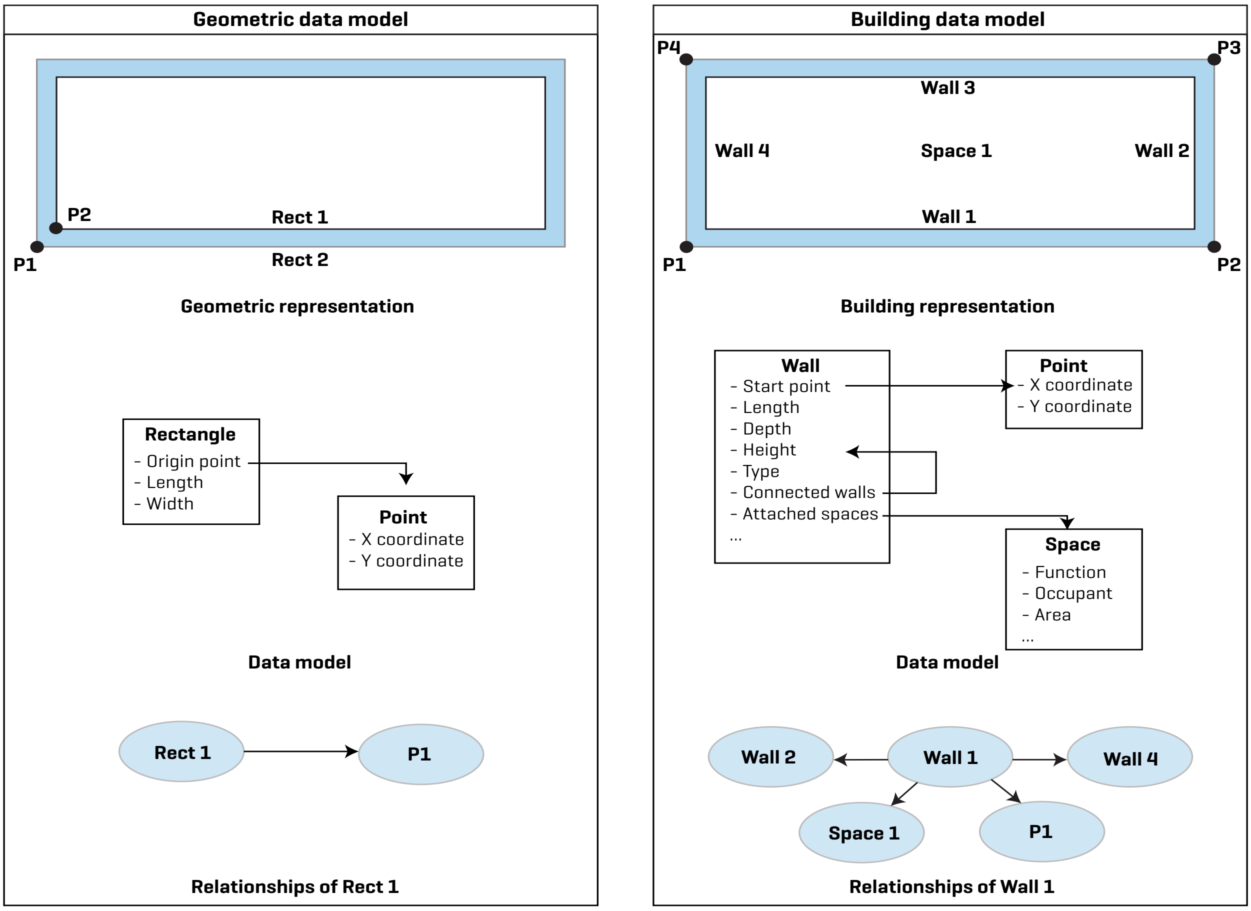


Image reprinted with permission from AECbytes (www.aecbytes.com).

described as ‘dumb’ CAD, which constrains the use of this approach in the built environment sector.

Geometric information alone is not capable of the project representation that is needed for the entire BIM process. Here is where the technology has shifted to using object-based representation that is specific to the domain.[60] In the case of the built environment sector, this translates to a representation schema that is modelled around project entities and their relationships to one another (as shown in Figure 9). For example, while defining a wall object, geometry is only one of the properties, among others, of these building elements. In this example, a room consisting of four walls, in addition to geometric information, has information such as connected walls and attached spaces. This is sometimes referred to as the ‘building representation’ referring to the domain-specific nature of the information embedded in the objects.

With this type of domain-specific object representation, one can first store and then extract useful information. For example, because of the encapsulation of appropriate relationships to walls, ceilings and floors, information about the attached or enclosed space can be extracted. This information about spaces can be used for programme analysis and energy and egress analysis in the BIM process.

This clearly highlights the importance of object orientation in BIM. Objects used in BIM are further enhanced by the addition of:

- Object properties or attributes: these allow storage of useful information about the object in the model; for example, wall thickness, wall material, thermal conductance of the wall and so on. Object properties or attributes are needed to interface with analyses, cost estimations and other applications. Figure 10 shows a basic wall object with its properties in a BIM-authoring environment.
- Parametric characteristics of the object: these allow some degree of automation in the modelling process; for example, defining a parameter that captures the design intent that the centre of a hole in a steel plate is midway between its horizontal edges. When a modeller uses this plate in the model and defines the size of the plate, the location of the hole is automatically set using the parametric characteristic of the object. This allows an object in a BIM environment to update itself as its context changes. This is called its behaviour.

Through a combination of these enhancements, rich modelling features can be meaningfully derived. For example, wall objects in a room can be related to each other, doors and windows can be hosted in the wall, rules related to the relationships between objects can be defined and automated generation and revision of schedules can be performed. Figure 11 shows these features exploited in a BIM environment. In modern BIM environments the user has the capacity to extend the modelling behaviour of objects by adding user-defined

Figure 10: Building object in a BIM tool

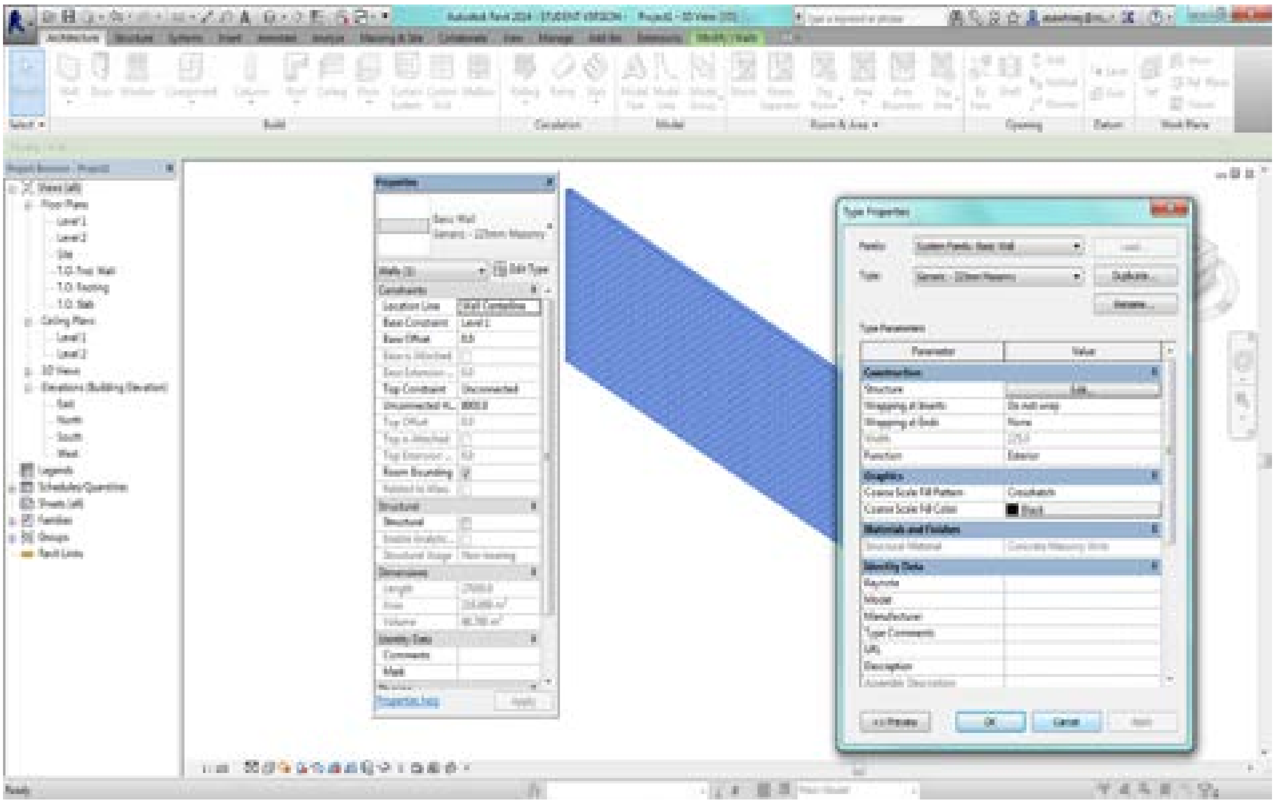


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Figure 11: Behaviour of objects in BIM

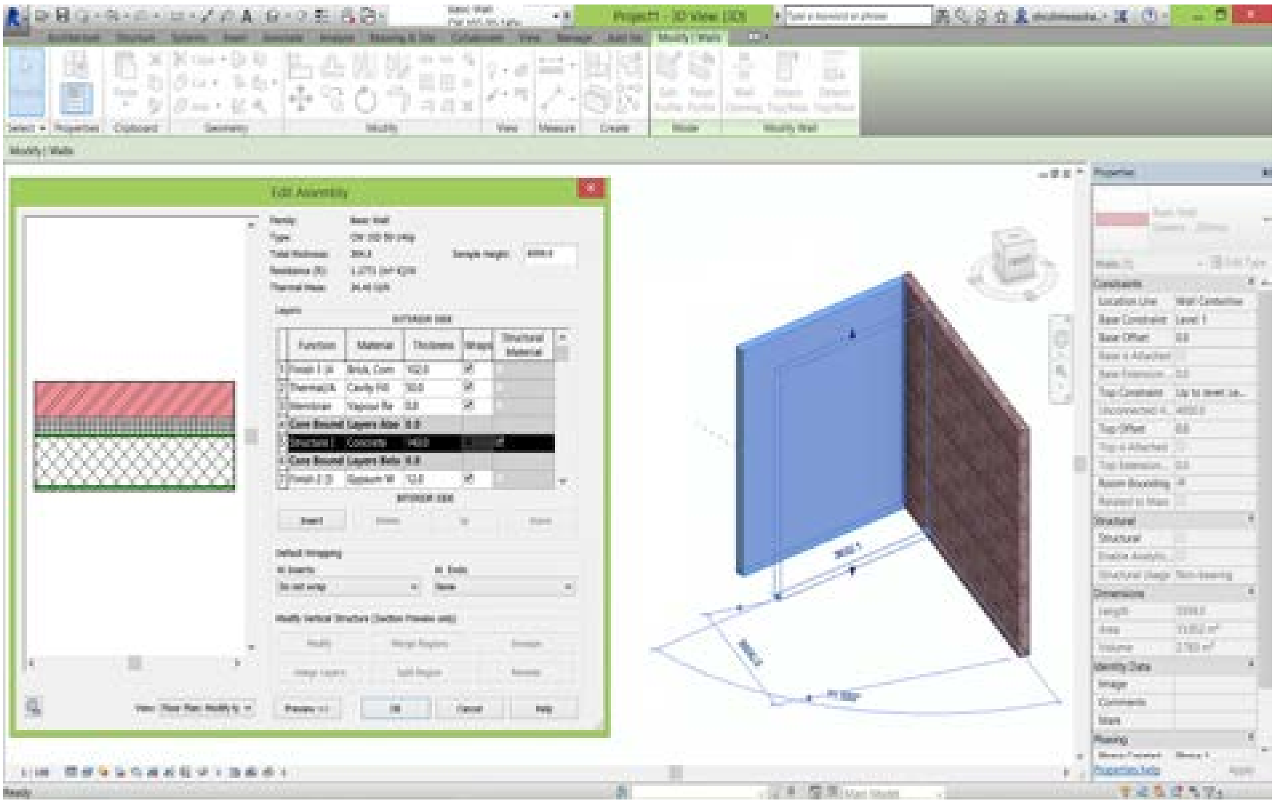

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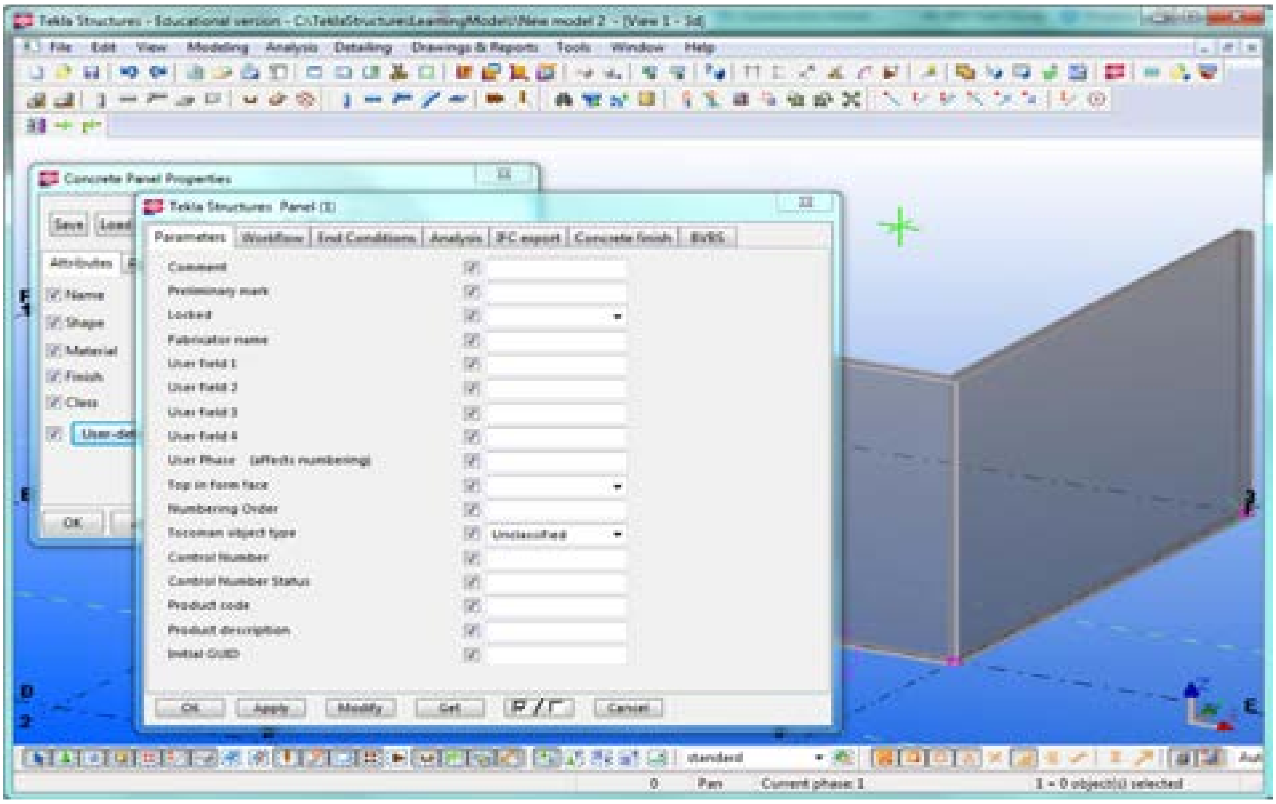
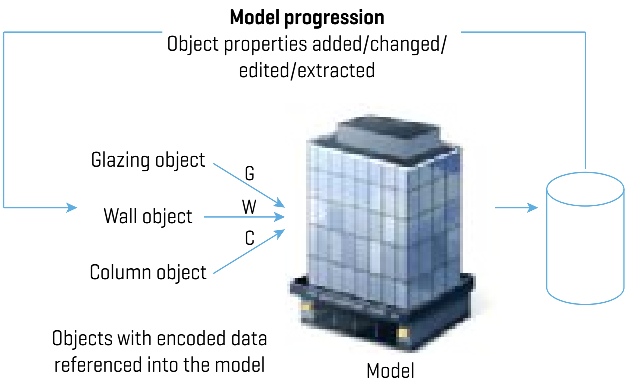
Figure 12: User-defined properties and attributes



Courtesy of Tekla. Tekla is a registered trademark of Tekla Corporation.

Figure 13: Model progression in a BIM environment



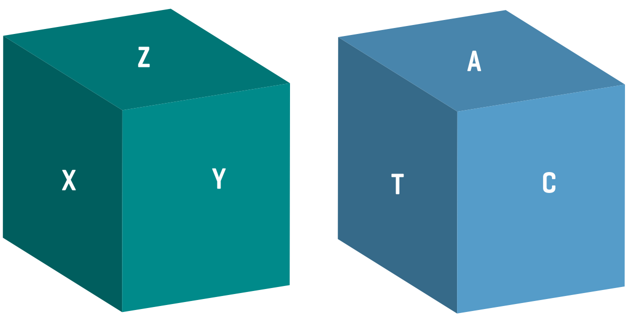
Adapted from *Automation in Construction*, 18/3, B. Succar, Building information modelling framework: A research and delivery foundation for industry stakeholders, 357–375, © [2009], with permission from Elsevier and Bilal Succar.[62]

Figure 14: Dimensions of BIM

X & Y	=	2D
X, Y & Z	=	3D
3D + B + P	≈	BIM
BIM + time	≈	4D CAD
BIM + cost	≈	5D CAD
BIM + sustainability	≈	nD CAD

B = behaviour; P = parametric properties

Figure 15: Six dimensions of BIM



Key:
Y, Y, Z: the three spatial dimensions
T: the time dimension, for construction sequencing
C: the cost dimension, quantities and rates
A: associated information, including specification

Adapted from Growth through BIM, R. Saxon, 2009, © Construction industry council[63]

properties and attributes, as shown in Figure 12.

In Figure 13, the conceptual idea of smart objects in a BIM database is shown. Using the smart objects, their properties, parametric design and behaviour, model progression in a BIM environment is accomplished. Using the central repository of information, various members of the project team in different project life cycle phases can add, edit or extract information from the repository.

As additional information is added to the objects, the model becomes richer. In this context the literature classifies BIM as 4D, 5D, 6D and 7D (albeit with some differences in terminology in different parts of the world) as shown in Figure 14 and Figure 15.

2.2 Data representation and exchange standards

Fundamental to the attractiveness of BIM as a way to transform the built environment sector is its ability to inherently allow collaboration, coordination and communication between the various stakeholders in the project-delivery network. This is easier said than done: in a practical sense this would mean a neutral or open-source data-representation format that would allow seamless electronic exchange of information. A plethora of design and analysis software with overlapping data requirements are used in the built environment sector, each using a proprietary form of data representation. On an individual level, each software tool, while subscribing to the object-orientation that was described in subsection 2.1, may internally store the object data in a proprietary format, hindering the interoperability of software, and rendering the promise of collaboration, coordination and communication untenable. This lack of software interoperability has been a major cause of slow BIM adoption in the built environment sector.

In a general context interoperability is defined as the ability of software and hardware, on multiple computing platforms from multiple vendors, to exchange information in a useful and meaningful manner. In the construction context interoperability is the ability to use, manage and communicate electronic product and project data between project participants in the design, engineering, construction, maintenance and related business processes.[64]

Additionally, it is crucial to highlight that data for the built environment sector can be drawn from multiple sources. For example, geospatial data is used in the design and construction processes of the built environment sector. Additionally, data can also be both in the form of graphical data, text data and linked data.

Technically, interoperability in BIM parlance can be achieved by using an open and publicly managed schema (dictionary) using a standard schema language. A schema is a description of the formal structure of a defined set of information. This is generally defined using a schema language, the most common being extensible markup language (XML) and EXPRESS. A number of such schemas exist but only a few have reached the acceptance and maturity levels to make them worthy of consideration. Data representation and exchange formats developed by BSI (and buildingSMART alliance which is the North American arm of BSI) and Construction Operations Building Information Exchange (COBie) have received wide industry acceptance and are in current use.

2.2.1 BSI overview

BSI is an industry body consisting of both public sector and private sector partners that have come together to provide technical expertise to develop standards which can provide open and public data representation and exchange in the built environment sector.

The buildingSMART alliance is the North American chapter of buildingSMART International, a neutral, international and unique organisation supporting open BIM throughout the life cycle. BSI has regional chapters in Asia, Australia, Europe, the Middle East and North America. The work that has resulted in industry-accepted standards was originally started by its parent organisation, the International Alliance for Interoperability (now renamed BSI) in 1995.

To allow the use of BIM in the industry there needs to be a common 'language' that defines the objects which make up a built environment sector project. To provide such a robust, scientific and standardised platform, essentially the following four things are provided by BSI:[65]

1 data model or Industry Foundation Classes (IFC)

2 data dictionary or BuildingSMART Data Dictionary (bSDD)

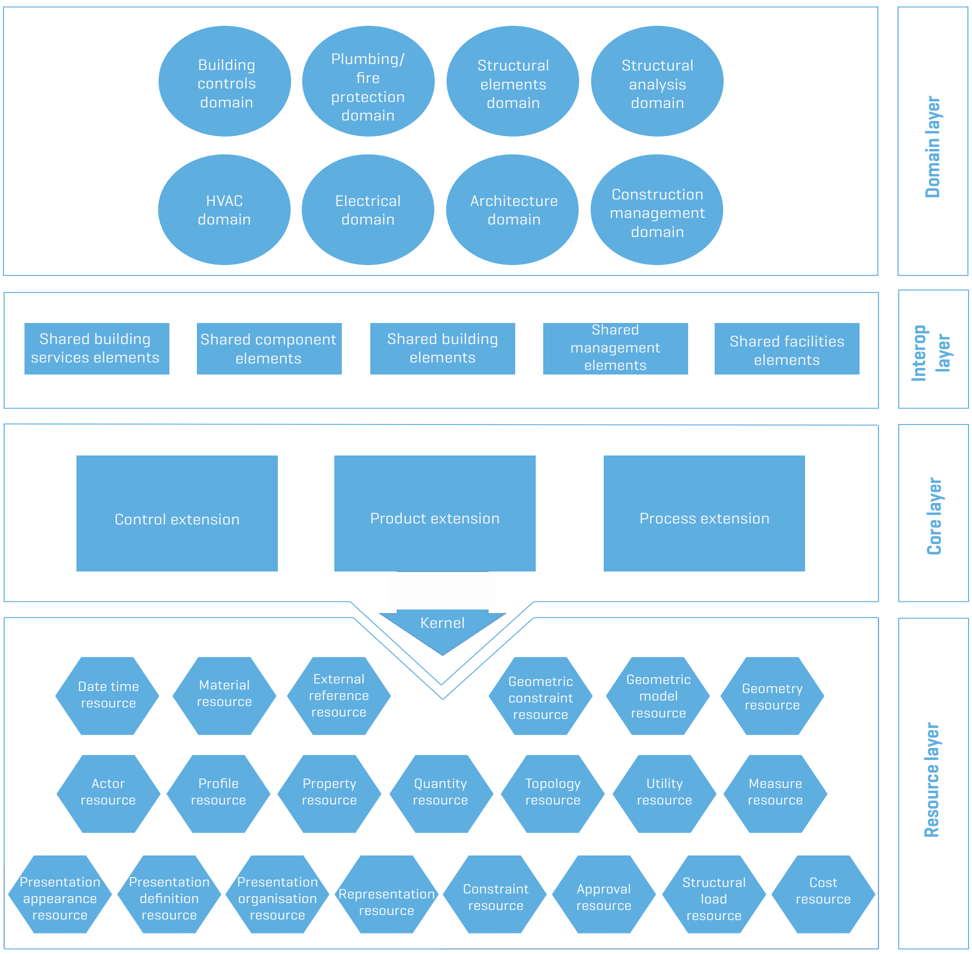
3 data processes or Information Delivery Manual (IDM); and

4 model view definition (MVD).

2.2.1.1 Industry Foundation Classes (IFC)

The IFC specification is a neutral data format used to describe, exchange and share information in the built environment sector. IFC is the international standard for openBIM and is registered with the International Standardisation Organisation (ISO) as ISO 16739, *Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries* (2013).[66] The overall structure of IFC is shown in Figure 16.

Figure 16: Core structure of IFC



IFC consists of four major layers. The conceptual schema is defined in EXPRESS data specification language. Using this language, objects such as wall, window, duct and so on are defined. In Figure 17 a partial structure of the IfcWall object defined in this schema is shown. Figure 18 shows an example of a wall instance created using the IfcWall object.

2.2.1.2 Data dictionary or BuildingSMART Data Dictionary (bSDD)

The bSDD is a protocol that allows for the creation of multilingual dictionaries. It is a reference library intended to enhance interoperability in the built environment sector and is one of the core components of the BSI data standards programme.[67] The idea of bSDD is simple in that it provides a comprehensive multilingual dictionary of terms used in the built environment sector, as shown in Figure 19.

2.2.1.3 Data processes or information delivery manual (IDM)

IDMs provide detailed specifications for the information needed for all the processes in the project delivery life cycle. They encapsulate and progressively integrate business processes of the built environment sector. IDMs specify the nature and timing of information that various project team members need to provide during the project life cycle.[68] To further support the information exchange, IDMs also propose a set of modular model functions.

2.2.1.4 Model view definition (MVD)

Model view definitions (MVDs)

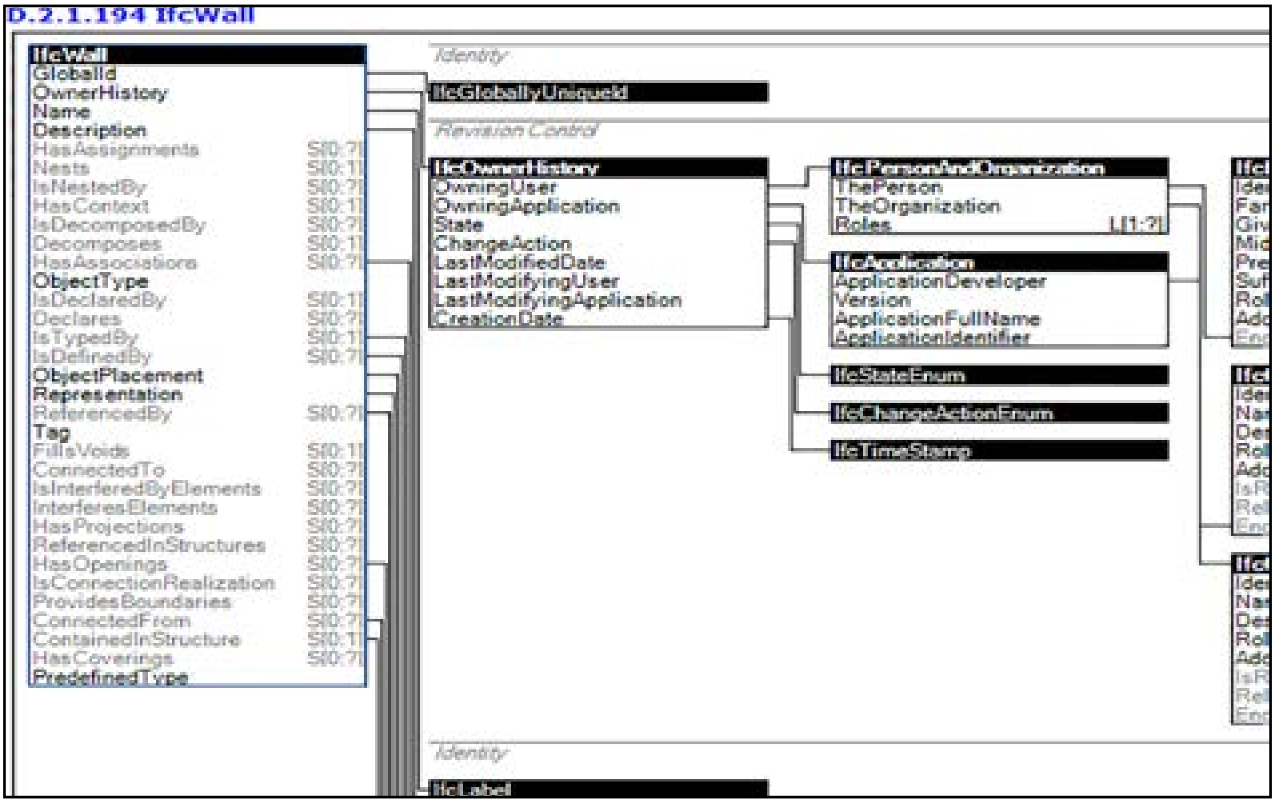
> 'define the subset of the IFC data model that is necessary to support the specific data exchange requirements of the built environment sector during the entire life cycle of a project'.
>
> (*bSI standards and solutions*, BuildingSMART, 2014)[69]

They provide implementation guidance for all IFC concepts (classes, attributes, relationships, property sets, quantity definitions, etc.) used within a particular subset. They thereby represent the software requirement specification for the implementation of an IFC interface to satisfy the data/information exchange requirements.

2.2.2 COBie

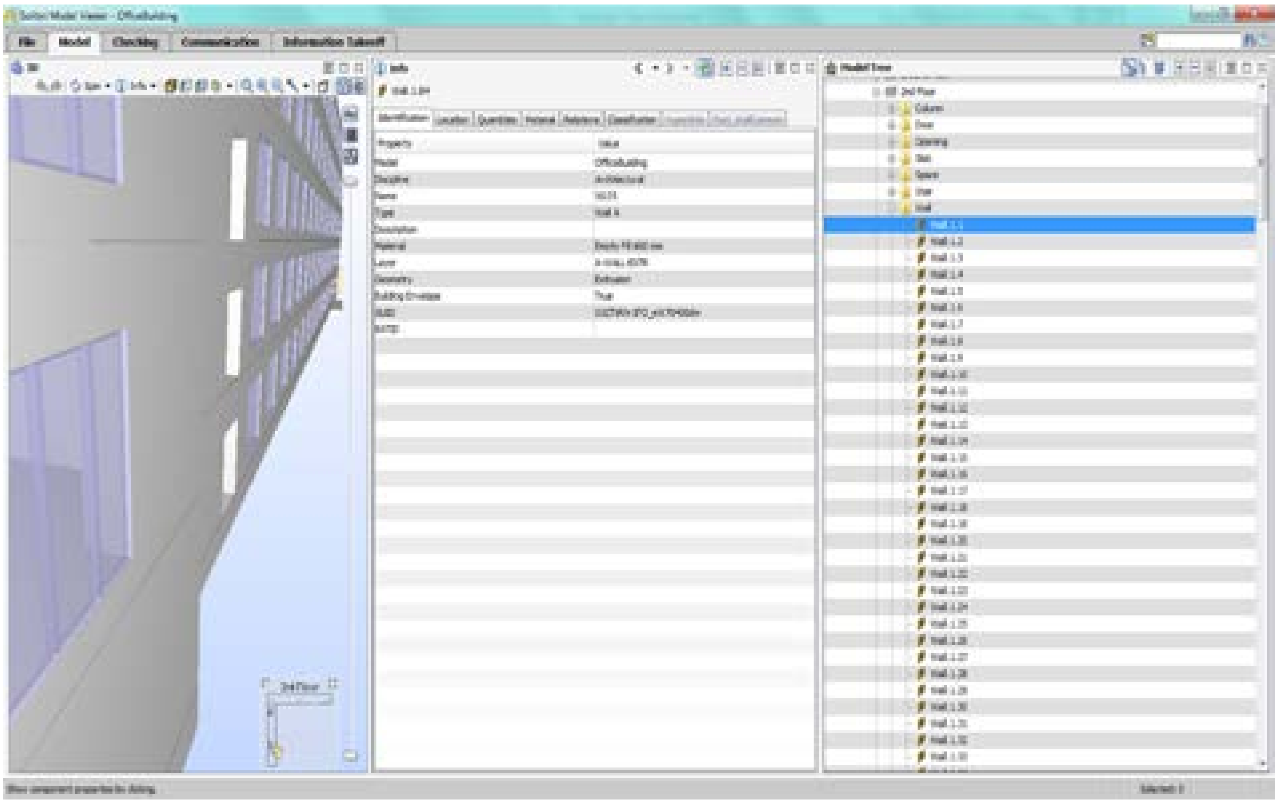
COBie is a standardised approach that allows the incorporation of essential information in the BIM process to support the operations, maintenance and management of assets by the owner and/or property manager. The approach is centred on entering the data as it is created during design, construction and commissioning of the facility, as shown in Figure 20. Designers provide floor, space and equipment layouts. Contractors provide make, model and serial numbers of installed equipment. Much of the data provided by contractors come directly from product manufacturers who can also participate in COBie.

Figure 17: Partial view of IfcWall object



Reproduced with permission from BuildingSMART.

Figure 18: Example of a wall instance with window using the IfcWall object



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Data acquired in the COBie process are held in a neutral format and can be exchanged between various stakeholders using the IFC format. In the UK the government has adopted COBie2 version 2.4.

2.3 Building information models (disciplinary and federated)

Using the object orientation described in subsection 2.1 and the data representation schema described in subsection 2.2, BIM-authoring tools can be used to develop a model for a project. Ideally a project should have a single model that stores all the information. However, current practice, primarily driven by available technology, requires that each project is modelled in the form of a number of discipline-specific models. These models are combined to create a federated model to produce a centralised repository of information for the entire project. For a typical building project the federated model may consist of an architectural model, a structural model and other specialist models, as shown in Figure 21.

As shown in Figure 22, the federated model contains information from the building owner (1), architect (2), structural engineer (3), mechanical, engineering and plumbing (MEP) engineer (4), and the contractors (5) that aid in the completion of the owner's building (6).[70] Development of the federated model and the process of managing and securing this model are very crucial to the entire BIM process.

Similar to federated BIM for buildings, federated models

Figure 19: Naming concept in bSDD

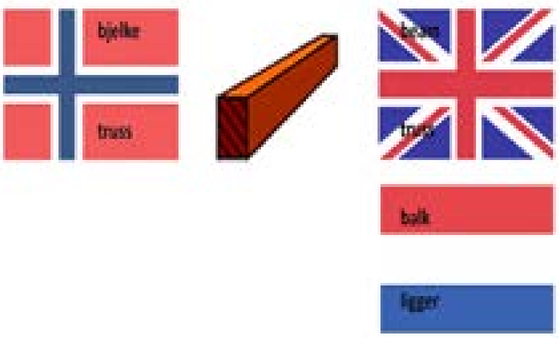


Figure 20: COBie process

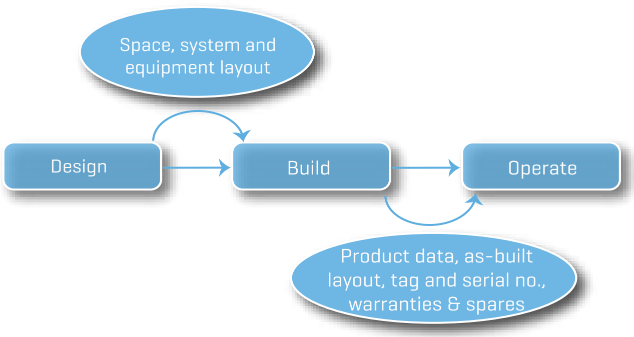
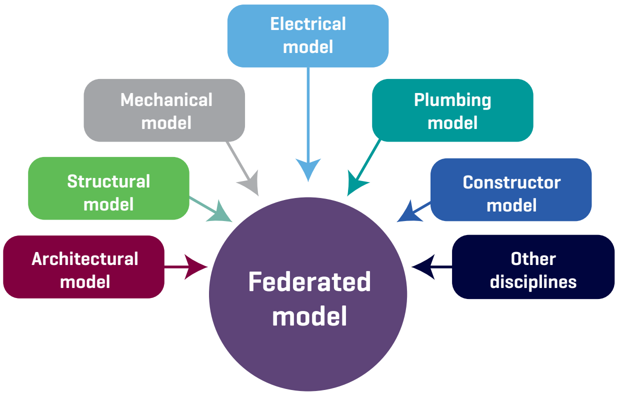


Figure 21: Federated model for a building



for infrastructure projects and process plants are also developed and used in a similar fashion (shown in Figure 23 and Figure 24).

2.4 BIM content and objects

Fundamental to the success of BIM in the industry, in addition to data representation and exchange, is the availability of BIM content in the form of (smart) objects that can be used by project stakeholders to develop their project-specific model(s). There are three primary sources of these objects (as shown in Figure 25):

1. predefined content available in the form of objects in BIM-authoring tools
2. online native and IFC content/objects; and
3. an in-house library of objects.

An adequate supply of objects is necessary for organisations to successfully implement BIM.

A limited supply of objects is built into the BIM platforms/software that are commercially available. Efforts to develop in-house libraries of objects by architects, designers and other specialists are equally important. However, a major supply of objects will come from product manufacturers who supply products to the built environment sector. A number of efforts are already afoot in this regard. For example, the National Building Specification (NBS) National BIM Library is an online repository of product-manufacturer supplied BIM objects (as shown in Figure 26).

In addition there are a number of other product-manufacturer libraries available which, like the National BIM library, offer BIM objects, at no charge, to designers and construction professionals. Figure 27 shows the online BIMobject library.

2.5 Model serving

In many BIM discourses discussion of a very simplified model development process that assumes seamless model sharing and progression is provided. For example, an architect designing a building develops an 'architectural model' and seamlessly passes this on to the structural designer. The structural designer in turn then takes this model and effortlessly converts it into a 'structural model'. The process can be repeated for the remaining design consultants and also in fact for the constructor. Is this really true in practice? In most instances this is not the true version of model development, sharing and progression. It is not farfetched to imagine that, on many projects, model sharing still takes place using emails and file transfer protocol (FTP) servers. A typical process that is followed in the building sector

Figure 22: Use of federated model on a building project

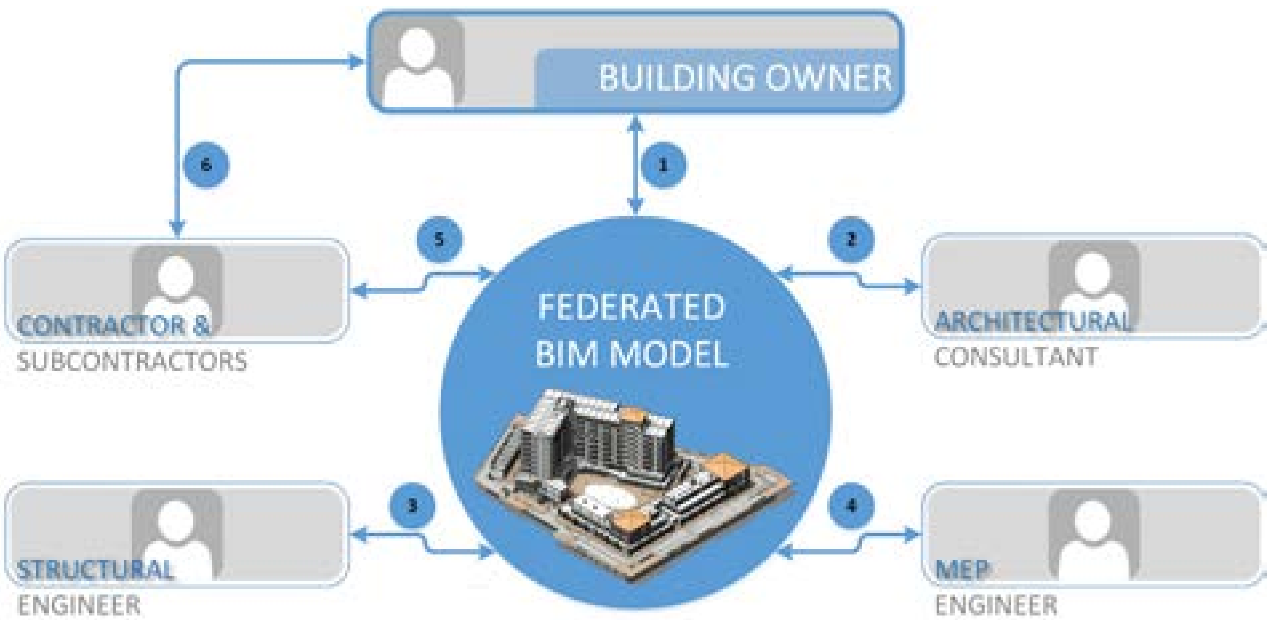


Figure 23: Federated model for civil infrastructure project

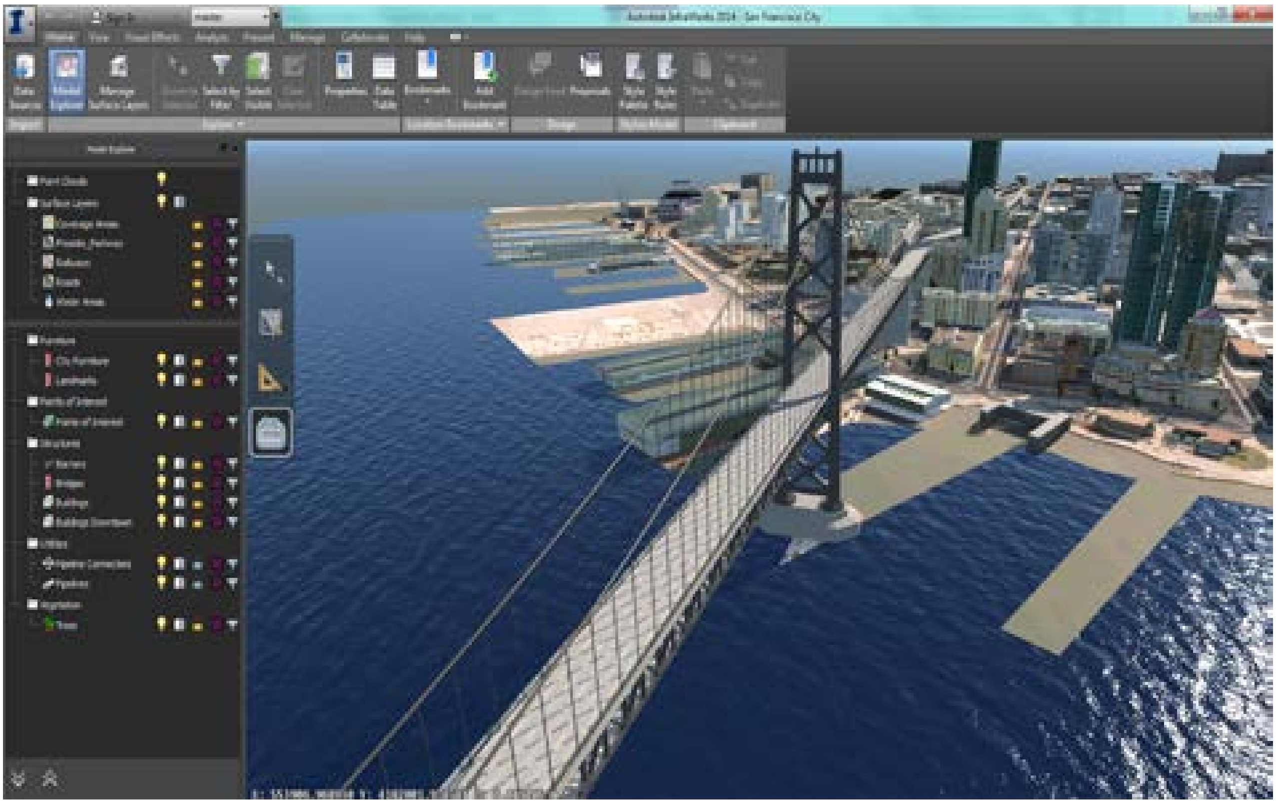


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Figure 24: Federated model for process plant

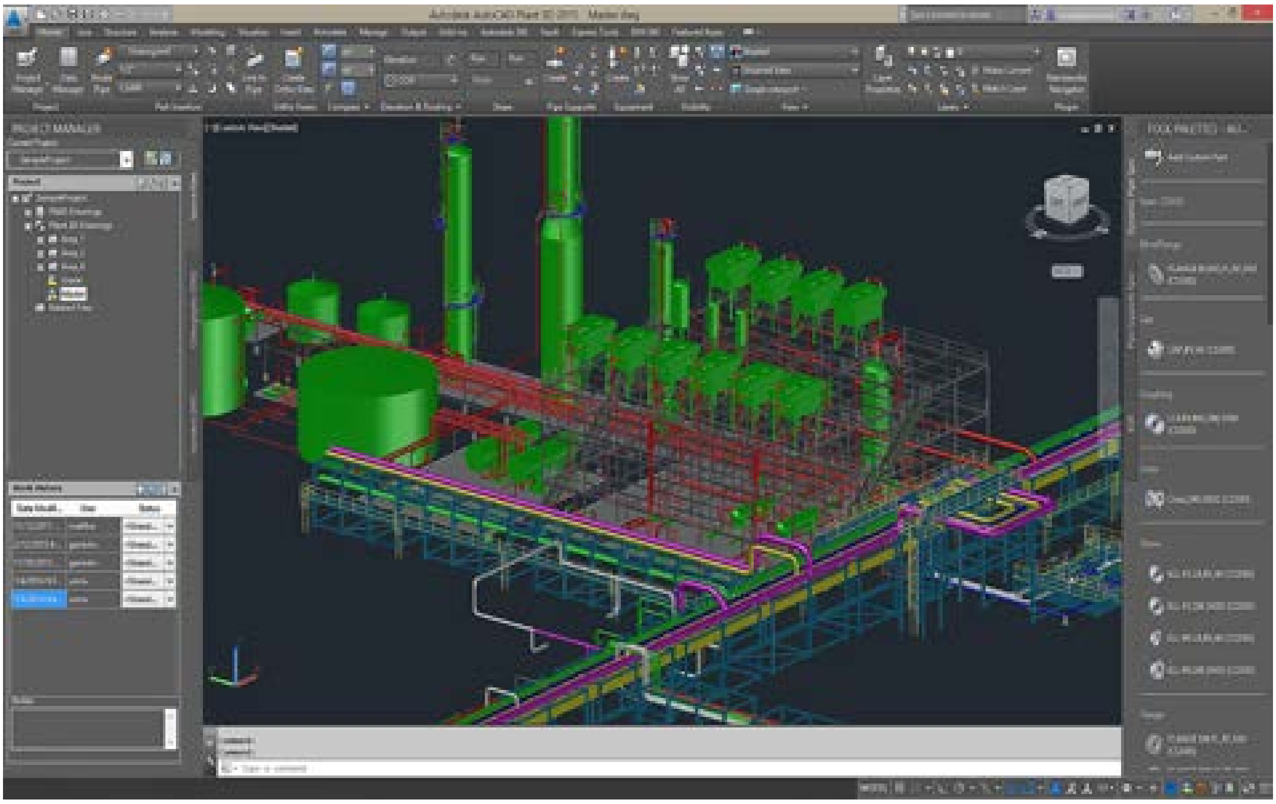

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Figure 25: Sources of BIM objects

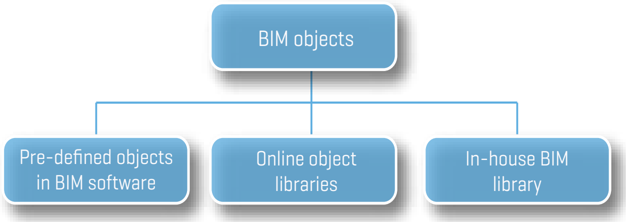
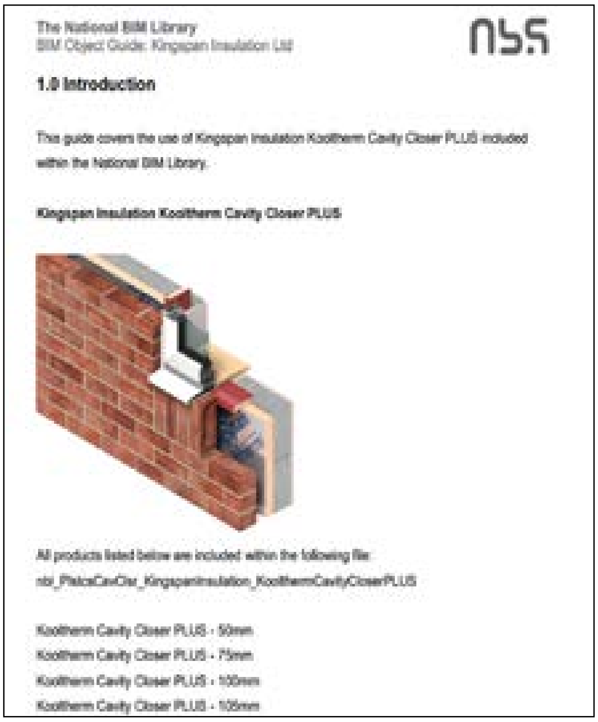


Figure 26: Sample product manufacturer BIM objects



The National BIM Library
BIM Object Guide: Kingspan Insulation Ltd

1.0 Introduction

This guide covers the use of Kingspan Insulation Kooltherm Cavity Closer PLUS included within the National BIM Library.

Kingspan Insulation Kooltherm Cavity Closer PLUS

All products listed below are included within the following file:
nbl_PlstcsCavClsr_KingspanInsulation_KoolthermCavityCloserPLUS

Kooltherm Cavity Closer PLUS - 50mm
Kooltherm Cavity Closer PLUS - 75mm
Kooltherm Cavity Closer PLUS - 100mm
Kooltherm Cavity Closer PLUS - 105mm

Reproduced with permission from the NBS National BIM library.

is shown in Figure 28.

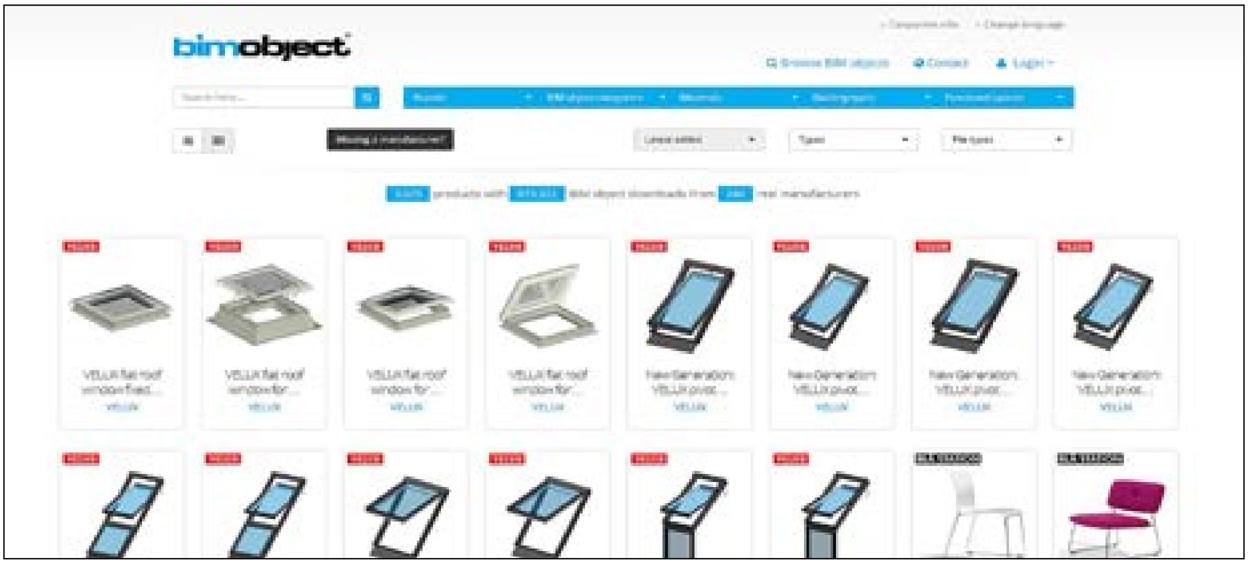
While this system largely works, it is not something that can be termed an integrated BIM process. Ideally the coordination, collaboration and communication surrounding the model development and progression processes will be more seamless and integrated. The process should actually be in real time. This can happen if the project team decides to unify the process by deploying a BIM server. The server hosts the model centrally, and this allows the project team to work in an integrated and collaborative fashion. Figure 29 and Figure 30 show two examples of BIM servers.

2.6 OpenBIM and similar initiatives

Even though neutral data representation and exchange formats are available for an integrated whole-of-building life cycle, BIM implementation is still not easy: numerous challenges remain. Use of non-compliant software is one of the main challenges faced by the industry.

OpenBIM is a concept that promotes collaborative design, construction and operation of assets based on open standards and workflows. This concept has been initiated by BSI and several leading software vendors using the open buildingSMART Data Model.[71] This concept supports a transparent, open workflow allowing project teams to participate in the BIM process regardless of the software tools they use. It creates a common and standardised platform for industry processes and practices, allowing all stakeholders to participate as per their respective terms of reference. Similar industry efforts are simultaneously taking place to allow this type of open and neutral platform to take hold in the industry.

Figure 27: BIM content from BIMobject library



Reproduced with permission from BIMobject.

Figure 28: FTP-based model sharing

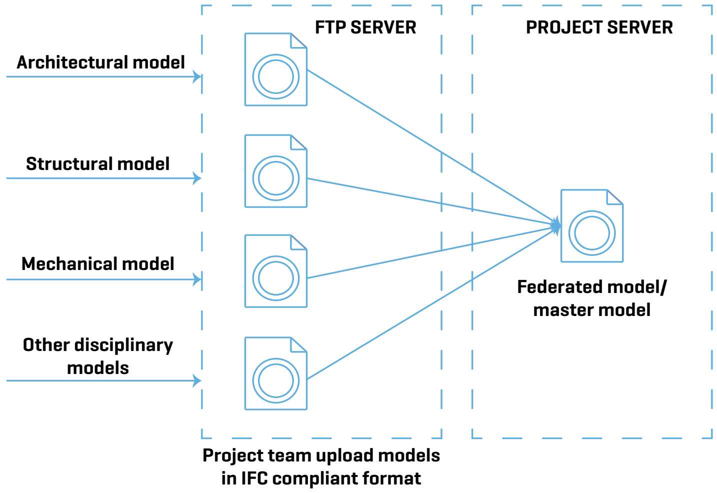


Figure 29: IFC-compliant model server

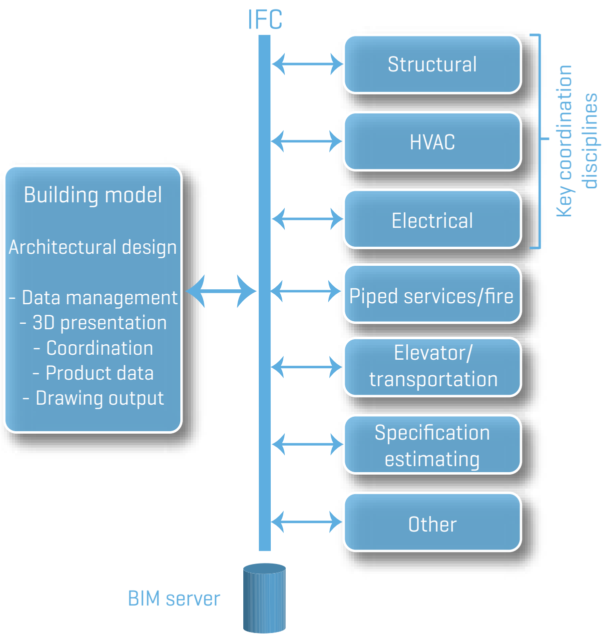
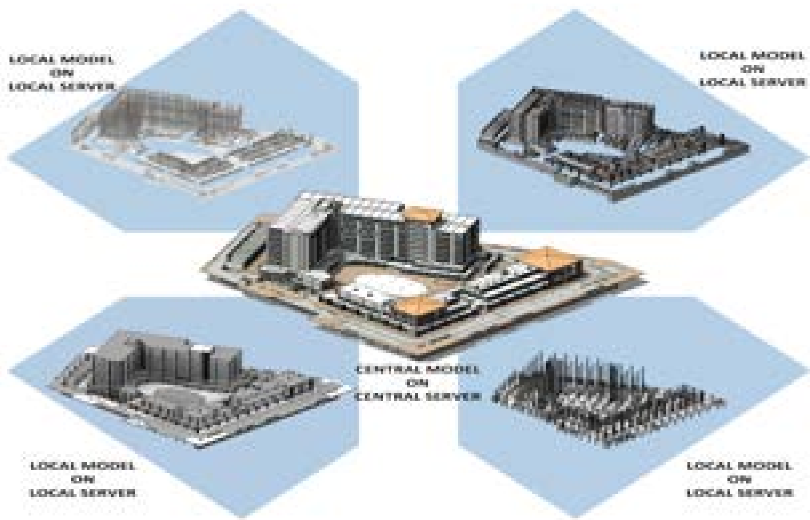


Figure 30: Commercially available model server



2.7 BIM's links with other up-and-coming technologies

A few technological developments happening simultaneously with the increased uptake of BIM in the industry can have a significant impact on the future state of BIM. These technologies help store data, access data and expand organisations' modelling capabilities (especially SMEs).

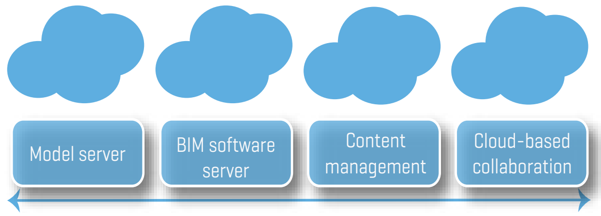
2.7.1 Cloud computing

The power of BIM is limited by numerous factors pertaining to people, process and technology. The industry is striving to solve the people and process issues. On the technology front, cloud computing can provide many fundamental enhancements to the way BIM can be deployed and used.[72]

Cloud computing is not a specific technology or a particular software solution but instead is an umbrella concept for different methods of sharing resources over the Internet.[73] The National Institute of Standards and Technology (NIST) in the US has defined cloud computing as a:

> 'model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction'.
>
> (*Computer integrated construction*, Arayici and Aouad, 2005).[74]

Figure 31: Four-pronged functional benefits of cloud computing



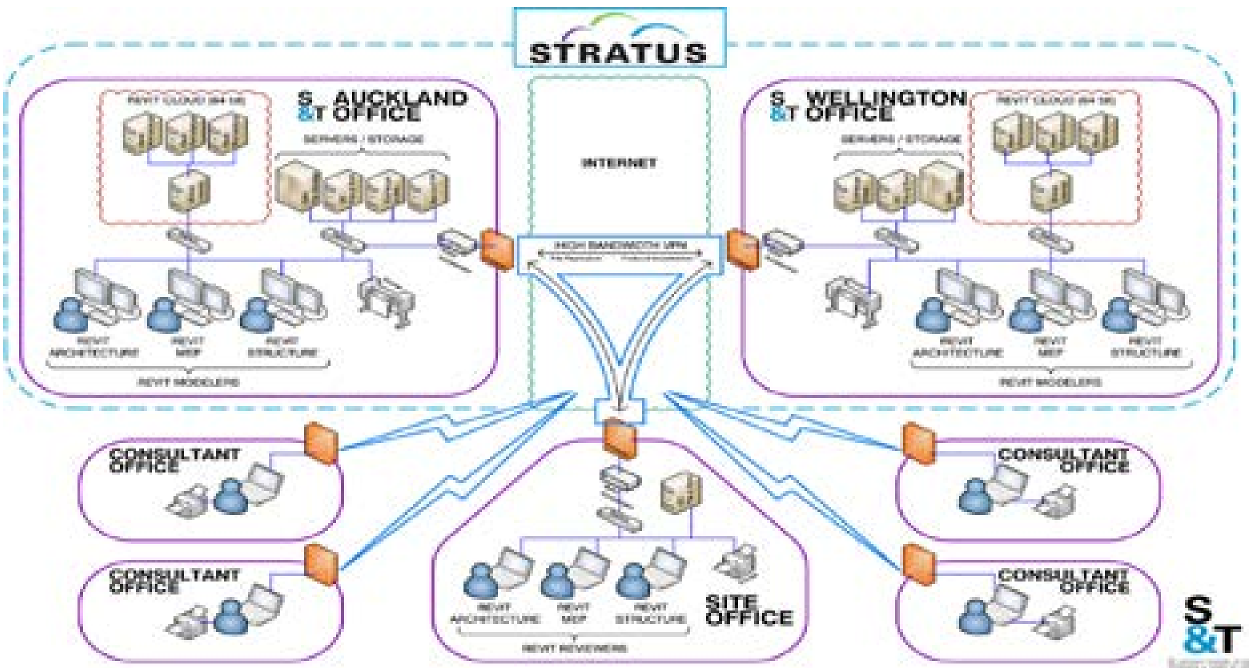
Simply put, cloud computing is a technology used to access computational services offered via the Internet.[75]

When BIM is deployed on a cloud platform it further enhances the collaborative process that leverages web-based BIM capabilities and traditional document management to improve coordination. Four aspects of cloud computing can impact BIM implementation (shown in Figure 31):[76, 77]

1 **Model servers**: using a cloud-computing platform, the central model(s) of the building can be hosted to allow inter- and intra-disciplinary secure access to the model's content in a seamless fashion that is currently not possible (shown in Figure 32).

2 **BIM software servers**: current BIM software requires significant hardware resources in order to run. This hardware can be deployed in the cloud and shared efficiently between the project participants through virtualisation (shown in Figure 32).

Figure 32: Hardware and software deployment using cloud computing



Stratus is a New Zealand based company specialising in BIM cloud technology. The system referred to in this report was created by Des Pudney, Managing Director of Stratus. Leading the way in NZ the system was initially deployed by Stephenson&Turner Architects, The system is now used by Stratus and Stephenson&Turner with both companies reaping the benefits and gaining fantastic results and gaining interest from companies worldwide. For more info contact us at www.stratus.net.nz

Figure 33: Mobile device using cloud computing

Autodesk screen shots reprinted with the permission of Autodesk, Inc.

3 **Content management**: cloud computing provides a centralised and secure hosting environment for content in the form of data attributes/libraries needed for BIM use and deployment.

4 **Cloud-based collaboration**: cloud computing provides a new way of collaborating, coordinating and communicating within the project team. With project team members spread across the globe, cloud-based collaboration platforms with BIM capabilities will play a significant role in the built environment sector.

Using cloud-computing technologies, the mantra of 'information anywhere, anytime' can also be realised. A number of cloud-based information-sharing and collaboration tools are now commercially available. As shown in Figure 33, access to models remotely from a mobile device is possible.

A major benefit, especially for SMEs, is access to powerful software that may be expensive to purchase otherwise. Using cloud computing, software resources can be 'rented' on a per-use basis. Figure 34 shows structural analysis software that is available to users over the cloud. An analytical model of a building extracted from BIM can be submitted for analysis purposes to this cloud-based structural analysis tool without having to buy the software. Such approaches are going to significantly impact the way BIM implementation can take place.

While evaluating cloud-computing technologies, it is crucial to understand the potential downside of these technologies. One key requirement of cloud-based tools is a stable and constant Internet connection. If connectivity is lost, cloud-based tools become unavailable unless caching is in place. Other difficulties include security issues, data ownership issues and reliability of vendors providing cloud computing.

2.7.2 Big data

Today data is everywhere – in and around the designer's office, on a project site, in a product manufacturer's factory, in a vendor's database or a census database. Can an architect have real-time access to this data as the design process is evolving, especially connected to a BIM-authoring platform? This is now possible using a technology called 'big data'. Big data is a popular term used to describe the exponential growth and availability of data, both structured and unstructured, which governments, societies and businesses can tap to improve our lives.[78] Big data provides unprecedented insight and improved decision-making for the tasks that we perform. This technology can be tapped to enhance the design, construction, operation and maintenance of our built environment. Conceptually, as shown in Figure 35, a BIM platform can be linked to a large volume of data that can enhance the decision-making power of the stakeholders

Figure 34: Software as a service

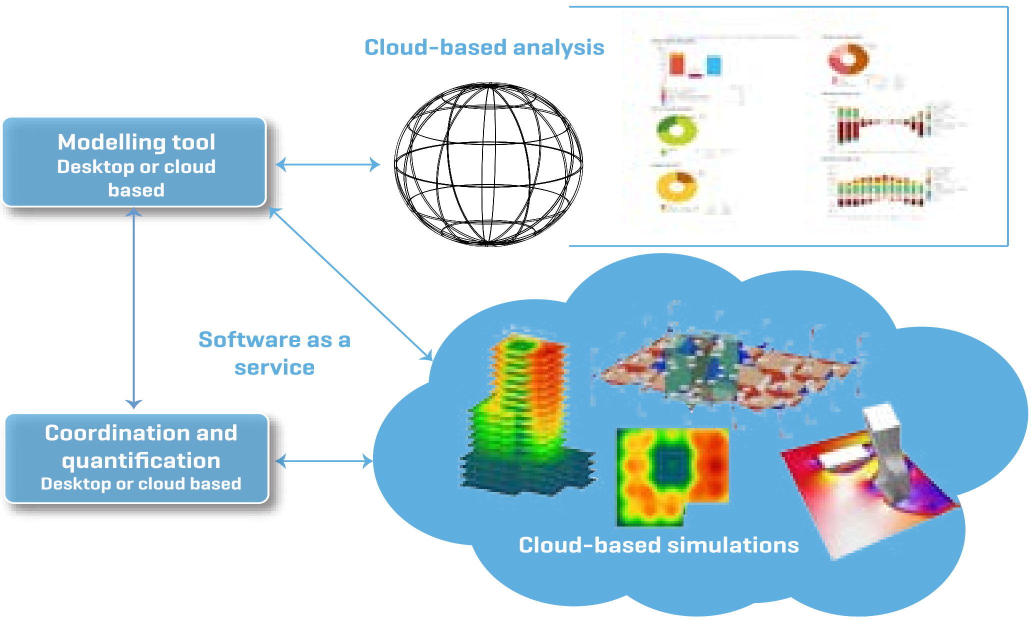
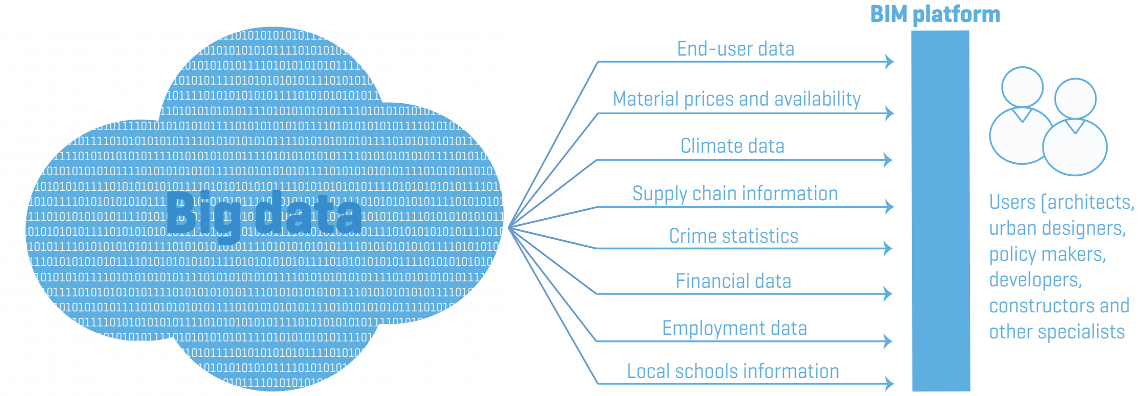


Figure 35: Big data-supported BIM platform



in a team. A project can benefit from real-time information sources such as supply chain data, commodity pricing data, marketing data, sensor data, point-cloud data, crime statistics, employment data and so on.

2.7.3 Physical to digital

With the proliferation of BIM there is now a need to capture as-built information, especially for large-scale retrofit and renewal projects. In these situations it is useful to start with the base digital model of the facility as it exists on site. This is now possible by linking laser scanning and 360-degree video or camera vector technology. Figure 36, Figure 37 and Figure 38 show samples of laser scans and video images of as-built environments that are ultimately connected to a model.

A detailed measured survey specification with agreed accuracies and required outputs is critical to the success of converting a ‘physical’ environment to a ‘digital’, modelled one. This can be a difficult process and specialised survey skills in ‘point cloud’ interpretation and software are needed (as well as classical measured survey procedures). Another issue is that current BIM software is essentially design based, and it can be difficult to fit ‘real-world’ survey data into BIM software.

Other avenues for accurate survey output can be explored, such as high-accuracy wireframe models for architecture purposes which bring true accuracy to the survey. Laser scanning, although increasingly prevalent, is just one of many survey techniques that can be used. Care should be taken to relate the building information model to its external environment (if needed). This can be done through a connection to relevant national coordinate systems.[79]

2.8 Data management

Large volumes of data are created in the BIM process. To succeed in large-scale BIM projects, data management software should be used. Data management technology allows the modelling process to be connected with extended, dispersed and remote team members. Access control and security along with version control on the model and associated files is ensured through this technology. Figure 39 shows ProjectWise® Explorer which is used to manage building information models and associated CAD files.

Figure 36: Laser scanning of the interior of a building

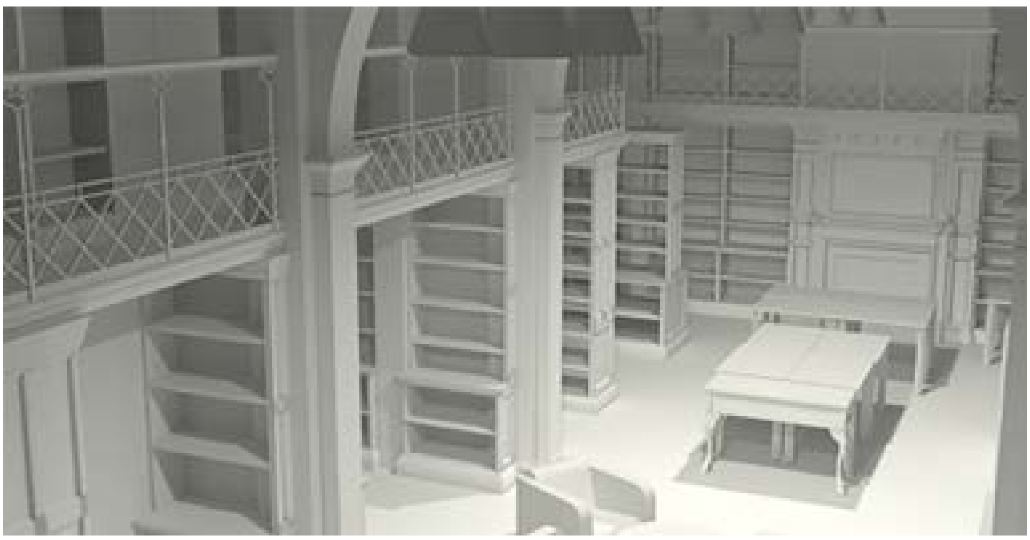
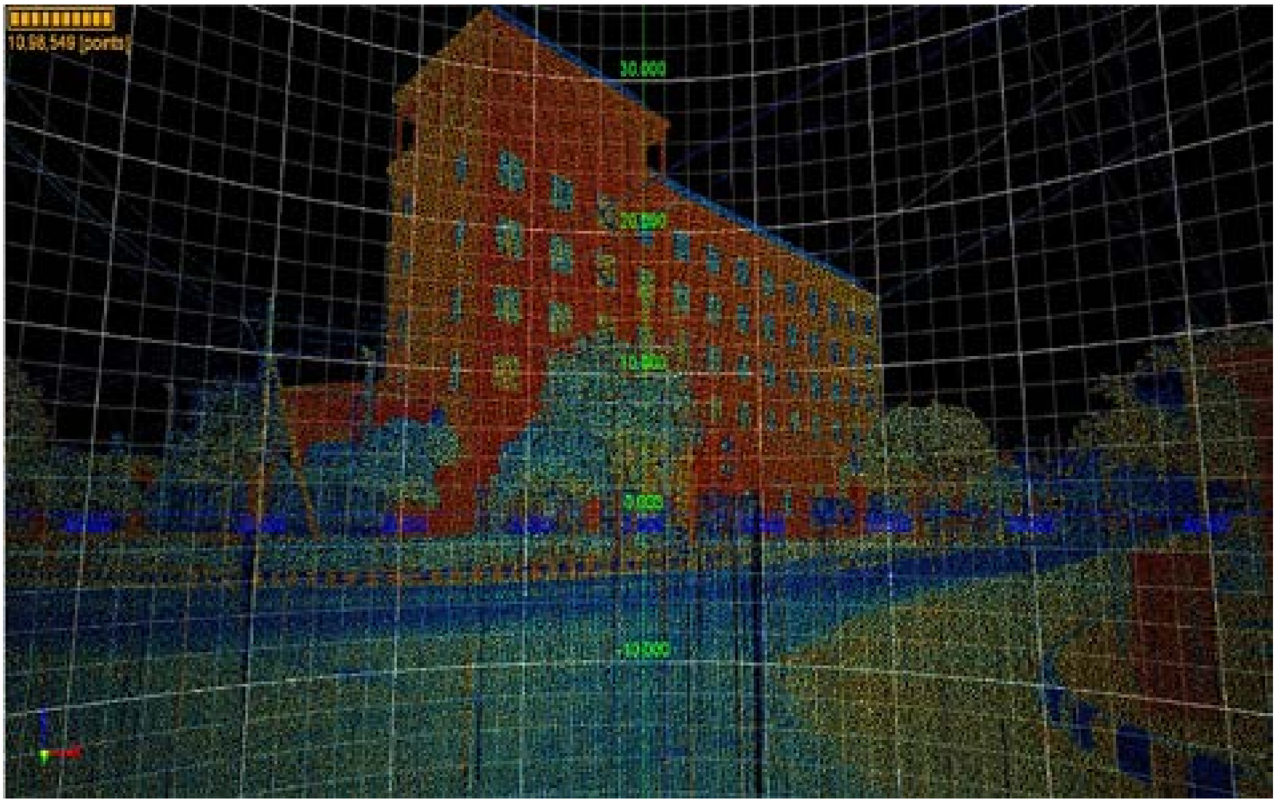


Figure 37: Still of a 360-degree video of an urban neighbourhood

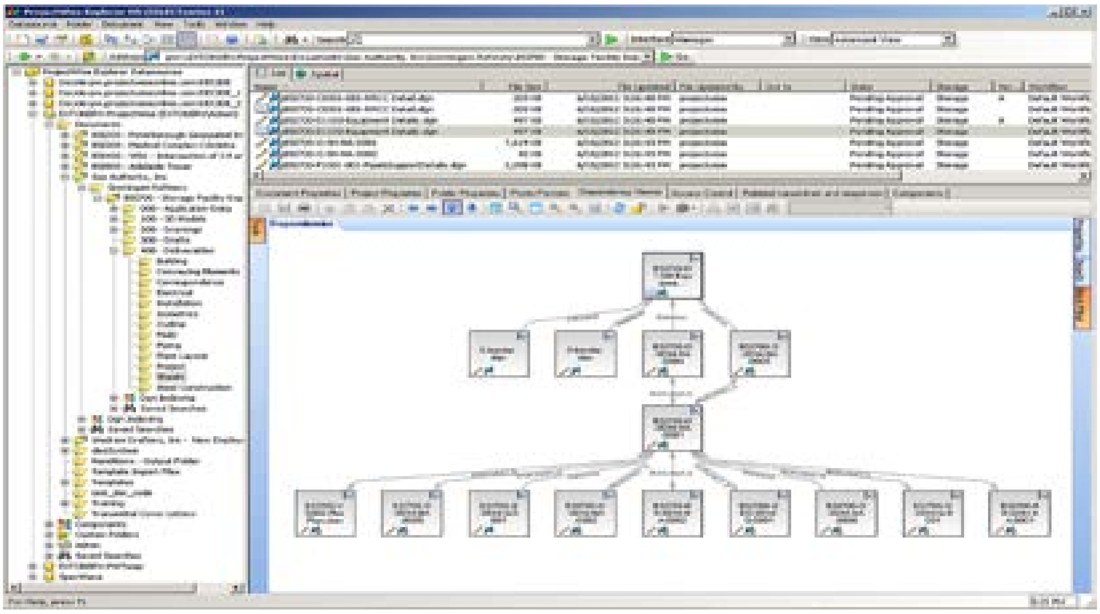
Figure 38: Laser-scanned image of an urban neighbourhood



2.9 Content management

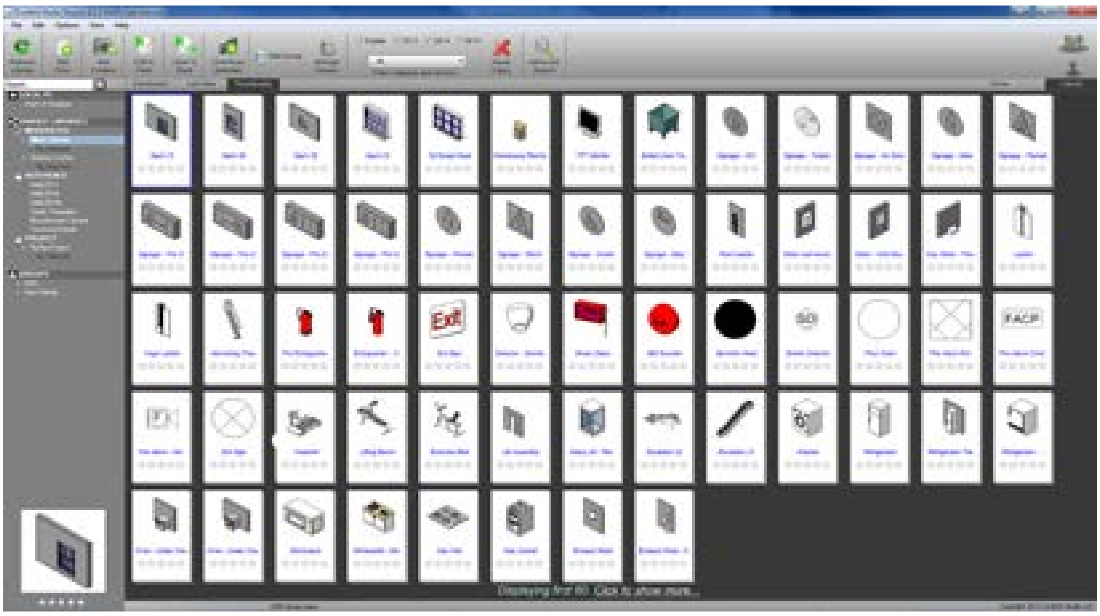
As BIM implementation matures in an organisation it is anticipated that the in-house BIM library will grow exponentially. For example, an architect's office may have thousands of doors and windows objects (embedded with data and information) stored internally. As models for new projects are created, additional objects will be developed, adding to the already-existing library. Management of this library will become an important task. Content management tools that have the ability to sort, search and leverage library objects and BIM content more effectively on BIM projects will be needed. Figure 40 shows content management software that is currently commercially available.

Figure 39: Data management using ProjectWise®



Reproduced with permission from Bentley Inc.

Figure 40: Content management in design organisations



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3 Use of BIM in project delivery

This section discusses the application of BIM at the project level. As described in subsection 1.2 (and shown in Figure 1), it is crucial to understand the impact of BIM on built environment professionals and projects before studying the implications at the organisational level and sector level.

Projects form a crucial part of our economic activity producing important assets such as physical infrastructure, ships, aircrafts and software. Organisations that undertake projects as their core business are generally called project-based organisations (PBOs)[80] or project-based firms (PBFs).[81] PBOs or PBFs require a unique synergy between strategy, project, programme and portfolio management[82] and face a different set of challenges when looking at technology adoption. What happens on a project is therefore indirectly linked to the organisation's programme and portfolio management approach, with links between project strategy and corporate strategy. Keeping this in mind, project-level BIM implementation is first discussed here, while organisation-level (including inter-organisational) issues are discussed in section 4, Implications of BIM on organisations.

To realise its full potential, it is crucial that BIM is used over the entire project-delivery process in a systematic, integrated and seamless fashion – perhaps something easier said than done. This requires a new way of thinking and a somewhat radical change in workflows and work practices. It also requires the organisations involved in the project to understand the implications of using BIM both at the project and organisational level. This section addresses the implications of BIM at the project level for the major project stakeholders. In this context it is crucial to first understand the following interrelated dimensions of BIM deployment at the project level:

- project-level goals of BIM deployment and the identification of a champion for BIM deployment
- articulation of value proposition for use of BIM for the project as well as all stakeholders
- implications of BIM on functions and subfunctions within the project life cycle phases; for example, which functions or subfunctions will be performed using BIM, what will the possible inputs and outputs be from BIM-driven functions and subfunctions?
- information flows between project team members in a BIM environment as compared to the traditional 2D environment
- roles and responsibilities of various project stakeholders in relation to BIM by project life cycle phase, and how they differ from current (non-BIM) practices; and
- issues pertaining to model development, model progression and model quality through the entire project life cycle.

Structured solutions to these issues generally form the basis of a BIM project deployment and execution plan. A number of such planning documents exist and can be used by professionals working on project teams to lay the foundations for successfully implementing BIM across all project life cycle phases (e.g. *BIM execution planning guide version 2.0* by Penn State University,[83] *The VA BIM guide* by the US Department of Veterans Affairs,[84] *Singapore BIM guide: version 2* by the Building and Construction Authority,[85] *BIM execution plan* by CPIx (UK),[86] and *BIM protocol* by the Construction Industry Council (CIC)/BIM Pro).[87] As per the Penn State University's *BIM execution planning guide*,[88] four broadly defined steps are needed for BIM implementation:

1. define high-value BIM uses during project planning, design, construction and operation phases
2. use process maps to design BIM execution, clearly showing process steps, roles and responsibilities of project team members, and input and output from each step
3. define the BIM deliverables in the form of information exchanges, information encapsulation, model progression and model quality; and
4. develop a detailed plan to support the execution process via identification of major deliverables.

The *Singapore BIM guide*[89] mandates the development of a BIM execution plan and the following implementation details:

1. define roles and responsibilities for model creation, maintenance and collaboration across the project life cycle phases
2. clearly define the process of BIM implementation
3. identify resources and services that may be needed; and
4. define a project management plan for BIM implementation.

At the project level, BIM execution plans must include:[90, 91]

- goals and use of BIM to set expectation levels for all stakeholders
- roles and responsibilities of the project team members
- an overall BIM strategy, keeping in mind the procurement strategy and delivery methodology
- a BIM process and exchange protocols to be used by the team members
- data requirements at various stages of the project
- collaboration procedures and methods to handle shared models
- quality control of models; and
- technology infrastructure and the software required for proper implementation.

Alongside the implementation plan it is also important to have a clear understanding of contractual and legal implications, insurance-related issues, training and education requirements, commercial issues and copyright and intellectual property right issues. These need to be addressed at the organisational level with links to each BIM project undertaken by the organisation. More details on these issues are provided in section 4, Implications of BIM on organisations.

3.1 Types of projects and BIM implementation

Broadly speaking the built environment sector can be divided into two major categories of projects:

- real estate projects; and
- infrastructure projects.

Some industry parlances also refer to these as building projects and non-building projects. From the amount of literature and guidance available it is evident that, today, BIM is far better documented, understood and used in the building sector or the real estate sector compared to the infrastructure subsector. The level of BIM adoption in the infrastructure or non-building sector is a few years behind,[92] but these types of projects are also well suited for a model-driven BIM process. In fact, a 2013 report by McKinsey Global Institute entitled *Infrastructure productivity: How to save $1 trillion a year*[93] points out that BIM can be one of the 'productivity-enhancement' tools that the industry can embrace to contribute to an annual global saving of US$1 trillion. Many proponents of BIM in the infrastructure sector believe that 'lonely' BIM use (i.e. single stakeholders using BIM) has been going on for a longer period than the popular literature leads us to believe.

The McGraw Hill report *The business value of BIM for infrastructure – addressing America's infrastructure challenge with collaboration and technology*[94] refers to BIM used on building projects as 'vertical BIM' and that used on infrastructure projects as 'horizontal BIM', civil BIM (CIM) or heavy BIM. As many organisations may be involved in both building and non-building projects it is crucial to understand the subtle differences in the project-level BIM implementation in both cases. For example, the scale of data to be gathered and understood for the initial phases of an infrastructure project can be massive compared to a real estate development project. Data about the existing conditions, constraints of nearby assets and landforms along with regulatory considerations can be vast for an infrastructure project compared to a building project. The use of geographic information system (GIS) data along with BIM may therefore be more crucial in the initial stages of an infrastructure project.

While the composition of the project team and life cycle phases (in naming convention and relative effort distribution) may vary between building projects and non-building projects, the project-level BIM implementation remains consistent in its core themes of model-centricity, importance of information, collaboration and team integration. Subsection 3.2 provides a detailed description of BIM along the project life cycle phase with special emphasis on people and project-level issues.

3.2 BIM and project life cycle

Empirically it is amply clear that using BIM only in the early life cycle phases of a project limits its power and does not provide the return on investment that organisations seek. Figure 41 shows the use of BIM across the entire life cycle of a building project. Understanding the BIM process along the project life cycle phases, from 'cradle to cradle', is therefore essential for professionals who are working in project teams charged to deliver projects of different kinds and scale. It is also essential to understand that BIM use cuts across both 'new-build or retained estate'.[95]

As a best practice, using BIM should begin at the conceptual design or planning stage of a project. Models developed at this stage should be converted into a full-blown building information model as the design and planning of the project evolves. Having a data-rich and computable model then allows project teams to conduct a variety of analyses that enhance the value generation of the project through time, cost and sustainability-related efficiencies. The same model then allows the project team to drive the documentation, procurement and pre-construction planning activities on the project. It should then drive the construction process and, after commissioning, the same model can assist in the operation and maintenance phase. Retrofit and demolition decisions can also be driven by the building information model. Ideally, organisations should use BIM for the complete asset management cycle.

Useful resources for the deployment of BIM on a project are the:

Figure 41: Project life cycle phases and BIM use

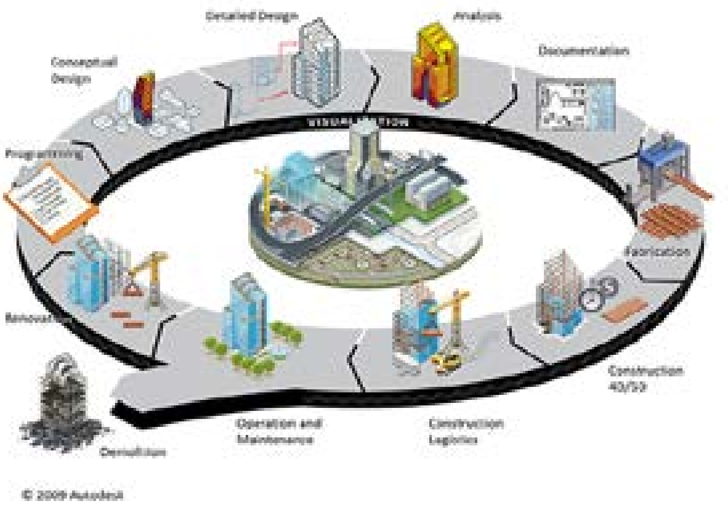


Image provided courtesy of Autodesk Inc., © 2009

- RIBA Plan of Work 2013 with BIM Overlay
- BIM Task Group Digital Plan of Work
- AIA Building Information Modelling and Digital Data Exhibits; and
- UK government Digital Plan of Work.

To succeed in implementing BIM it is important to develop a matrix in which the project life cycle phases, key objectives of the phases, BIM objectives, model requirements and level of detail (or development) are captured. In Table 2 such a matrix using the RIBA Plan of Work is shown.

Table 2 highlights important issues such as model progression, model coordination, model serving and quality of information embedded in the model along the project life cycle. In subsections 3.2.1–3.2.7, detailed project life cycle phase-wise description is provided for project level BIM implementation. For the purposes of simplicity, RIBA Plan of Work 2013 stages are adopted for the discussion in subsection 3.2.1. For the sake of uniformity, Table 3 shows equivalent stages used for infrastructure development or non-building projects.

It is crucial to understand that, over the life cycle of a project, the building information model becomes progressively data and information rich. In addition to the design, engineering and construction-related information, cost-related information also evolves as the project progresses. The utility of the BIM process can be enhanced if the project team ensures that design, engineering, construction and cost information is conjointly carried through effectively over the project life cycle. Commercially available software tools are equipped to manage the evolution of design, engineering and construction information but cost-related information over the life cycle may need special attention. Using classification systems and standards is essential in ensuring the development and use of cost-related information along the project life cycle. For example, the RICS new rules of measurement (NRM) help in presenting the basis of a good life cycle cost management system. This can be used jointly to ‘develop and manage life cycle cost plans (LCCPs) for construction, maintenance and renewal works, to inform investment appraisals, and selecting the best value option’.[97]

3.2.1 BIM during the strategic-definition phase and preparation and brief phase

Using BIM in the early phases of a project is not currently widely practised. However, exemplars do exist in the literature highlighting the importance of using BIM at this stage. In the early stages of project development, it is important to perform the following key tasks relating to BIM implementation:

- Formulate and define the BIM process which is to be adopted for the project. In fact, this is the primary task that the project team engages in at this stage regarding BIM. Many useful resources are available to develop a BIM implementation framework. For example, the *BIM execution planning guide* by Penn State University[98] provides an extensive framework that allows definitions of the key parameters of BIM implementation (Figure 42 shows the overall approach for this activity).
- Develop an initial project plan and identify preliminary project team definitions that clearly identify BIM-related activities and project team requirements according to life cycle phases of the project (generally incorporated in point 1 above).
- Collect information about the project, site(s) and surroundings/vicinity that will be needed for informed decisions as the project progresses. The role of the land, engineering and measured building surveyors is important and should be planned as per

Table 2: BIM and project life cycle matrix

	Key objectives	BIM objectives/activities	Model	Level of detail
Strategic definition (stage 0)	• Business case • Strategic brief	• BIM implementation plan across project life cycle phases • Cost of implementation • BIM strategy	N/A	N/A
Preparation and brief (stage 0)	• Project objectives • Project outcomes • Sustainability goals • Project budget • Initial project brief • Feasibility studies • Site information	• Collect data for models • Identification of BIM manager and champions • BIM work plans • Responsibility matrix	Site model (optional)	Low
Concept design (stage 2)	• Concept design • Cost information • Project strategies • Final project brief	• 3D sketching and form generation • Massing • Spatial programming • Sustainability studies • Project budget • Identify key modelling elements • Existing conditions; e.g. as-built models (if any)	Concept design model(s)	Low
Developed design (stage 3)	• Developed design • Cost information • Project strategies	• Disciplinary models • Federated models • Time and cost dimensions • Sustainability information • Model extraction for design and analysis • Preliminary design coordination • Detailed modelling, integration and analysis	• Federated design model with links to disciplinary models • 4D, 5D and 6D models • Design documentation	Medium to high
Technical design (stage 4)	• Technical design and specifications • Design responsibility matrix • Project strategies	• Disciplinary models • Federated models • Time and cost dimensions • Sustainability information • Model extraction for design and analysis • Project procurement documentation • Detailed design coordination	• Federated design model with links to disciplinary models • 4D, 5D and 6D models • Specifications	High
Construction (stage 5)	• Off-site manufacturing and on-site construction	• Phasing and prototyping • Quantity extraction • Specifications • Fabrication models • Contract administration • Collect as-built information	• Federated construction model	High
Handover and close out (stage 6)	• Handover of building	• As-built models • Validation and testing • Integration with facilities management systems	• Federated as-built or record model	High
In use (stage 7)	• Undertake in use	• Integration with building management system (BMS) • Integration with monitoring systems	• Federated as-built or record model	High

Table adapted from *BIM overlay to the RIBA outline plan of work*, Sinclair, 2012.[96]

Table 3: RIBA stages versus stages for non-building projects

RIBA stage number	RIBA stages	Stage	Stages for non-building projects
0	Strategic definition	1	Initiation
1	Preparation and brief	2	Planning
2	Concept design		
3	Developed design	3	Design and procurement
4	Technical design		
5	Construction	4	Construction and handover
6	Handover and close out	5	Operation and maintenance
7	In use		

the RICS guidance note *Measured surveys of land, buildings and utilities* (3rd edition).

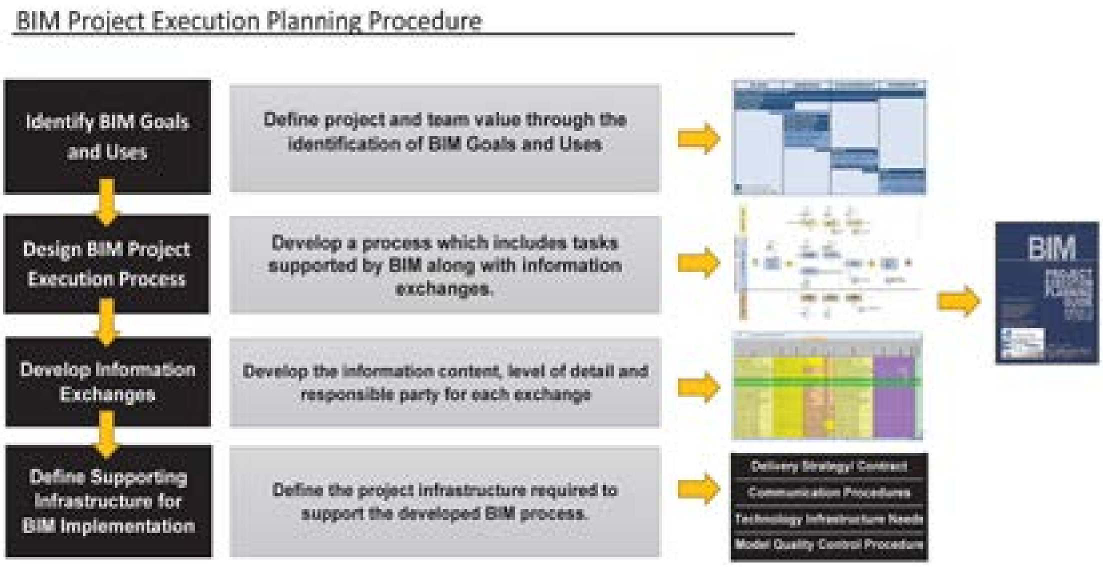
- Develop an initial understanding of the project owners'/sponsors' requirements and business needs.

It is important to have a detailed measured survey specification with agreed accuracies and required outputs in the early stages of the project's life cycle. The measured survey can be expensive but should be seen as an 'insurance policy' by all users as it removes a very large amount of risk and potential confusion. The measured survey sets the spatial framework for all additional information elements and is a key element of any BIM project.

The following information is collected during this phase and is needed for modelling in the downstream processes (there is other information not linked to BIM implementation that is also collected during this phase but is not listed here):

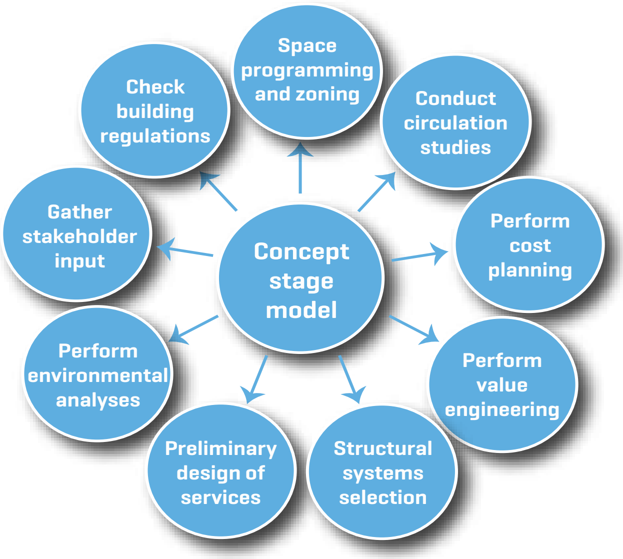
- a site or multiple sites available for the project, preferably in a GIS environment
- site measurements including topographic surveys, photogrammetric surveys, aerial surveys, site photographs and so on
- a digital terrain model of the site(s) if available, including drainage information using a laser scan wherever needed
- existing buildings and structures information preferably in the form of a pre-existing building information model or point-cloud information from laser scanning including geo-referenced photographs
- as-built information of neighbouring structures
- underground infrastructure (services) in and around

Figure 42: BIM execution plan[99]



Adapted from The Computer Integrated Construction Research Program at the Pennsylvania State University, BIM Project execution planning guide, http://bim.psu.edu/. © 2010 The Computer Integrated Construction Research Group. This work is licensed under the Creative Commons Attribution-Share Alike 3.0 United States License. http://creativecommons.org/licenses/by-sa/3.0/us/

Figure 43: Concept design-stage model and its uses



the site including any ground penetrating radar data; and

- local zoning ordinance and building code regulations with specific BIM requirements.

With this information and the help of the BIM execution/implementation plan the project team can proceed to the next phase of the project. Key BIM-related outcomes in this phase are:

- buy-in from the client/project sponsor on using BIM, clear identification of the role and purpose of using BIM, and definition of success factors of BIM implementation
- definition of the extent of BIM implementation including 4D (time), 5D (cost) and 6D (life cycle/facilities management/sustainability) and the concomitant deliverables and expectations; and
- determination of the delivery mechanism of BIM-related tasks including the role and responsibilities of each project team member, requirements for specialists and appointment of a BIM manager (if needed). Also, long-term responsibilities and ownership of the model and BIM inputs and outputs are defined.[100]

Generally no models are developed in this stage of the project but the output of this phase is crucial for successful BIM implementation on the project.

3.2.2 BIM during concept design

Using BIM in the concept design stage is a recent development and is in its nascent stage in terms of mainstream industry practice. In the past most BIM implementation simply started from the detailed design stage of a project. Partly this happened due to limitations in technology, especially lack of commercially available tools. Concept-level models developed by the designers carried information limitations that did not allow these models to be used for anything other than visualisation and animation. Nor could these models be taken forward into the detailed design phase of the project due to interoperability issues. Transfer of concept-stage models via IFC file format yielded unsatisfactory results due to significant data loss.

The situation has significantly changed in regards to technology and software features. Some BIM authoring tools have extensive features (either built in or via links to other concept stage design tools) that allow:

- performance of tasks that are expected in the concept design stage of a building or infrastructure project; and
- downstream utilisation of concept design-stage models in the design development stage.

Figure 43 shows the activities that can be performed in the concept design stage by using early stage BIM. A variety of software tools are now available to take a simple mass model for a building project and conduct design and analysis tasks needed at this stage of the project. Figure 44 shows a typical mass model of a building in which floors and building envelope elements are defined. Using this type of mass model, a variety of design and analysis tasks can be undertaken. As shown in Figure 45, a mass model of a building can be used to calculate the floor area, perimeter at each defined level of the building, volume of enclosed spaces and surface area of the building envelope. Calculation of these parameters is useful in conducting further analysis such as space programming, energy analysis and structural system selection, developing a better understanding of the design intent and preliminary services planning. Table 4 shows possible concept design-stage activities that can be driven by models developed at this stage of the project.

Figure 46 shows the use of mass models for sustainability analysis. The model available at this stage can broadly specify spaces, services requirements, material use, broad location and orientation information and other

Figure 44: Typical mass model for a building project during concept design stage

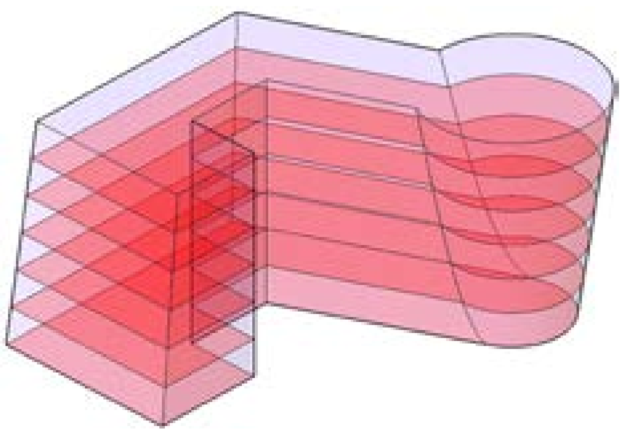


Figure 45: Workflow for analysis using a mass model

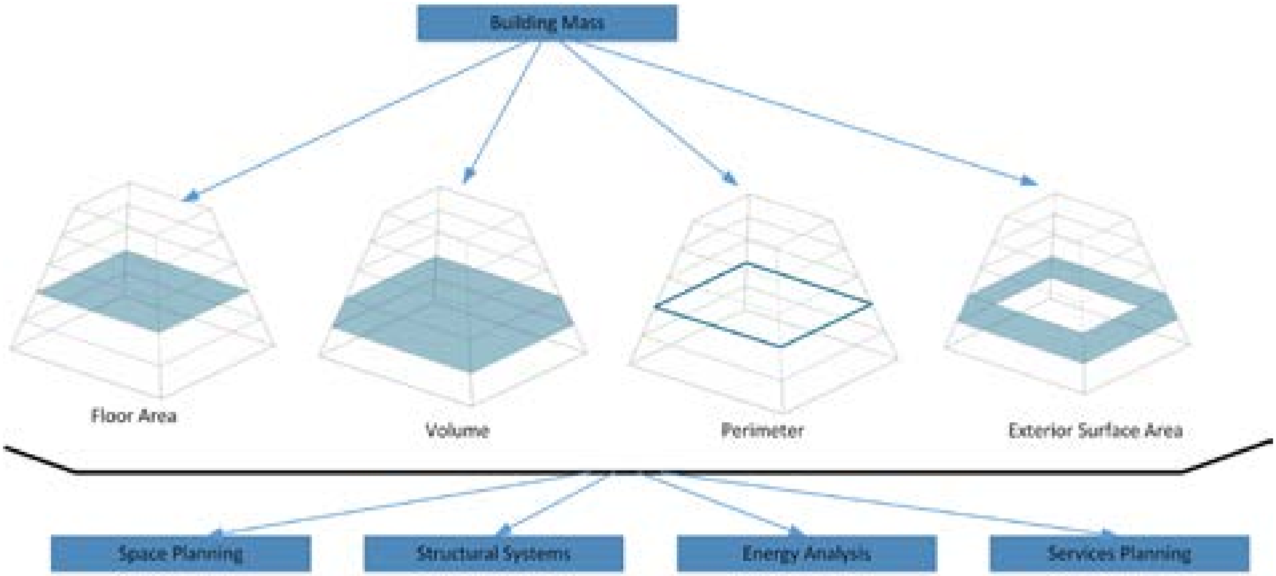
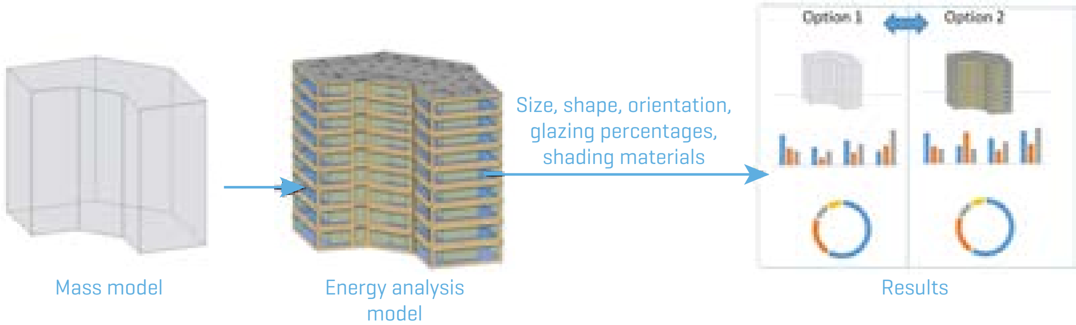


Table 4: Summary of concept design-stage activities using BIM

Concept design-stage activities	BIM activity
Produce concept design (multiple alternatives to be developed)	Mass model(s) with appropriate level of detail
Validate initial brief against the concept model(s)	Model-based programming calculations supporting a client's business need, asset and organisation strategy
Develop plans for stakeholder inputs	Use 3D models with visualisation and animation techniques for stakeholder participation (public participatory initiatives for non-building projects)
Establish financial viability and cash flow projections	Use historical cost and revenue databases to generate financial and cash flow calculations
Preliminary structural systems identification	For building projects develop floors, walls and building envelope elements to identify feasible structural systems
Preliminary services (mechanical, electrical, plumbing, fire-fighting, security etc.) identification	Services system choices, space requirements for services and service-area diagrams for the project
Structural system and services system coordination at the schematic level	Combined/federated model to demonstrate the first level of coordination between disciplines
Check building regulations with respect to concepts	Code compliance and regulations checking
Analyse sustainability issues	Carbon footprint, energy consumption, thermal comfort and other sustainability and efficiency parameters
Conduct constructability analysis and review off-site potential	Constructability analysis, comparison of concept models, find off-site potential using exploded models, site logistics
Prepare a preliminary cost plan	Areas, volumes and quantities based on conceptual cost plan, order of cost estimate, authorised budget
Details of project team formation	BIM expertise and experience, process- and practice-related issues
Seek client's input and approval	Visualisation and animation, design alternatives, comparison with financial, sustainability and other project targets

Figure 46: Sustainability analysis using mass models



sustainability-related information for the project. Most sustainability and energy analysis software can take this preliminary information and provide results that allow comparisons of concept design options and broad sustainability objectives.

Figure 47 shows a concept-stage building information model converted into a preliminary analytical model that can be analysed using cloud-based structural analysis software. This type of preliminary analysis that is now possible makes the use of BIM advantageous during the concept design stage.

Figure 48 shows a space programming tool called DProfiler™ that takes a mass model and performs spatial and financial analysis for the client to justify the investment.

Concept-stage models can be used to develop early stage cost plans (as shown in Figure 49). Model-based cost planning allows rapid development of cost plans for various early stage design alternatives.

3.2.3 BIM during developed design

Use of BIM in the detailed design stage of building and non-building projects has matured significantly over the years. In fact most of the literature available is focused on the use of BIM during this stage of the project, which is used extensively, primarily to perform:

1 BIM-based design authoring

2 detailed analysis using BIM; and

3 coordination of models.

Figure 50 shows the typical workflow for a detailed design of a project using BIM. The concept-stage model along with all the information collected for the project (both in 2D and 3D format) in the concept design phase is used to develop the core design model. For a building project this will be the architectural model. In the case of a non-building project the core design model could be an engineering model that forms the basis for modelling the remaining disciplines. In the design-authoring step the core design model is shared with other design and engineering consultants. This forms the basis of design authoring of disciplinary models by these specialist consultants.

Figure 47: Structural analysis using concept-stage model

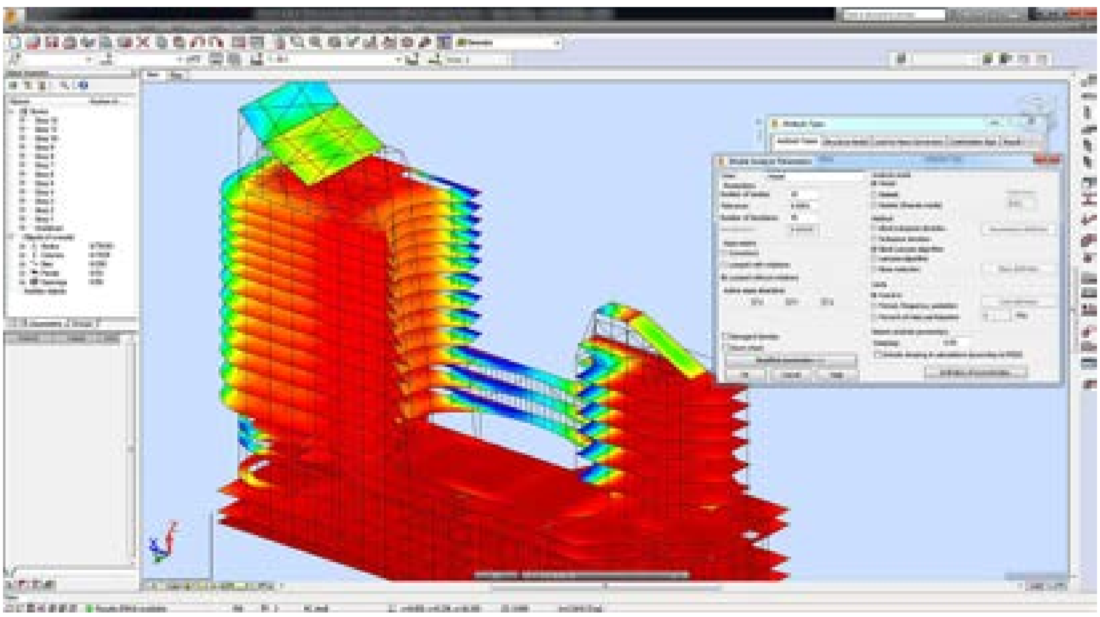


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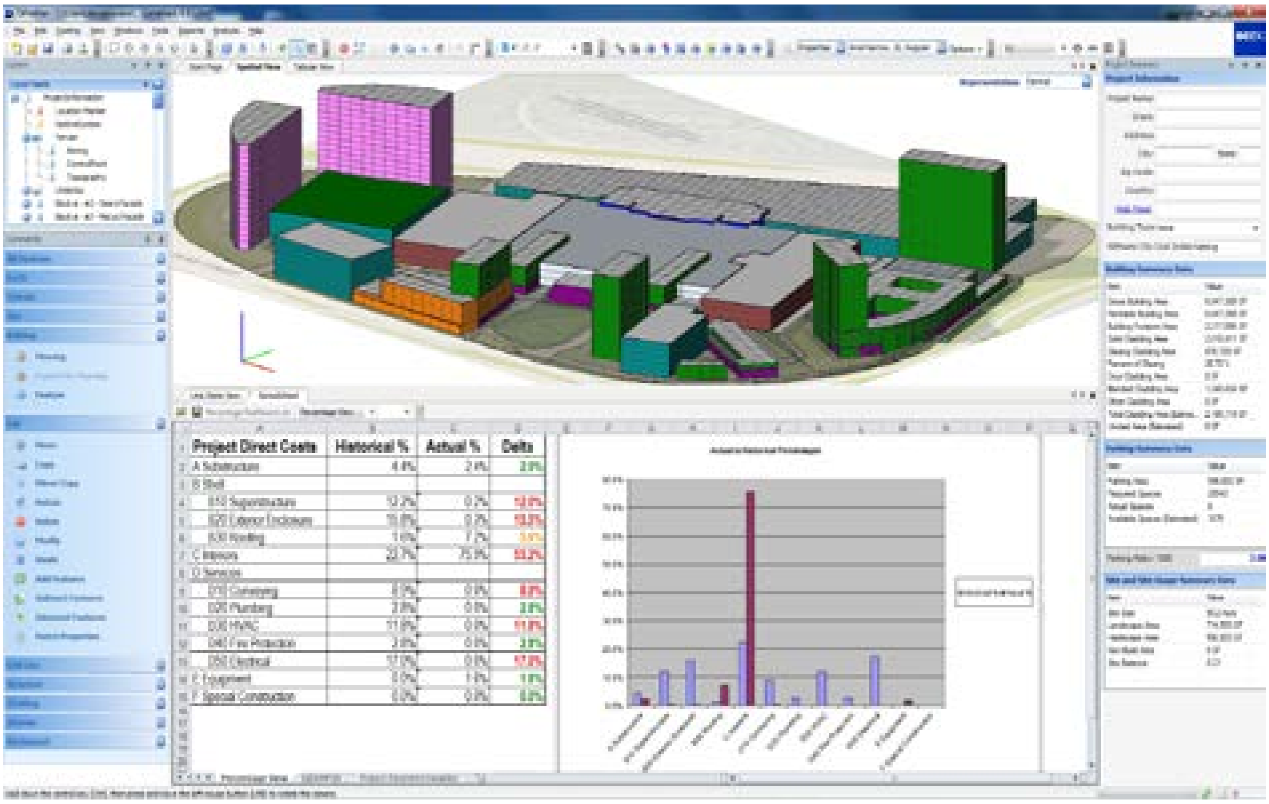
Figure 48: Space programing using concept-stage model



DProfiler™ screen shot reproduced with permission from Beck Technology Ltd.

Figure 49: Concept stage model-based cost planning

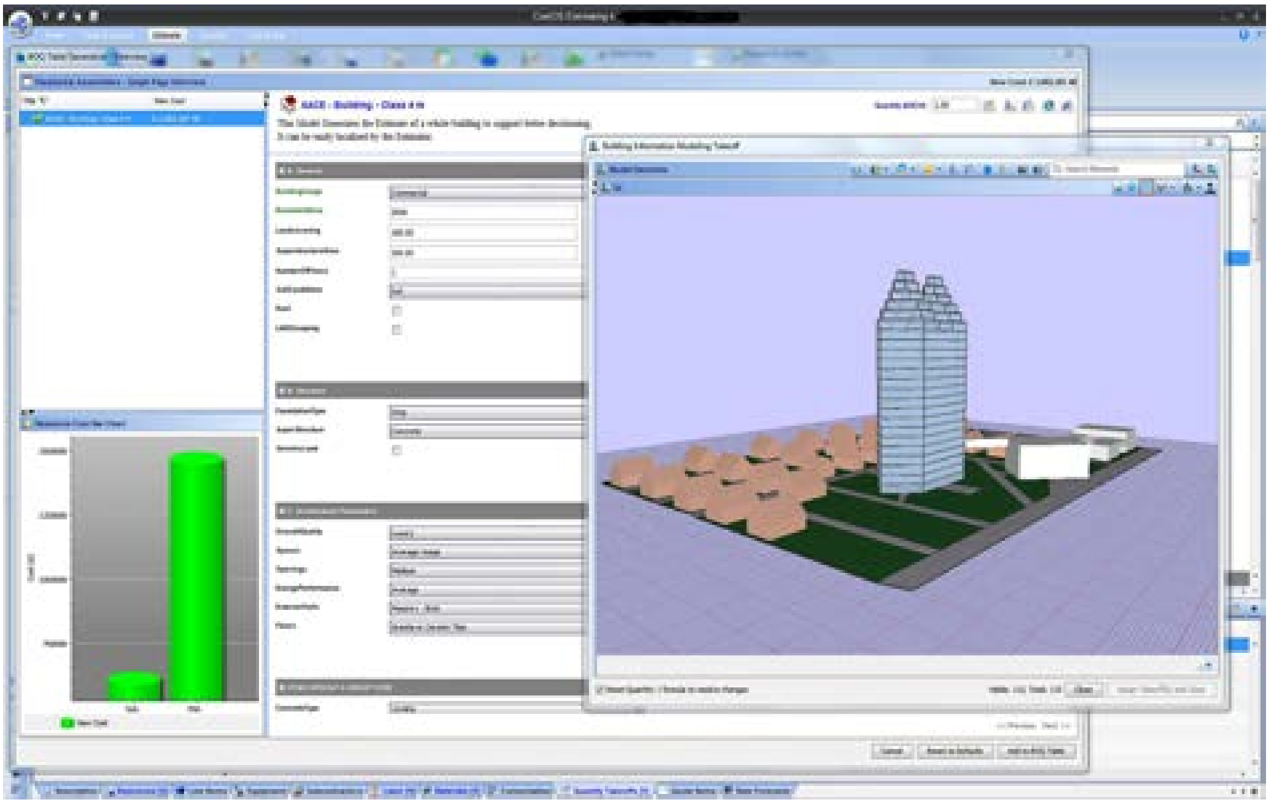


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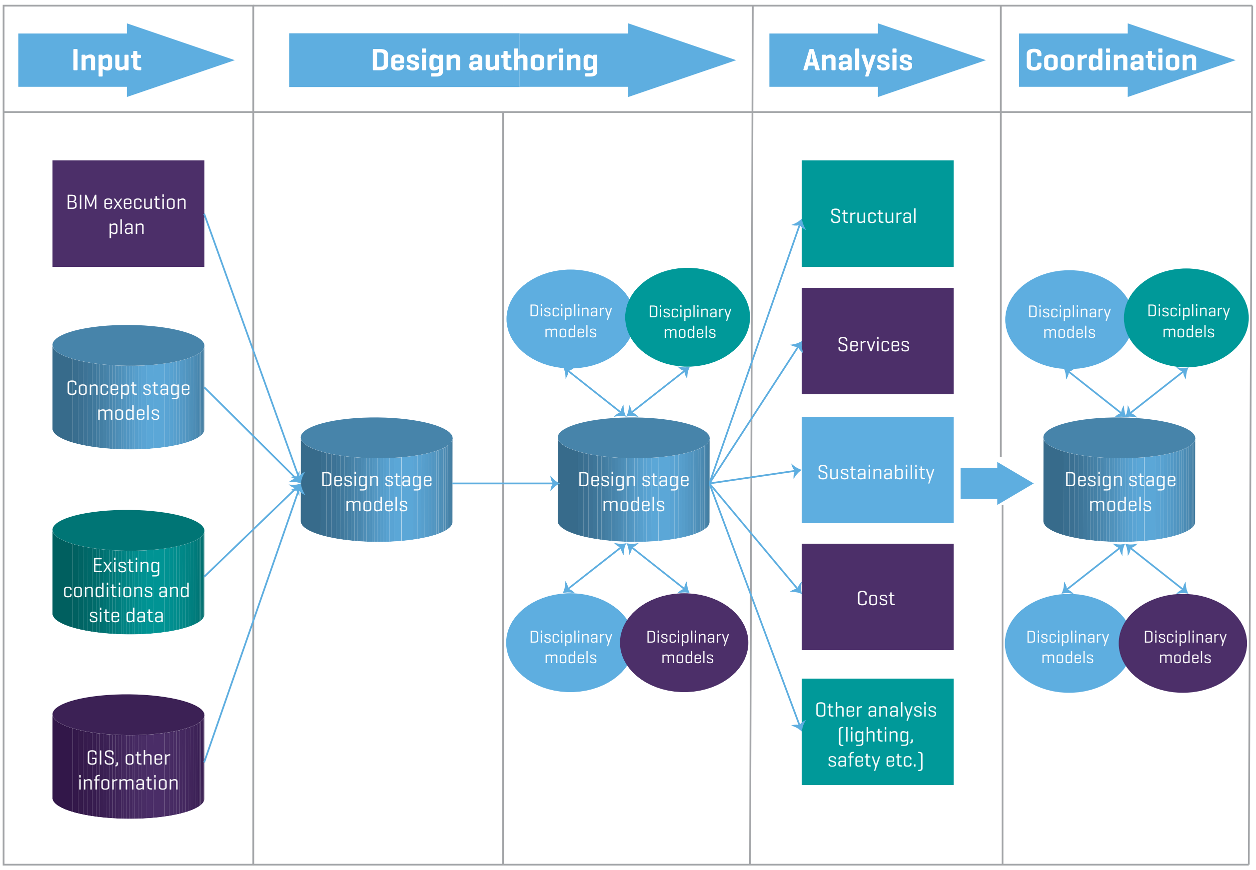
Figure 50: BIM-based detailed design process



The core design model is combined with the disciplinary models to develop a 'federated model'. The federated model serves the purpose of design coordination which is in fact an iterative process. After the initial coordination the federated model and disciplinary models are used for carrying out a plethora of analyses that include:

- structural analysis
- services analysis
- energy, environmental and sustainability analysis
- cost analysis; and
- other detailed analysis such as area analysis, lighting analysis, acoustic analysis, drainage analysis, shadow analysis, safety and security analysis and so on.

These detailed analyses enabled by the building information model developed so far are then typically used to finalise the design. Iteratively these revised models, enriched with disciplinary information, are coordinated to produce a near 'zero-defect' design. During these iterative steps the design team further enriches the models with specifications and other specific information about the models and the constituent modelling elements.

Figure 50 shows a high-level explanation of data-sharing and integration for design coordination and detailed analysis. Figure 51 shows a detailed workflow

Figure 51: BIM-based structural analysis and design

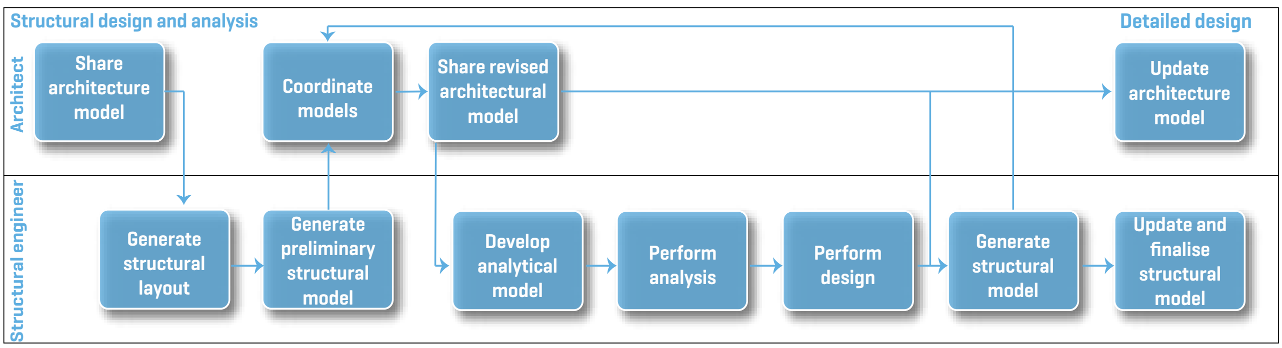
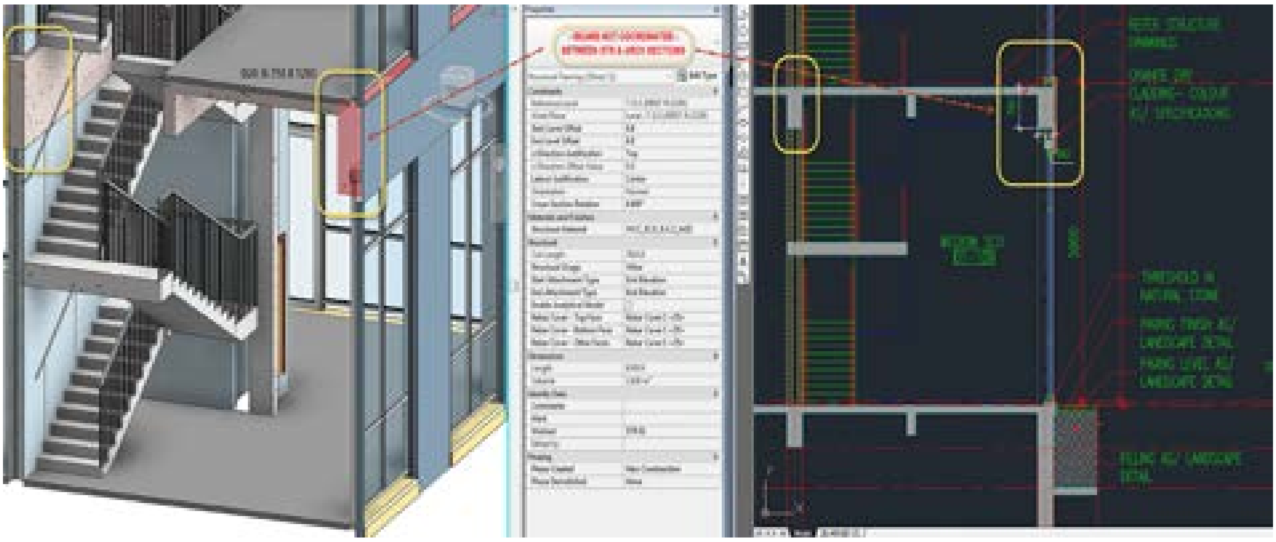


Figure 52: BIM coordination – 2D versus 3D



for structural analysis and design for a building project. Using the architectural model the structural engineer develops a general structural layout of the building. From this a preliminary structural model is developed. This is shared with the architect to conduct a preliminary coordination exercise with the architectural model.

After the coordination is completed the structural engineer typically proceeds to extract an analytical model (sometimes referred to as the 'stick' model) from the coordinated structural model. This analytical model is used to conduct structural analysis and design. After this a more accurate structural model is developed which is coordinated with the architectural model. This coordination step leads to the development of a design model for the structural discipline. A similar process is followed for the design development of other disciplines in the project. At the completion of this step, a coordinated and data-rich building information model of the project is ready.

Traditionally, design coordination has relied on drawing and other two-dimensional paper-based design information. With the use of BIM this process has been greatly enhanced. Software tools such as Solibri Model Checker, Tekla® BIMsight® and Autodesk® Navisworks® assist the design team in federating the disciplinary BIM and streamlining the coordination process. These tools greatly assist in the coordination process. Figure 52 shows the coordination process in a 3D environment compared to the coordination using 2D drawings.

Coordination performed using BIM systematically provides:

- identification of the relevant design issues and their coordinates
- data associated with the modelling disciplines and modelling elements causing the coordination or collision problem
- easy linkage of the issue back to the disciplinary models that are responsible for the issue; and
- the ability to track the issues until they are resolved.

Figure 53 shows a typical coordination report generated in this process.

At the successful completion of this stage the following key deliverables are produced:

- coordinated design models with a pre-determined level of detail
- confirmed spatial and circulation programmes
- project permitting and approvals information
- cost plan and financial information
- disciplinary models such as structural, MEP models; and
- client buy-in and approval of the design and the design-stage models.

Building information models produced at this stage of the project have a sufficient level of detail and specificity such that the project team can start considering procurement strategies and supply chain management issues. Models produced are taken forward seamlessly to the next stage of the project.

3.2.4 BIM during technical design

In the technical design stage of the project the primary aim is to provide construction-level detailing in the model developed so far. The key BIM-related activities during this phase are:

- detailed modelling, integration and analysis by discipline
- finalisation of the design stage model of all disciplines

Figure 53: Coordination report

WCC_SCO_MEP_PARCEL_3D								
S.No.	DRAWING / DOC No.	LOCATION / GRID REFERENC	DISCIPLINE	QUERY	REFERENCE IMAGE	REMARKS	RESPONSE FROM CLIENT	STATUS
1	WCC-00006	B4/A3P	MEPF	Coordination	[illegible]	Walls not coordinated	Location of store rooms to be confirmed b/w MEP & Architect	Open
2	WCC-00004 & 00003	Basement 02	MEPF	Missing	[illegible]	Drainage pipe layout missing	MEP to update drawing with pipe layout	Open
3	WCC-00001 & 00002	Basement 01	MEPF	Coordination	[illegible]	Walls / doors not coordinated	Location of store rooms to be confirmed b/w MEP & Architect	Open
4	WCC-00001 & 00003	Basement 01	MEPF	Coordination	[illegible]	Walls not coordinated	Location of store rooms to be confirmed b/w MEP & Architect	Open
5	-	Al electrical layouts	MEPF	Missing	[illegible]	Fixture legend missing	Revised legend received on 13-03-2014	Close
6	-	Basement 01 Electrical layout	MEPF	Coordination	[illegible]	Ceiling not available for light fixtures above ramp on ground floor	MEP to update FF drawings and share the same	Open
7	Grid : X4-A7	Basement 03 Electrical layout	MEPF	Coordination	[illegible]	Cable Tray Clashing with Duct & no space to accommodate other services above or below the duct.		Open
8	Grid : B30-A1	Basement 03 Electrical layout	MEPF	Coordination	[illegible]	Cable Tray Clashing with Duct & no space to accommodate above or below the duct.		Open
9	NOTE: For complete coordination and specific clash detection in Basements refer following files					Coordinated NWD file "WCC_SCO_MEP_COORD_3D_508" "WCC_SCO_3D_Typical clashes" "WCC_SCO_MEP_3D_508_CLASH_REPORT"		

- final coordination of the model
- pre-construction planning using BIM including safety planning, phasing and prototyping, procurement planning and supply chain management and so on
- finalisation of specifications at the building element level based on the creation of production-level parametric objects for all major elements in the project
- code checking and export of data for building control analysis
- quantity take-off and cost planning
- perform risk management activities associated with the project
- document production as per the procurement strategy
- final review and sign off of model; and
- finalising and enabling access to model for constructors(s).

Figure 54 shows the process map for the technical design stage of the project. The lead design consultant for the project, working closely with other design and engineering consultants, undertakes the finalisation of the models by using specific modelling elements and by enriching the model with specific technical information. These disciplinary models are coordinated with the main discipline model (i.e. the architectural model for a building project or the engineering model for a non-building project) with close interaction with the entire project team. In the process map in Figure 54 it is assumed that the project management consultant (PMC) has been made responsible for conducting the coordination tasks and developing a federated model.

After numerous iterations the final technical design stage models are completed and approved by the client or the client's representative. After this the PMC publishes a federated building information model that combines all disciplinary inputs. Additional analysis is carried out using this federated model; for example, code compliance checks by the lead design consultant, cost planning by the quantity surveyor (QS) (in some regions terms such as estimators, construction economists and cost planners may also be used to refer to a QS) and 4D planning by the construction team. Thereafter the technical design-stage models are frozen, the client's approval is obtained and the project proceeds to the construction phase.

During the technical design stage very specific information pertaining to the modelling elements in the model is provided. The model is essentially ready to be

Figure 54: Process map for technical design stage

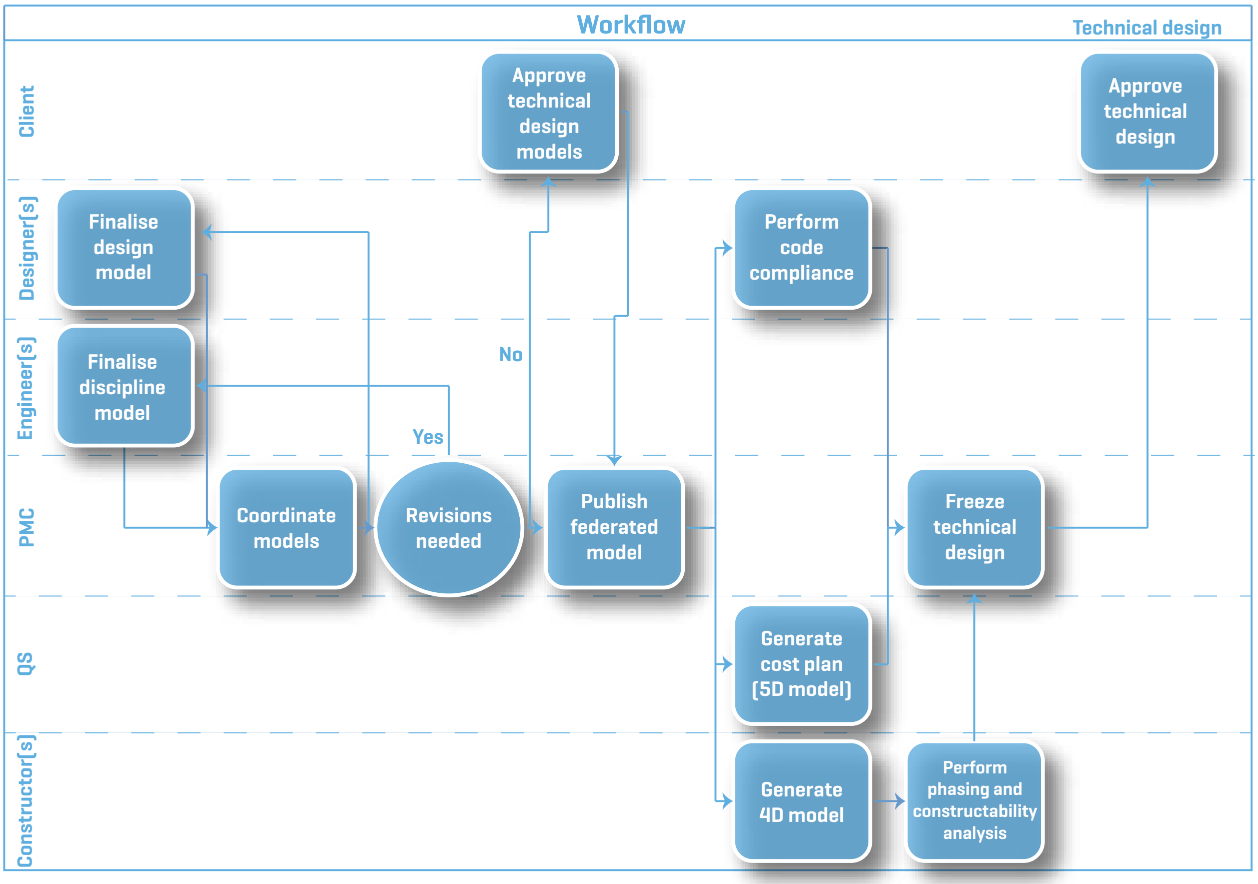
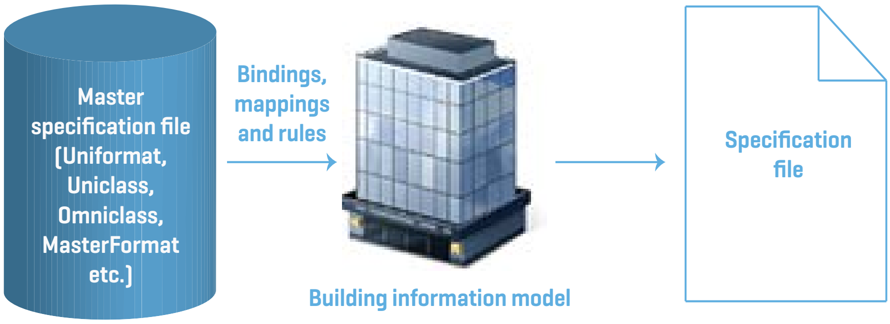


Figure 55: Adding specifications to the building information model



transferred as a construction-stage model. In this phase of the project specifications are added to the model using an open-definition and interoperable format. The objective is to establish a protocol for the identification of properties required to specify materials, products and equipment used in the model.

As shown in Figure 55, the process of adding specifications to the modelling elements involves using a master specification file (e.g. UniFormat or Uniclass) and then binding and mapping modelling elements in the building information model. For example, using a BIM-authoring tool called e-SPECS the modeller can add specifications to the modelling elements using the 'assembly code' property of the object (shown in Figure 56).

Similarly, the process of quantity extraction and cost planning is also undertaken in the technical design stage of the project. This task is performed by the QS. In Figure 57 the cost planning process map is shown. The QS utilises the model in BIM-authoring tools or special BIM-based cost planning tools. If not already set, the QS sets the classification system for the model so that the model elements can be classified and quantified using an industry-accepted classification standard. Using the accepted rules of measurement the QS then produces a schedule of quantities for various modelling elements. Objects that are not modelled or cannot be quantified using the models are separately calculated using manual procedures. This results in the production of a bill of quantities that can then be priced to produce a cost plan for the project.

In Figure 58 the 4D planning process completed in the technical design stage is explained. The process involves linking the model with the project schedule. A variety of

Figure 56: Adding Uniformat codes to modelling elements

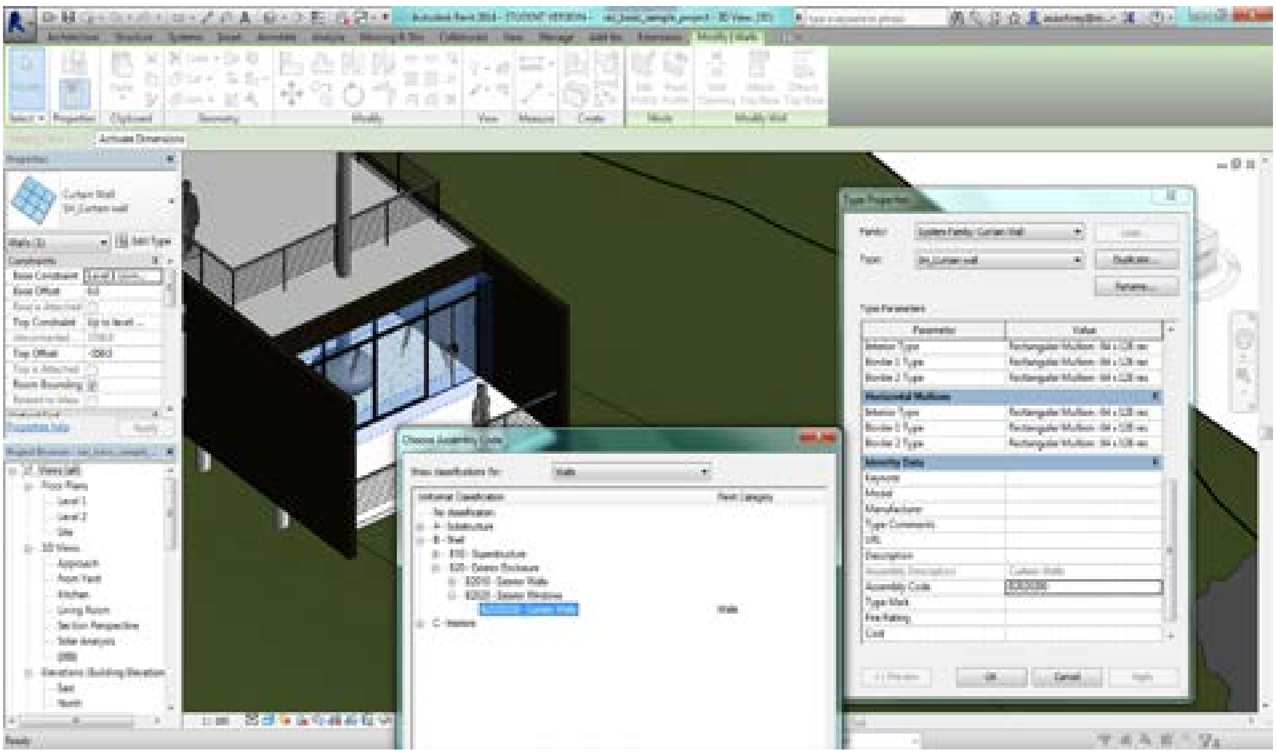


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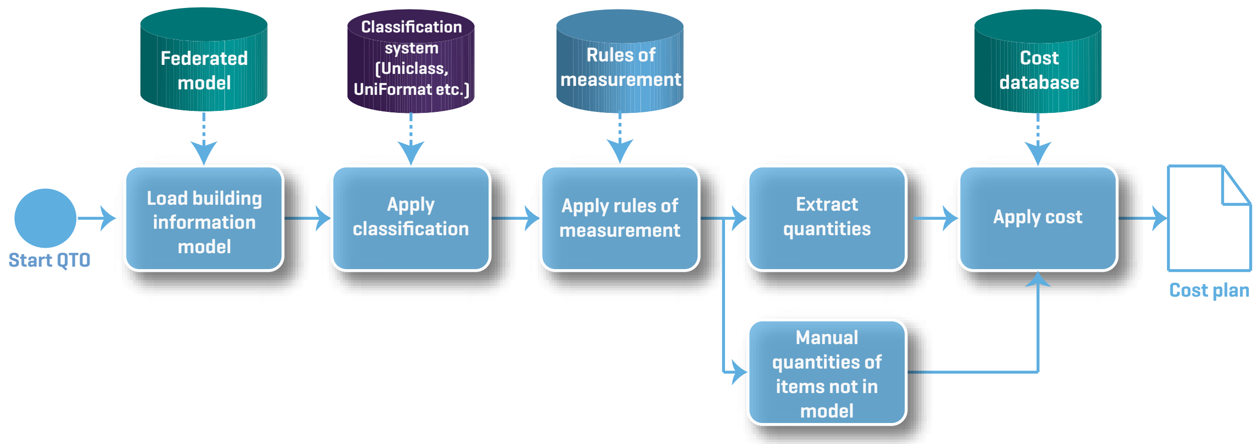
Figure 57: Cost planning process using BIM



schedule formats can be used in this process.

The technical design phase of the project is completed and all the deliverables in pre-determined level of detail are provided to the constructor(s) for the construction stage of the project.

3.2.5 BIM during construction

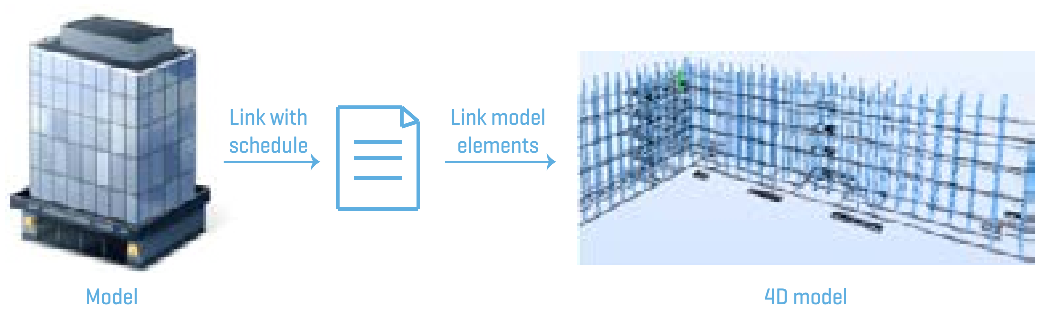
BIM in the construction phase is being used extensively on projects. The model used during this phase is commonly referred to as the construction model. Sometimes also referred to as 'field BIM' or 'mobile BIM', BIM in the construction phase is generally used to:

1. develop a better cognition of the design intent of the project and the components that are to be constructed
2. achieve better on-site collaboration and coordination between contractors and subcontractors
3. identify and resolve construction issues/problems in the most expeditious manner using BIM-based request for information (RFI) systems
4. design temporary works (scaffolding, hoists, shoring, etc.) and understand construction phases and sequencing using time-based clash detection
5. enable use of off-site components and their planning and coordination
6. obtain procurement and supply chain information about construction components and products used in the project
7. develop shop or fabrication drawings and other production information, such as specifications associated with each building component that the contractor must supply or construct. This information is used for procurement, installation, and commissioning
8. obtain the design and construction status of each construction component to track and validate the progress relative to design, procurement, installation, testing and commissioning
9. perform risk management activities associated with the project
10. integrate with cost and schedule control and other project management functions including verification, guidance and tracking of construction activities using BIM-based tools;[101] and
11. prepare models and documentation for handover and commissioning.

In most circumstances the constructor takes charge of the model during this stage. In newer forms of project delivery constructors get involved in the early stages of the project which makes the transition to development and use of the construction model easier.

Maximum gains during this phase can be made by

Figure 58: BIM-based 4D modelling process



collaborating with vendors and suppliers to streamline the procurement and delivery of products and equipment. Efficiencies gained in the supply chain management processes can be significant. As the model contains detailed product information, supply chain management and procurement management tasks become more streamlined.

One of the common challenges in this phase is the issue of communicating with site staff who are more attuned to reading project documents such as 2D drawings and related information. This issue must be carefully handled on a project-by-project basis. Some construction organisations use innovative visual communication tools to overcome this issue, as shown in Figure 59. Similarly, tools are available to deploy the construction model on various easy-to-use devices such as tablets and touch-screen computers.

Detailed information about various components including quantity and component property information can be extracted with ease from the building information models if they have the appropriate level of detail or development. Specification information associated with each building component can also be obtained (shown in Figure 60). This information can be used for cost management, procurement, installation, testing and commissioning. The project monitoring and control process can also be enhanced by using the 4D plan generated earlier to track the status of the project and its activities. Such tools are now commercially available.

Construction-stage models can also be used for proper site layout planning, temporary works planning (e.g. scaffolding and its possible interference with construction progress) and modelling equipment such as tower cranes, hoists and so on. Figure 61 shows the modelling of construction equipment and temporary works on a building project.

One of the major outcomes of BIM implementation is to reduce 'hassle' during the construction stage. BIM can be used to cut down on waste, rework and other inefficiencies on the construction site. Full utilisation of BIM during the construction stage and preparation of the models for the downstream phases is essential for successful implementation of BIM.

3.2.6 BIM during handover and close out

In the life cycle of any asset, a large proportion of cost and resource use takes place during the operation and maintenance phase. The full potential of BIM can be realised only if the model(s) is used during this phase of the project. Figure 62 shows the typical cost and resource use over the life cycle of an asset. With a large chunk of cost expended during the use life of the asset it is crucial that the design and construction processes of the asset are geared towards delivery of a record model or as-built model of the asset to ensure that the operation and maintenance phase of the project can be run efficiently.

As explained in section 2.2.2, COBie (COBie2 2012 in the UK) is currently the de facto standard to be followed. It simplifies the work required to capture and record project handover data and prepare a record model (an as-built model) with the sufficient level of detail that is needed during the operation and maintenance phase. The approach is to enter data as they are created during design, construction and commissioning. Designers provide information

Figure 59: Field use of BIM

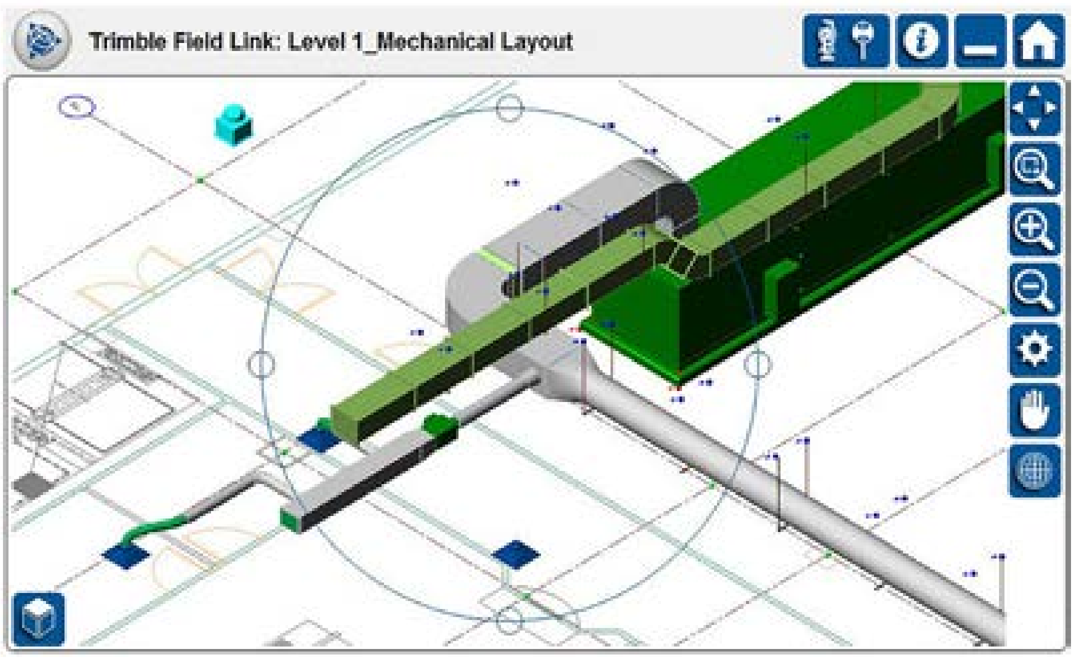


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Figure 60: Obtaining detailed information about components

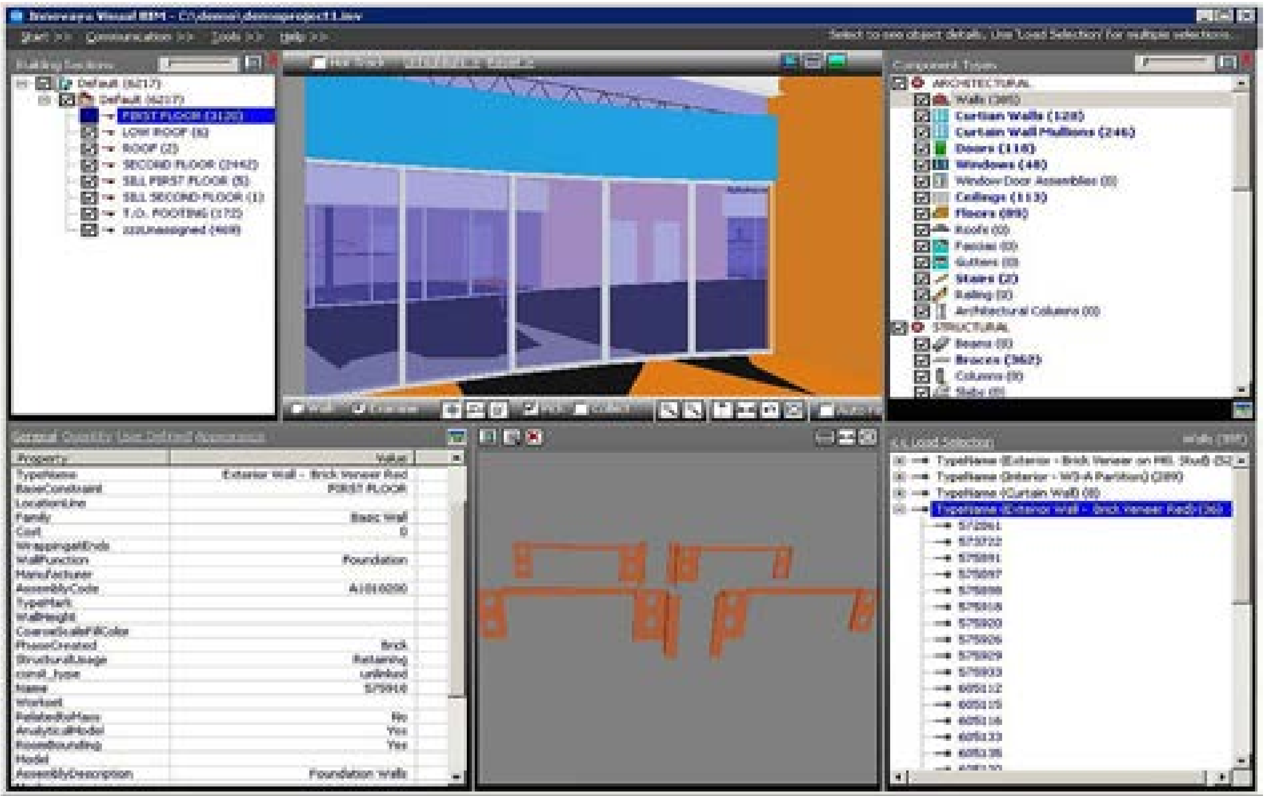

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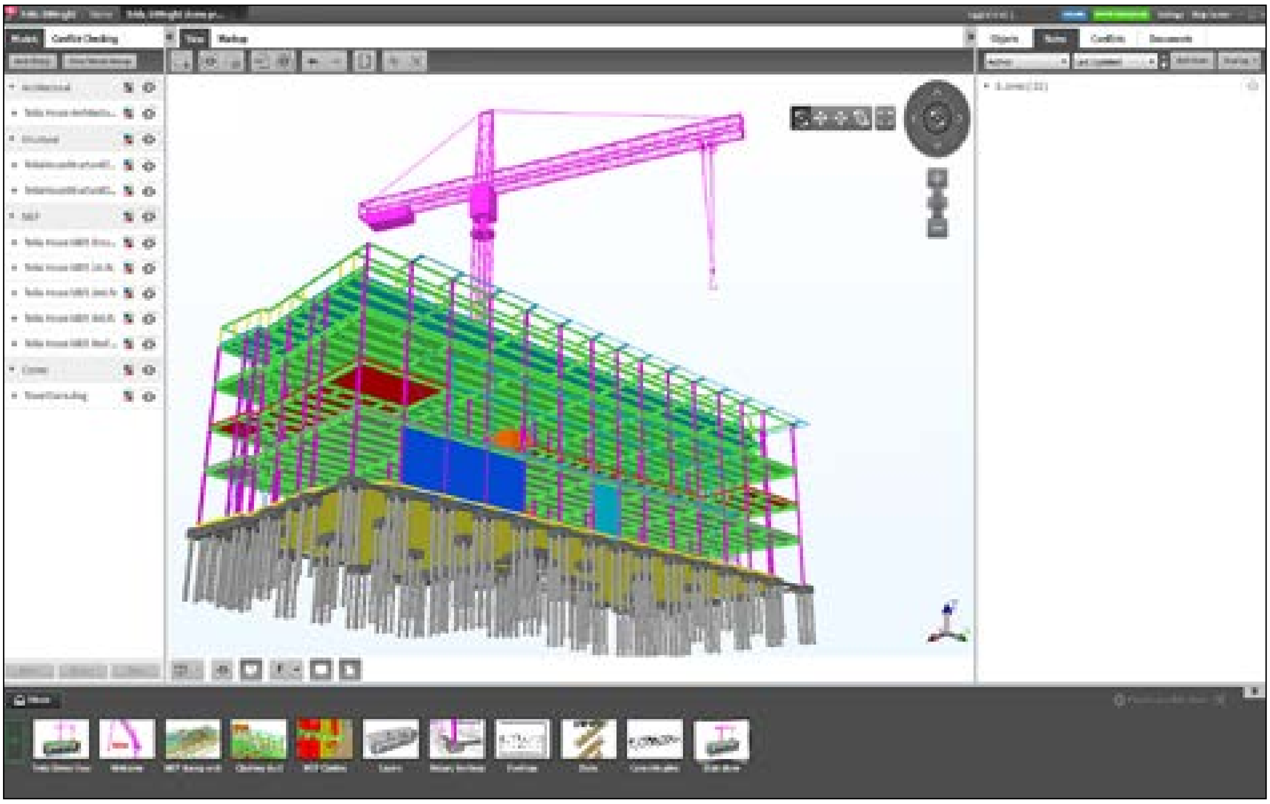
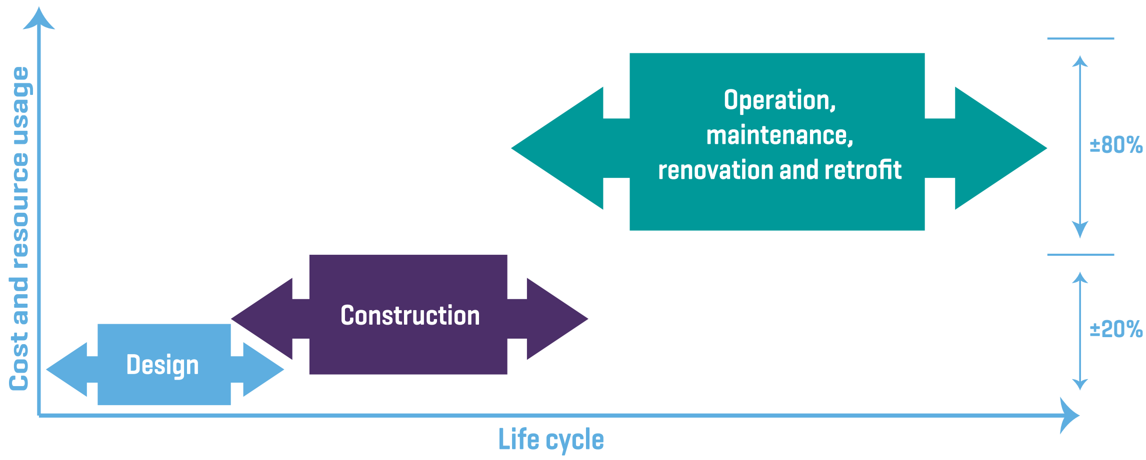
Figure 61: Construction equipment and temporary components modelling using BIM



Courtesy of Tekla. Tekla is a registered trademark of Tekla Corporation.

Figure 62: Cost and resource use over the life cycle of an asset



pertaining to floor, space and equipment layouts.[102] Contractors provide specifications such as make, model and serial numbers of installed equipment. Data provided by contractors come directly from product manufacturers who participate in COBie2.[103] Figure 63 shows the COBie process.

COBie is an evolving standard with differing levels of maturity and usage in different parts of the world. The UK BIM Task Group has prepared a UK-specific COBie entitled COBie-UK-2012. Construction-Operations Building Information Exchange (COBie), as the name suggests, is geared towards building projects and is somewhat weak in capturing data for a non-building project. Efforts are underway to investigate the potential for common data structures: the 'COBie for all' project has been taking a close look at the technical issues surrounding the storage of data for both buildings and infrastructure.[105]

There are other standards that are useful during this phase of the project; for example, the Open Standards Consortium for Real Estate (OSCRE) Occupier Portfolio Management standard is useful for BIM-based facility management of assets.

3.2.7 BIM during operations and end of use

BIM is becoming increasingly popular during the operation and maintenance phase of a project. End users and asset owners can use BIM during this phase to:

- plan, prevent or correct the maintenance of building components
- operate the asset in its optimal capacity as per the business requirements of the owner and consistent with design intent
- plan space and occupancy and optimise portfolios
- proactively manage, monitor and adjust building functions in a more energy efficient way against a baseline performance model
- monitor building sensors and real-time control of building systems
- eliminate or minimise energy waste while maintaining a comfortable and safe environment, increase efficiency and reduce costs
- plan and prepare for evacuation and other emergency crises; and
- make renovation, retrofit and demolition decisions using accurate as-built information.

To perform these functions it is crucial to connect the accurate as-built record model of the building with a number of other hardware and software technologies. Integration with the sensor network and the asset or building management system is crucial. A number of software platforms are now available to accomplish this integration. Figure 64 shows an example of such a software platform for a building.

3.3 Types and progression of models

As the BIM implementation on a project moves along the project life cycle stages the associated model(s) also changes and information enrichment progresses. This progressive set of models is also sometimes referred to by different naming conventions. One convention that is common in the industry categorises the models into:

1 the concept-stage model (also called the mass model)

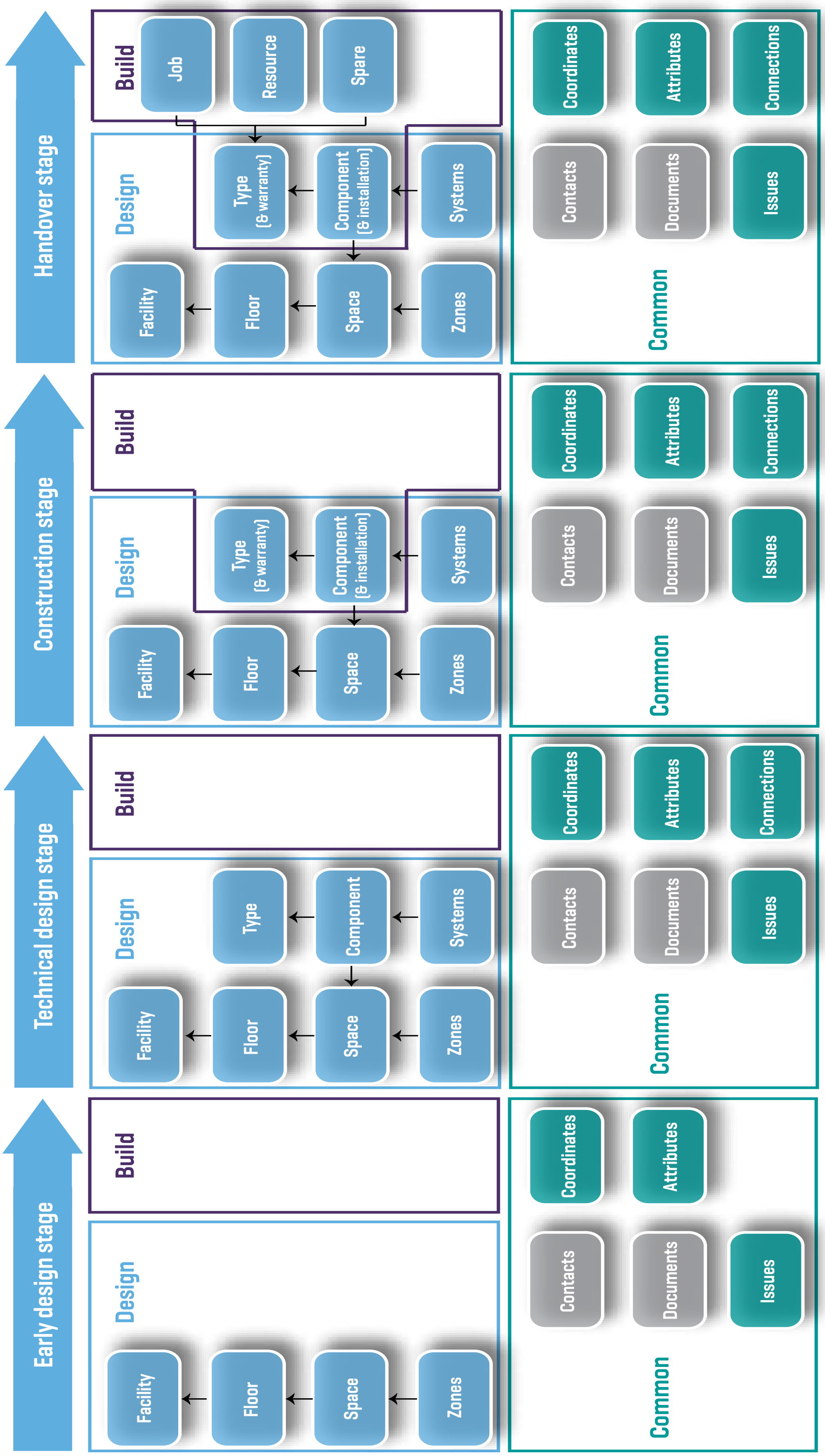
2 the design-stage model (also called the design model (in the case of a building project these can also be referred to as the architectural model, structure model, MEP model etc.))

3 the construction-stage model (also called the construction model); and

4 the operation and maintenance-stage model (also called the record model).

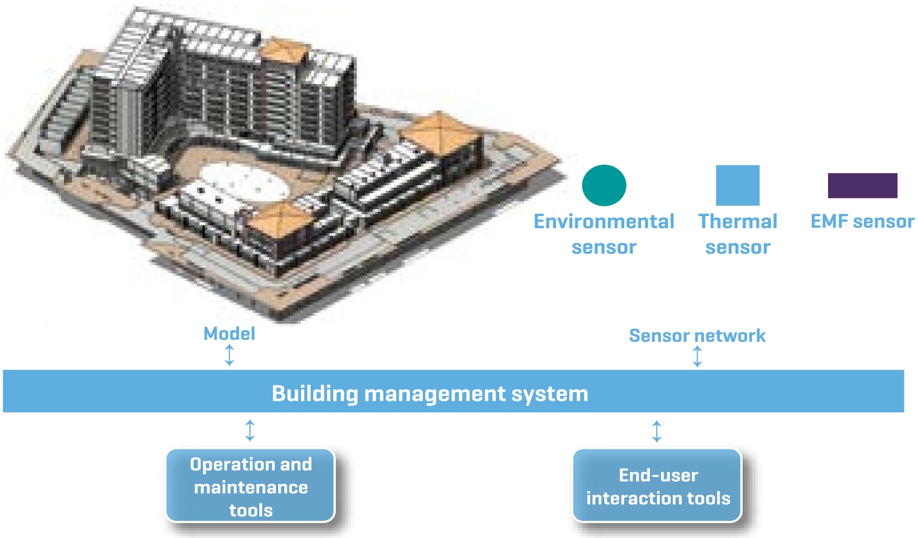
Two main criteria that define model progression along the project life cycle are:

Figure 63: COBie-based handover of record models



Adapted from Whole Building Design Guide, a program of the National Institute of Building Sciences.[104]

Figure 64: BIM-based facility management



- level of detail[106] (detail in terms of the graphical representation alone) and level of development[107] (in terms of information richness); and
- the participation of the project team members.

Figure 65 shows the model progression along the project life cycle. The level of detail increases (signified by the height of the cylinder) as the project moves from one stage to the next. The contribution of project team members also increases (signified by the diameter of the cylinder). The contribution level of the project team members is defined in the BIM implementation plan in which roles and responsibilities are clearly identified for each team member. Defining the level of detail and development to be incorporated in the building information model is a bit more difficult.

The amount of information available for a project and its components increases as the project progresses from stage to stage. How much of the available information will be incorporated into the model and at what stage? This is a very important question that needs to be addressed.

It allows the project team to understand and specify phase-wise BIM deliverables and information/detail to be incorporated in a BIM deliverable. Using the notion of level of development (and level of detail; LOD) model progression can be defined.

Figure 66 uses the example of a chair to explain the LOD concept. Early-stage models have a 'block' representing the chair. As more design and construction detail becomes available and is incorporated into the model the LOD increases, thereby meaning that information captured in each of the modelling elements in the model increases.

The concept of LOD was originally provided by Vico Software Inc. and then embraced by the AIA in G202-2013 *Project building information modelling protocol form*.[108] The LOD specification is a concept that enables the project team to clearly specify and articulate the content and reliability of BIM at various stages in the design and construction process. It defines the characteristics of model elements of different building systems at different LODs. This clear articulation allows model authors to

Figure 65: Model progression

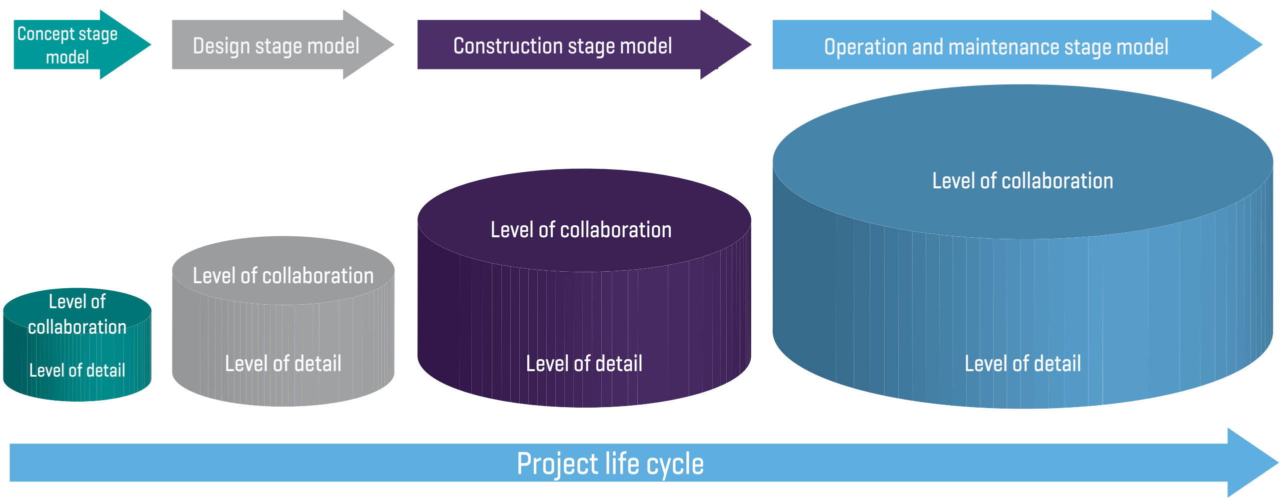
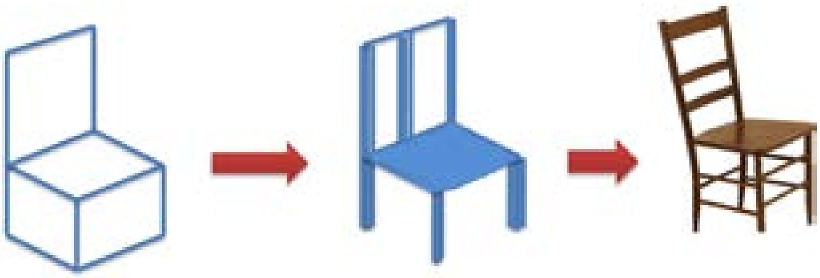


Figure 66: Level of development



define what their models can be relied on for and allows downstream users to clearly understand the usability and limitations of models they are receiving.[109] Table 5 shows the AIA LODs for model progression along with the authorised uses of the LOD models.

Figure 67 shows the AIA LODs in the model element table along with model element author information using the UniFormat classification system for a building project.

Similar information about LOD/level of model development is also available from PAS 1192-2:2013, *Specification for information management for the capital/delivery phase of construction projects using building information modelling*.[111] Model development stages defined in this document are:

1 brief

2 concept

3 definition

4 design

5 build and commission

6 handover and closeout; and

7 operation.

For each stage of model development the following dimensions are described:[112]

1 systems to be covered

2 what the model can be relied on for output

3 parametric information

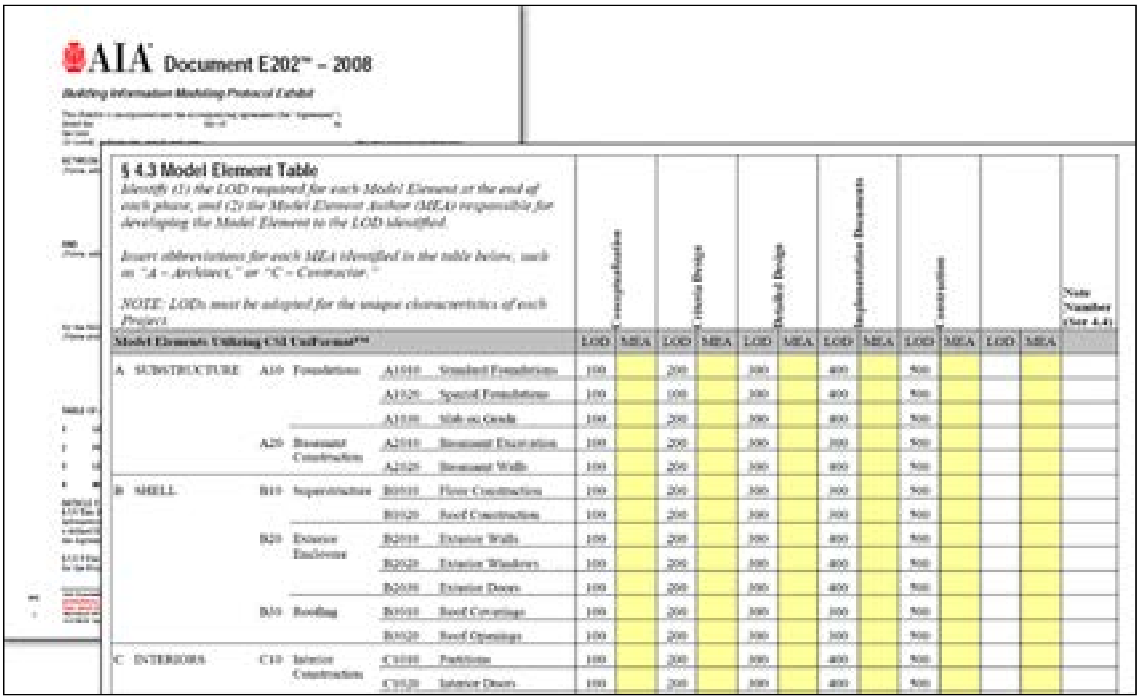
4 employer activities; and

5 critical interfaces and logic.

3.4 Collaboration and coordination using BIM

Collaboration and coordination are key for successful BIM implementation. Technology and process both play

Figure 67: AIA model element table with LOD and author information



AIA Document E202™ – 2008

Building Information Modeling Protocol Exhibit

§ 4.3 Model Element Table

Identify (1) the LOD required for each Model Element at the end of each phase, and (2) the Model Element Author (MEA) responsible for developing the Model Element to the LOD identified.

Insert abbreviations for each MEA identified in the table below, such as "A – Architect," or "C – Contractor."

NOTE: LODs must be adapted for the unique characteristics of each Project.

Model Elements Utilizing CSI UniFormat™						Conceptualization LOD	MEA	Criteria Design LOD	MEA	Detailed Design LOD	MEA	Implementation Documents LOD	MEA	Construction LOD	MEA	LOD	MEA	Note Number (See 4.4)
A	SUBSTRUCTURE	A10	Foundations	A1010	Standard Foundations	100		200		300		400		500				
				A1020	Special Foundations	100		100		300		400		500				
				A1030	Slab on Grade	100		200		300		400		500				
		A20	Basement Construction	A2010	Basement Excavation	100		200		300		300		500				
				A2020	Basement Walls	100		200		300		400		500				
B	SHELL	B10	Superstructure	B1010	Floor Construction	100		200		300		300		500				
				B1020	Roof Construction	100		200		300		300		500				
		B20	Exterior Enclosure	B2010	Exterior Walls	100		200		300		400		500				
				B2020	Exterior Windows	100		200		300		400		500				
				B2030	Exterior Doors	100		200		300		400		500				
		B30	Roofing	B3010	Roof Coverings	100		200		300		300		500				
				B3020	Roof Openings	100		200		300		300		500				
C	INTERIORS	C10	Interior Construction	C1010	Partitions	100		200		300		400		500				
				C1020	Interior Doors	100		200		300		400		500				

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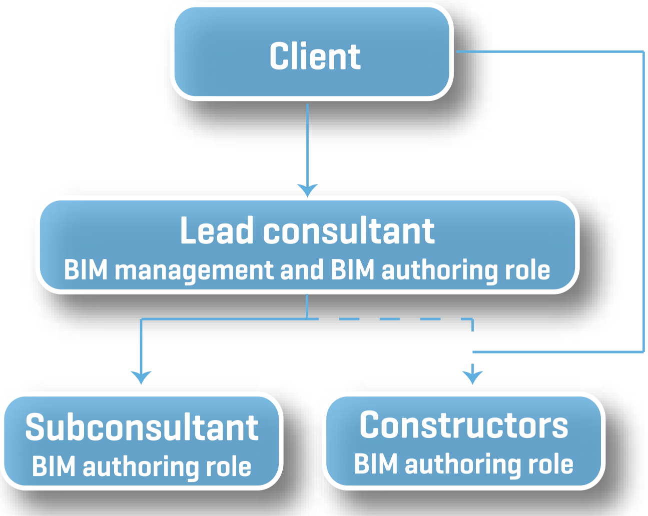
Table 5: Explanation of LODs

Level of development (LOD)	Modelling element content	Authorised uses
100	Illustrated generically. Not enough information is given to meet LOD 200.	Used for: • analysis based on area, volume, and relationships with other modelling elements • cost estimation, using area and volumes; and • phasing.
200	Illustrated as a generalised system, object or assembly. Quantities, size, shape, location and orientation are approximated. Non-graphical data may be included.	Used for: • analysis based on generalised performance criteria • cost estimation based on approximate data • scheduling to show when and in what order major elements and systems will appear; and • coordinating generally with other modelling elements, regarding size, location, and clearance.
300	Illustrated as a particular system, object or assembly. Quantities, size, shape, location and orientation are specified. Non-graphical data may be included.	Used for: • analysis based on specific performance criteria • cost estimation using specific information provided suitable for procurement • scheduling to show when and in what order major elements and systems will appear ; and • coordinating specifically with other modelling elements regarding size, location, and clearance, including general operation issues.
400	Shown as a particular system, object or assembly. Quantities, size, shape, location and orientation are specified. Additionally, specifics are given about detailing, fabrication, assembly and installation. Non-graphical data may be included.	Used for: • analysis based on actual performance criteria • costs are based on actual costs at buy-out • scheduling to show when and in what order major elements and systems will appear, incorporating construction means and methods; and • coordinating specifically with other modelling elements regarding size, location, and clearance, including fabrication, installation and detailed operation issues.
500	Details of size, shape, location, quantity and orientation have been verified in the field.	• As-built and record model.

Adapted from AIA G202-2013 Project building information modelling protocol form.[110]

Figure 68: BIM implementation infused in the project team



a crucial role in effective collaboration and coordination on BIM projects. In subsection 2.7, the model server technology aspect of collaboration and coordination was described, especially from the point of view that more than one model is developed on a project and that multiple project team members participate in the creation of these models. In addition to the technology aspect it is crucial to devise a collaboration and coordination process on BIM projects. The process is dependent on the nature (building or infrastructure) and complexity of the project, type of project delivery used on the project and the party responsible for BIM.

Collaboration and coordination on a BIM project will change based on the execution strategy and organisation structure that is adopted. Figure 68 and Figure 69 show two extreme possibilities. Figure 68 shows an organisation set-up in which the lead consultant, who retains the subconsultants and also works with the constructor(s), takes on the role of BIM management in addition to their modelling role for the specific domain. In this set-up each entity on the project team is responsible for the development of their domain-specific model while the lead consultant takes on the role of coordination and collaboration.

At the other extreme, as shown in Figure 69, the entire modelling and management responsibility is shifted to a specialist agency, either retained by the lead consultant or the client directly, which performs the coordination and collaboration role. This set-up, especially in the long run, may not be successful since adding another entity to the project team will complicate the project delivery and perhaps lead to less than optimal results.

The actual organisation structure adopted for a project may be somewhere in between these two extremes. Depending on the project team arrangement, a detailed model collaboration and coordination process can be included in the BIM execution plan. A generic process that can be adopted for a building project is outlined below:

1 Design team members assigned the task of modelling prepare their model in a pre-agreed format using a pre-determined software and a common repository of project information.

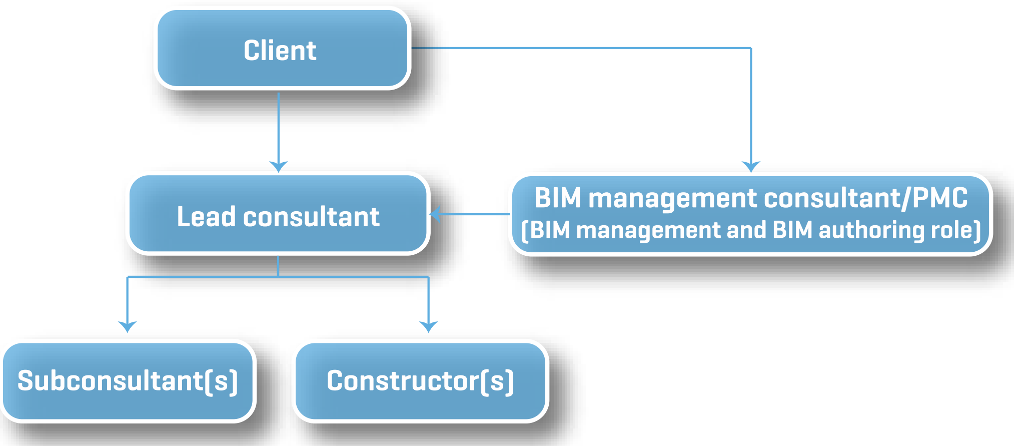
2 A single point of contact with BIM management responsibility provides all the project information.

3 Based on the pre-determined model progression plan, various project team members produce models as per the project life cycle phase that the project is currently in; for example, the architectural model is developed first and shared with other project team members.

4 After all disciplinary models have reached the LOD appropriate for that stage, models are federated by the project team member responsible for BIM management.

5 Coordination meetings are conducted on a regular basis to identify clashes among modelling elements. A report is generated clearly highlighting the issues and the project team members who need to provide input to resolve them.

Figure 69: BIM implementation outsourcing model



6 Feedback is provided to the project team members on discrepancies and missing information. Model quality issues are also discussed.

7 Using the identified clashes, all pertinent models are modified and the process is repeated to achieve coordinated models so that downstream activities can be started.

Technology, especially online (cloud-based) collaboration and document management tools, play a big role in the collaboration and coordination process.

3.5 Asset management using BIM

Asset management, an important business function for most organisations, can significantly benefit from BIM. ISO 55000 defines asset management as ‘coordinated activity of an organisation to realise value from assets’.[113] Recently organisations have realised that there is a mutually supportive relationship between BIM and asset management.[114] Asset management relies heavily on the availability of accurate, detailed and timely information about the asset. BIM provides information-rich models of the asset that can be used to populate the asset information model (AIM). With the help of the AIM, the organisation can make better decisions about the asset during its entire life cycle. BIM therefore provides an information-rich framework for the creation, collation and exchange of information about assets allowing effective asset management.[115]

4 Implications of BIM on organisations

Organisations involved in the built environment sector (comprising residential buildings, non-residential buildings and civil engineering facilities), falling under the complex, products and systems (CoPS) categorisation in the literature,[116] are normally typified as PBOs.[117] These project-centric organisations integrate diverse and specialised intellectual resources and expertise and thrive on the creation of project-delivery networks based on alliances between participants from contractually bound multiple organisations.[118, 119]In this type of project-centric network, any technology adoption must also be viewed from the people, process and organisational point of view. Therefore, application of BIM on individual projects has a direct implication on the organisations that are part of the project-delivery network. This leads to two complexities that need to be understood carefully for any organisational or sector-level BIM adoption initiative. These two complexities are:

1 Commercial and contractual characteristics of the project -delivery network are unique in the built environment sector. Even though there are a plethora of project-delivery systems available, the fundamental differentiator for the built environment sector is the uniqueness of each project and the resultant bespoke processes, functions and outputs. Figure 70 shows the project-delivery network for a typical built environment-sector project. The novel nature of the processes (as compared to the stable nature of processes in the manufacturing sector) and the contractual boundaries make the adoption of BIM more challenging.

2 The industry is currently in transition. Most organisations have both BIM and non-BIM projects ongoing. Very few organisations have completely switched to BIM with all projects being BIM based. This adds another layer of complexity to the project-delivery network, making the adoption of BIM even more challenging. Figure 71 shows project-delivery networks in the built environment sector becoming complicated due to the mixed nature of BIM adoption. Not only is it possible to have organisations with a mix of BIM and non-BIM projects, it is quite plausible to have organisations in the project-delivery network that do not use BIM at all. Many BIM projects in the industry currently are not using all aspects of BIM, so on some projects there are BIM-based functions and non-BIM based functions that need to be performed by the project-delivery network. This is shown in Figure 72.

Given these complexities it is easy to recognise that BIM adoption in the built environment sector is not a simple task. In fact, there are quite a few undocumented stories of failed BIM projects leading to some organisations shifting back to traditional methods and practices due to failed implementations at the organisational level. News of legal issues pertaining to BIM implementation is making the rounds. Figure 73 shows a news clipping of a dispute that arose due to improper use of BIM on a project. It highlights the improper use, or 'overselling', of BIM as a problem, which can be a significant mindset barrier for BIM adoption.

Figure 70: The unique nature of the project-delivery network in construction

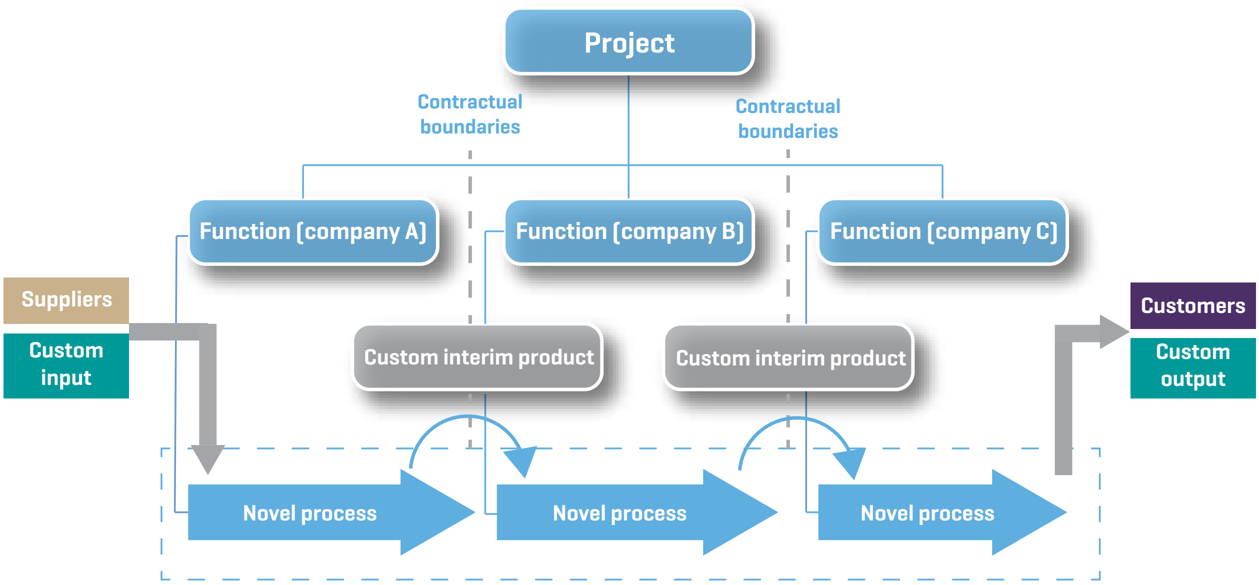


Figure 71: BIM and non-BIM projects in the project-delivery network

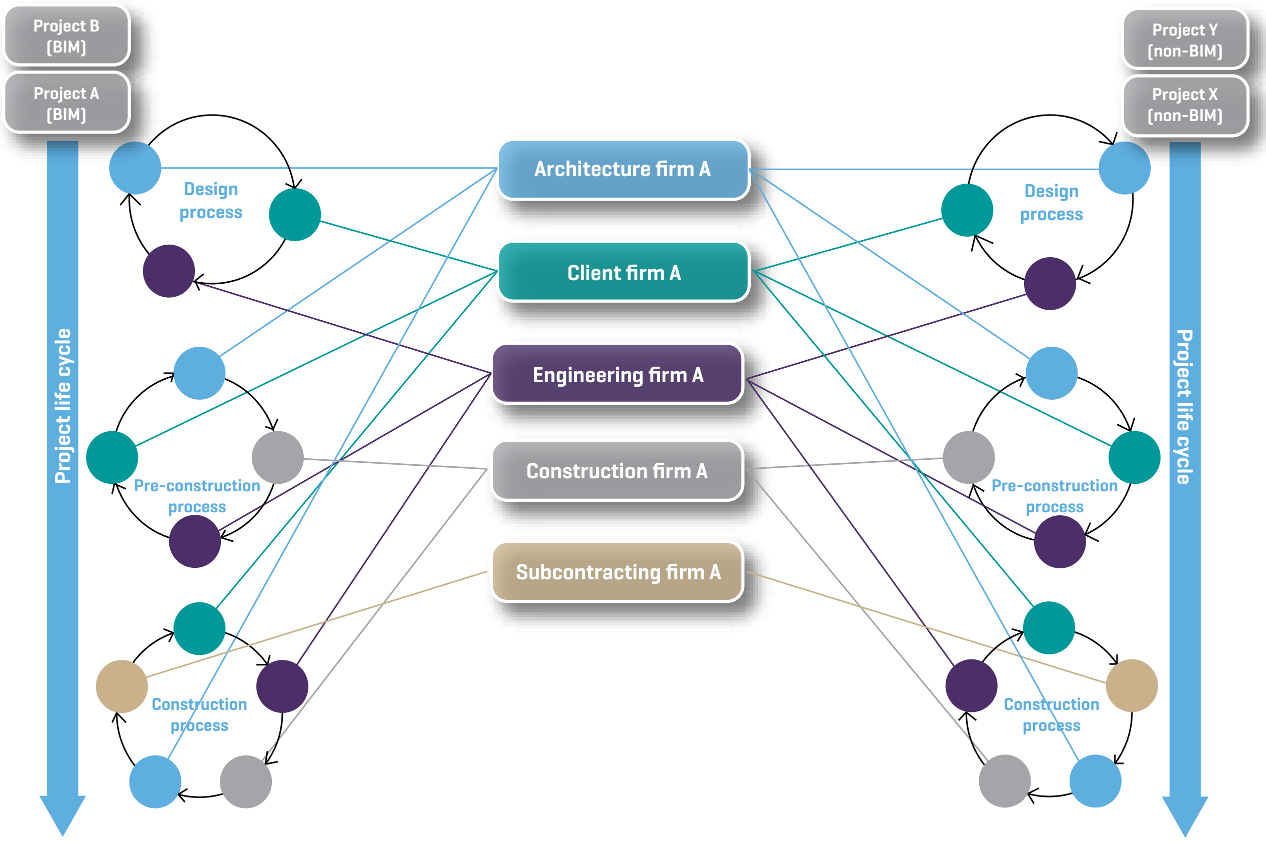


Figure 72: BIM and non-BIM projects in the organisation

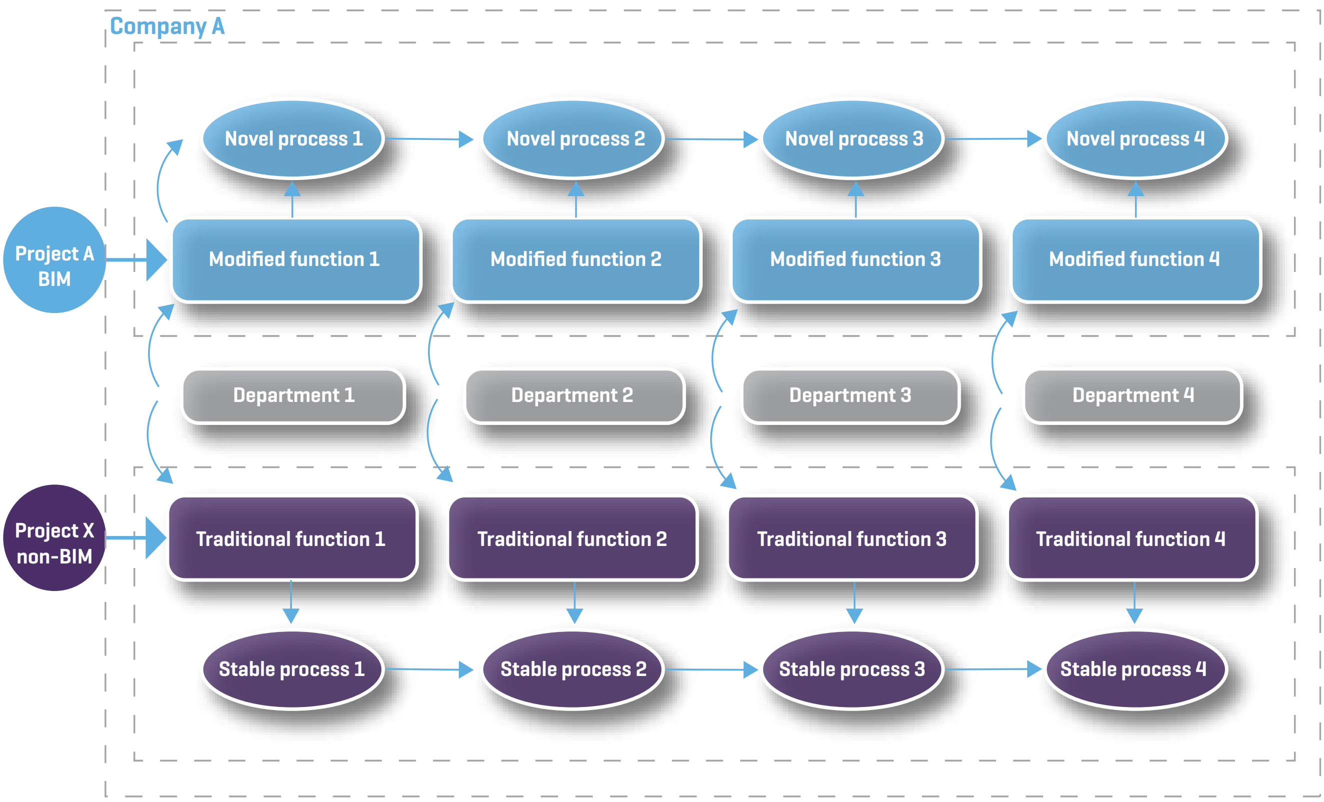
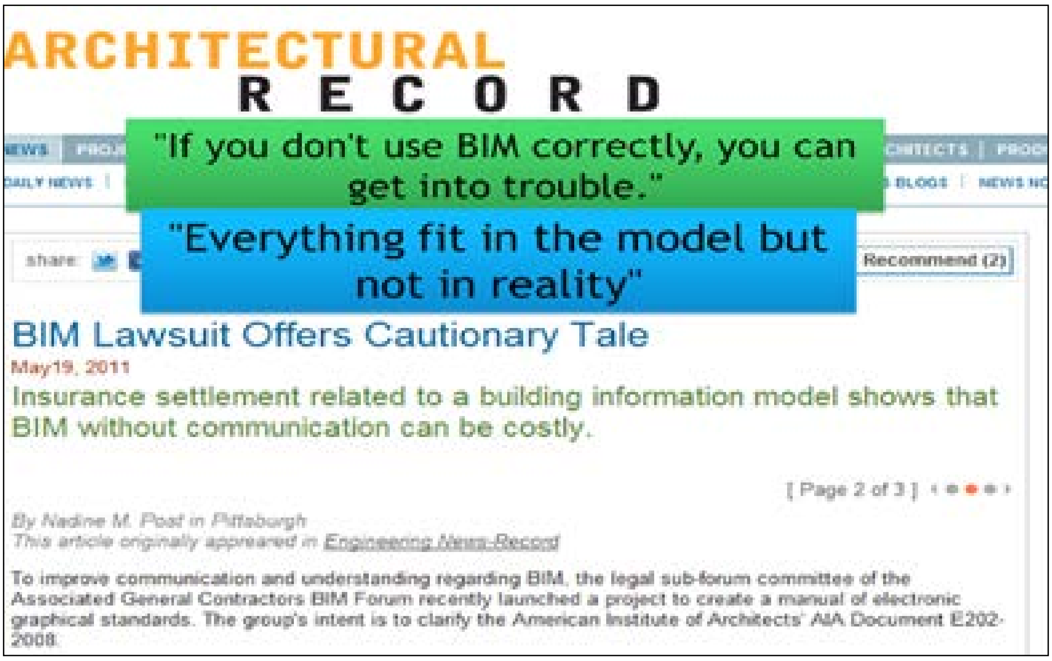


Figure 73: Failed BIM projects



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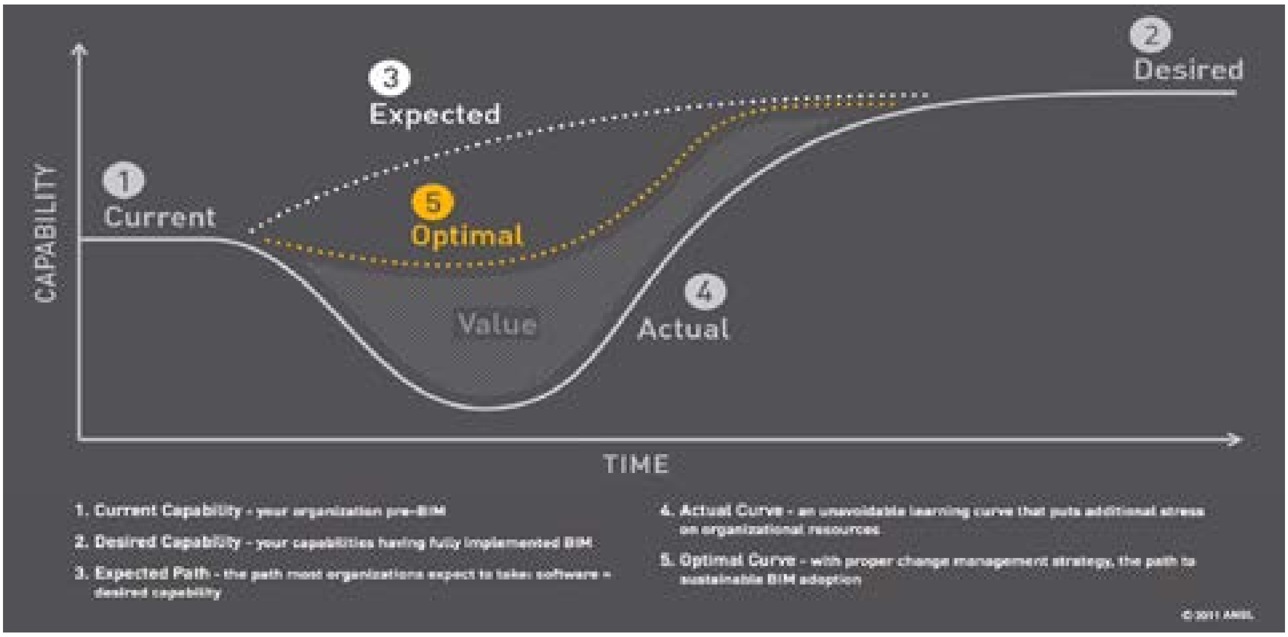
Implementing BIM at the organisational level is crucial and needs to be discussed while undertaking BIM implementation at the project level. There are instances of exemplary BIM projects conducted by organisations as a one-off experiment without clearly sustaining long-term implementation strategies at the organisational level. An interesting work by Josh Oakley of ANGL Consulting in this regard puts issues at the organisational level in perspective. Using what is called the J curve (see Figure 74), the journey that an organisation must take when implementing BIM is explained. To reach a 'BIM state' from a 'pre-BIM state' an organisation needs to strive hard to follow the 'optimal' path on this journey. Since a huge gap between the expected and actual path exists, any deviations from an organisational-level plan may make the journey inefficient or, in extreme cases, reverse the transition. Defining important aspects of this innovation journey[120] is therefore very crucial for the implementation of BIM at the organisational level. At the organisational level one has to pay special

Figure 74: The J curve of BIM adoption



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attention to the significant resource requirements of BIM implementation and reconfigurations of existing practices it demands. Organisations also face the challenge of capturing new practices developed through BIM-based project work for subsequent reuse.[121]

When looking at BIM at the organisational and inter-organisational level, the following key issues need to be addressed:

1 training and education in BIM (not just model authoring but also model usage and information extraction and processing)

2 hardware and software selection for organisation-wide BIM implementation (including compatibility issues)

3 BIM projects versus non-BIM projects happening within the organisation

4 BIM experience and capabilities of various members of the project team (inter-organisational issues)

5 human resource issues including whether or not there are experienced BIM personnel in the organisation

6 ownership of models and data embedded in the models

7 procurement of services so that BIM experience is available at the organisational level

8 risk allocation, risk mitigation and additional risk due to model exchange

9 copyright and intellectual property rights issues based on content development and use

10 contractual issues pertaining to BIM services

11 commercial terms for BIM services and selection of service providers (consultants and constructors); and

12 insurance and liability issues on BIM projects.

At the organisational level it is crucial to develop a ‘BIM strategy’ that stems from the organisational strategy and is in sync with it. Ad hoc implementation attempts at the organisational level are highly likely to fail. A strategy document that addresses some of the key issues listed above is needed before an organisation starts the implementation process. Most guidelines available today are focused on the project level and not much guidance is available to companies, especially SMEs, to develop an organisation-level implementation strategy.

BIM is a technology-driven process that requires organisations to address issues that are common with any technology-adoption process. All organisations looking to adopt BIM have to address issues relating to ongoing training of staff – both office and site-based. Keeping abreast of the latest developments on the technology front is extremely crucial. Along with training, deployment of hardware and software also needs to be addressed by the organisation. Most software vendors publish hardware requirements for their software. These can be used to develop standard hardware configuration for the organisation. Software must also be carefully selected. Compatibility of the software with open standards such as IFC and COBie must be evaluated before investing in hardware, software and training.

As with any change there is a transition period that an organisation has to plan for. In any organisation during this transition period there will be projects that use BIM and projects that do not. Any changes to the organisation’s policies, procedures and practices should be incremental and done side-by-side with existing production methods so that learning problems do not jeopardise the completion of other ongoing projects.

A common problem that an organisation faces is the differing experience levels of project team members participating on a project. Certain professions have been resistant to BIM adoption. Commonly cited examples of late arrivals on the BIM front are QS and PMC organisations. Disruptions caused by less-experienced project team members in other organisations has to be carefully analysed and accounted for in the BIM strategy. Selecting the network of specialist companies with which the organisation associates may have to be shifted so that more BIM expertise can be brought to the project-delivery networks in which the company participates.

One key challenge that organisations face is the issue of developing a team of skilled personnel to manage BIM implementation. This is especially true for specialist organisations such as structural engineers and MEP engineers. Skilled personnel who can perform domain-specific analysis and design tasks have to enhance their skills to adapt and adjust to the BIM environment. This is quite challenging, especially for SMEs.

Points 1 to 6 in the list above need to be addressed at the organisational level with guidance and advice from top management. If not managed properly, many of these issues can derail an organisation’s BIM implementation plans.

Points 6 to 12 are interconnected and are discussed in the rest of section 4.

4.1 Changes in contractual arrangements and related legal issues

With BIM adoption some adjustments to the contractual arrangements between various parties involved on a project are needed. In most standard forms of contracts used globally there is no specific coverage of BIM. These contracts do not explicitly or implicitly allow or stop the use of BIM in any phase of the project.

The most accepted procedure to contractually incorporate BIM implementation on a project is via the incorporation of an addendum or protocol specifically relating to BIM, making it binding on the parties entering into the contract. Three well-accepted BIM addenda currently available are:

- ConsensusDocs 301 Building Information Modelling (BIM) Addendum[122]
- CIC *BIM protocol*;[123] and
- AIA Digital Practice Documents consisting of:
  - AIA G201–2013 Project Digital Data Protocol Form
  - AIA G202–2013 Project Building Information Modelling Protocol Form
  - AIA E203–2013 Building Information Modelling and Digital Data Exhibit; and
  - AIA C106–2013 Digital Data Licensing Agreement.[124]

In most projects using BIM, the addendum is incorporated by reference in the standard form of contract that is used on the project. The addendum can be changed or defined appropriately to the level of BIM implementation planned for a particular project without impacting the standard contract between the parties. By using this approach of incorporating a BIM addendum most of the other legal issues are not impacted and as such no significant changes are needed to the main contractual framework.

BIM implementation gives project team members new roles and responsibilities. The procurement of services needs to be modified accordingly. Also, the schedules of services require modifications to clearly incorporate additional services and deliverables that might result from BIM-based projects. Clear definition of the role of the BIM manager or the entity responsible for BIM management needs to be created. This may simply require the addition of these responsibilities to the responsibilities of the lead design consultant on the project, or may require hiring a specialist organisation.

Generally, intellectual property rights (IPR) and copyright issues do not present any major roadblocks to BIM adoption. The main issues that have to be understood in this context are:[125]

- project team members need to assure others on the team that they own or have permission for all the copyrights in all of their contributions to the model(s)
- project team members should grant a limited, non-exclusive licence to reproduce, distribute, display or otherwise use their contributions to the model for the purposes of the project only
- copyright and IPR issues relating to a contractor's and subcontractor's contribution to the model also need to be clearly defined; and
- use of the model for facility management during the operation and maintenance phase should also be properly addressed.

Issues of insurance, including professional liability insurance, also need to be addressed in the BIM addendum. Will current professional indemnity insurance policies cover BIM activities? Many feel that insurance-related issues can be a barrier to BIM implementation if not handled carefully. As the project delivery shifts from work practices that rely on 2D static information to model-centric information sharing and collaboration, a new set of perceived challenges appear. Some of the questions that come to mind are:

- What risks are induced by sharing models among project team members?
- Is the BIM manager exposed to additional liability?
- Is there a change in the allocation of responsibility and liability exposure among project team members?
- How should intellectual property rights and copyright issues be addressed?
- What changes are needed to the contracts?

Organisations should address these legal and contractual issues before attempting to implement BIM.

4.2 Information sharing and collaboration using BIM

The most fundamental issue when addressing information sharing in a BIM environment is the use of information derived from the model by a project participant, where the model and the derived information has been produced by some other member of the project team. This certainly introduces a risk in the information-sharing process of the BIM environment, especially when this information is inadvertently used for a purpose that it was not intended for. BIM addenda can be drafted in such a fashion that this type of issue can be explicitly handled. For example, the ConsensusDocs 301 BIM Addendum provides the following three options when it comes to information sharing by project teams in the BIM environment (shown in Figure 75):[126]

1. Each model author in the project warrants that the dimensions in the model are accurate and take precedence over the dimensions provided in the drawings, if any. Under this option, the model(s) becomes the sole-basis of project delivery.
2. Dimensions in the model are accurate to the extent that the BIM execution plan specifies and all other dimensions (information) must be retrieved from the drawings.
3. No representation with respect to the dimensional accuracy of the model is explicitly provided by the model author. The model is to be used for reference only and all dimensions (information) must be retrieved from the drawings.

In all three options the project team can use flags for

Figure 75: Information sharing as per ConsensusDocs

Strategy 1	Strategy 2	Strategy 3
Each stakeholder represents that the dimensions in the model are accurate and take precedence over the dimensions called out in the drawings	Dimensions in the model are accurate to the extent that the BIM execution plan and all other dimensions must be retrieved from the drawings	No representation with respect to the dimensional accuracy of the model. Can be used for reference only and all dimensions must be retrieved from the drawings

marking the status of the information included in a model. There are various schemes available for such flagging, including PAS 1192-2:2013.[127] Commonly used flags are:

- issued for coordination
- issued for information
- issued for internal review and comment; and
- issued for construction approval.

4.3 Changes in workflow

Information flow and information management are central to an organisation's use of BIM. Changes in the way information flows or is managed changes project team members' workflow patterns. Fundamentally there are two major mechanisms available for information flow and information management. In the first approach each project team member is responsible for developing and authoring their model independently with no centrally stored model. The modelling process moves more or less in an asynchronous and linear fashion. This is shown in Figure 76.

Models and information stored in these models are shared among project team members by file sharing or other similar methods. Discipline-specific models that are developed separately draw information from other models but are authored by the respective project team members. Collaboration is possible but is not ingrained in the way the modelling process is laid out.

As shown in Figure 76, while models are being developed some information flow takes place between the authoring teams. Once models are submitted the project team member responsible for BIM management combines or federates these discipline-specific models, essentially for coordination purposes. The federated model is an assembly of the discipline-specific models. A reflection of the coordination issues in the form of model snapshots is provided to the disciplines that are causing the collision. Once again, model review and updating takes place independently after the coordination issues are communicated.

The process of model authoring, model federation, model coordination and model revision continues until the predetermined level of coordination is accomplished. Information sharing between discipline-specific teams is not integrated in its true sense. Generally, a fully coordinated model for each discipline is used to perform downstream tasks such as quantity take-off, document production, planning and so on. Sometimes information in this scenario is shared between project team members via 2D drawings. Workflow is centred on receiving and sharing information from one's discipline-specific model. Protocol for such sharing is needed in this type of file-based collaboration approach.

In the second approach, an integrated BIM environment, collaboration becomes the centrepiece. Rather than maintaining separate discipline-specific models, a single central model is developed and used in the project. Figure 77 shows this model information sharing, information management and workflow. Model-specific tasks such as authoring of the model, review of the model, coordination of the model and so on are performed by the project team members in a seamless

Figure 76: Asynchronous and linear modelling

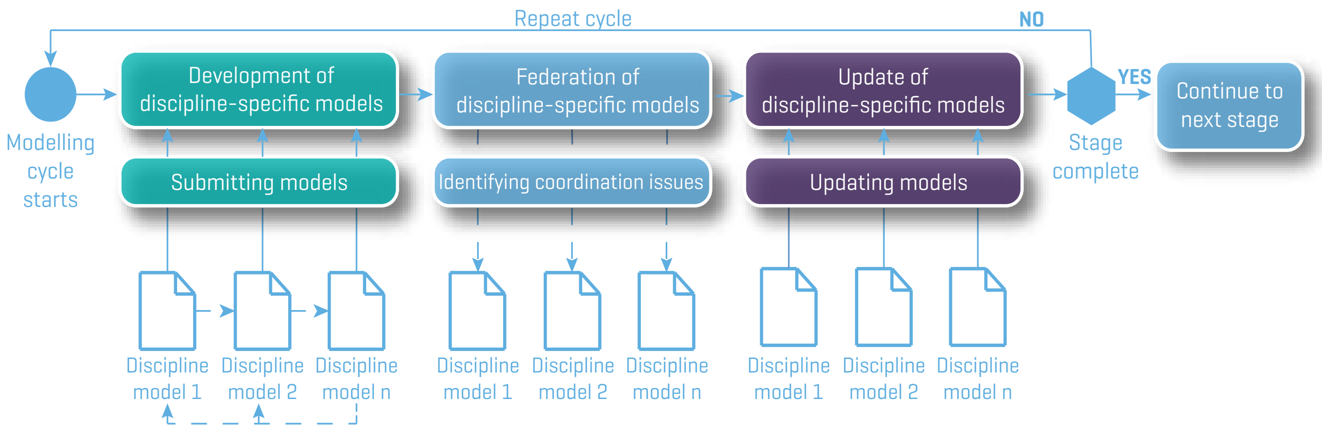
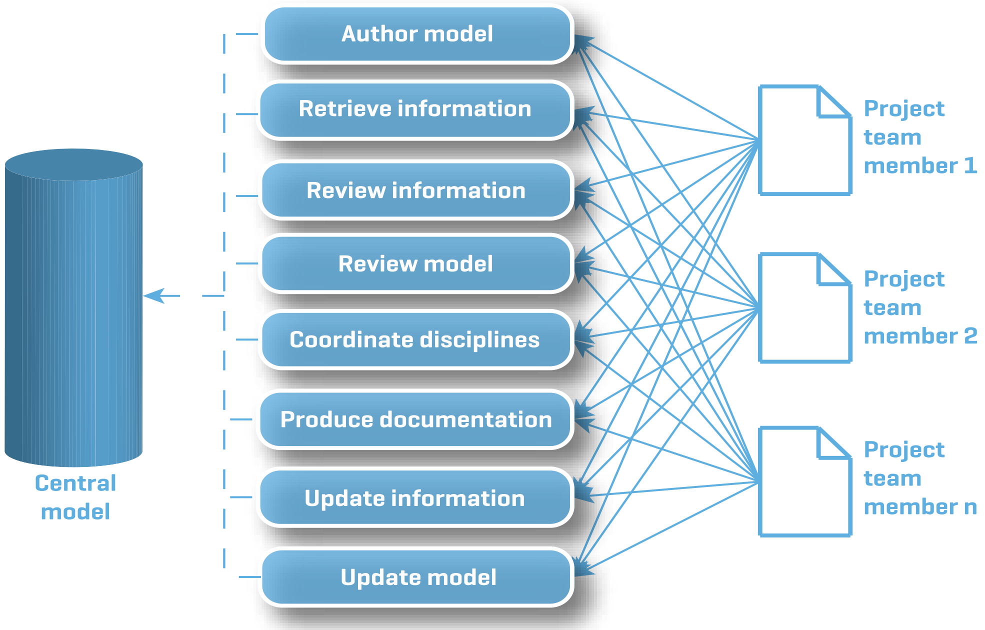


Figure 77: Central model-driven modelling



and integrated fashion. This type of BIM environment is model-driven and collaborative in the truest sense.

The central model is the single source of information for the project; it is used to collect, store, manage and disseminate project information, the graphical model and non-graphical data for the whole project team. Creating this single information repository facilitates collaboration between project team members and helps avoid duplication and mistakes.[128] The model server technology that was explained in subsection 2.7 is crucial for these types of central model-based BIM environments. Information flow can be managed by using a common data environment (CDE).[129] A CDE is defined as an information repository on a project server that is used to collect, store, manage and disseminate all relevant approved project documents including models and drawings.[130]

4.4 Inter-organisational aspects of BIM

As the information exchange on a project shifts from a 2D format (drawings, documents, etc.), which is highly fragmented, to a more streamlined BIM-based format (both file-sharing based and central-model based), it is crucial to modify the interfaces that take place between various organisations that participate in the design, construction, operation and maintenance of a built environment asset. As the design and construction process evolves, various project team members share information with each other using disciplinary models or the central model. Such exchanges define the inter-organisation linkages in the BIM environment. Protocols and systems need to be developed to manage these workflows and information exchanges. It is important to realise the emphasis on information and its linkages to technology, people and process (including work practices and workflow).

In project management literature information exchange in a project setting is traditionally defined, managed and controlled by defining a responsibility assignment matrix (RAM).[131] RAM can be defined on the basis of RACI (responsible, accountable, consult, and inform) – a commonly used framework in project management practice. In the context of built environment projects RACI can be re-defined as:[132]

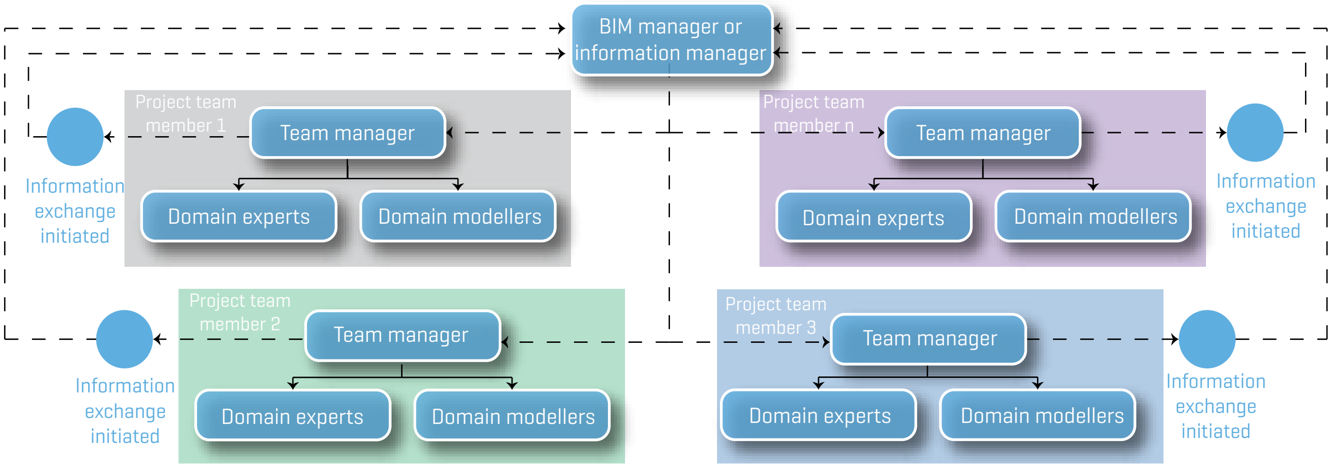
- **R**: responsible party
- **A**: authorising party
- **C**: contributing or consulting party
- **I**: party(ies) to be kept informed.

A typical information exchange in the BIM environment is depicted in Figure 78. The role of BIM manager or information manager is crucial in such exchanges. Internal to a project team, domain experts and domain modellers report to their team manager who in turn initiates any information exchange that has to interact with other project team members in a file-based sharing or central server-based BIM environment. This information exchange is processed by the project-level BIM manager or information manager who in turn identifies the roles of various team members using the RACI system.

4.5 Implications of BIM on practice

Each organisation playing a different role in the project-delivery network has to understand the implications of

Figure 78: Information exchange using RACI



BIM in their individual organisation, especially the work practices, keeping in mind their specific role in the project. While issues relating to hardware and software selection, skills training and other drivers and barriers are common for all players, there are some issues that differ by the type of role being played by each. The following subsections provide a brief overview of these implications on various members of the project-delivery network.

4.5.1 BIM for developers/owners/sponsors

The role of the real estate or infrastructure developer (owner or sponsor) in BIM implementation is crucial because it is they who can derive 'significant improvements in cost, value and carbon performance through the use of open sharable asset information'.[133] From the individual project point of view the owner is also the BIM sponsor. Since this changes the way the project will be delivered by the project team it is crucial that the owner makes adjustments at their organisational level to enhance the use of BIM.

Owner organisations also need to play an important role at the industry level so as to influence policy and drive the entire network or ecosystem towards effective and efficient BIM adoption. Owners are required to play an active role at:

1 sector level

2 organisational level; and

3 project level.

These roles are provided in Table 6.

4.5.2 BIM for architects and designers

While CAD allowed the architect and designer to use computers for the drafting and production of design documents, BIM fundamentally impacts the way design data is generated, shared and integrated. Some term this impact as an 'epochal'[134] transformation of the design practice – perhaps architectural and design practices are stakeholders undergoing both internal and external transformations caused by BIM. Internally, design practice and design culture are being impacted by BIM. Obviously this causes external interactions with the rest of the project team members to shift from the traditional CAD-based interactions.

Three major shifts that are taking place are:

1 Design processes are being impacted: BIM changes the design process by shifting the emphasis from a linear step-by-step process to a more iterative and collaborative process. This is changing the process of design itself.

2 Design culture is changing: BIM is changing the way designers think about design. The focus is shifting from a 2D to a 3D worldview. This is significantly impacting design culture.

3 The effort involved in the design process is significantly shifting to a frontend-loaded scenario: in a BIM environment, designers are required to shift attention from drafting and documentation to the generation of design options, enriching the design options with available data and enriching early stage design with more information. This has caused shifting and restructuring of the effort expended on design. Figure 79 shows the indicative redistribution of design effort.

The fallout of these implications is that architects and designers can now access the model to conduct detailed analysis. This enriches the design process and arguably leads to a better design. It is now possible to conduct sustainability analysis, value engineering analysis and constructability analysis in a much more robust fashion through early involvement of experts.

The changes caused by BIM adoption require rethinking of the fee schedule for the architect and designer. Perhaps the traditional timelines for fee payment and related commercial aspects need to be revised. The architect and designer can also offer additional new services as BIM adoption matures in their organisation.

Internally, new roles and responsibilities need to be

Table 6: Roles and responsibilities of owner

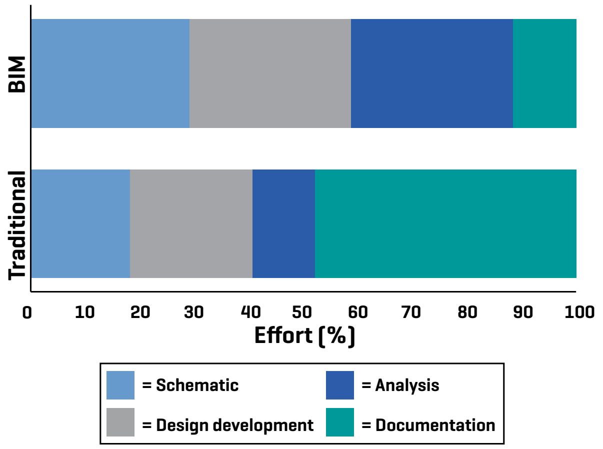
Level of influence	Activities
Sector level	Assist in developing sector-level BIM guidelines and standards
	Influence and encourage industry network/ecosystem
	Develop and participate in pilot or proof of concept projects
	Develop value proposition for the developer community
Organisational level	Building internal leadership and knowledge
	Link organisation strategy to project strategy
	Develop knowledge management plan
	Link business strategy to BIM strategy
Project level	Deploying BIM-ready project team or representative
	Selecting service providers with BIM project experience and know-how
	Participate in the BIM effort
	Develop employer's information requirement
	Have metrics to measure deliverables and progress
	Enhance collaboration by building trust and common goals
	Manage scope and services for the project-delivery network
	Manage expectations and risks
	Facilitate and approve BIM execution plan

defined to ensure BIM is used within the organisation. Depending on the size of the organisation, this could mean identifying a BIM champion along with a group of modellers through to having a designated BIM department. Ideally BIM use in an architectural practice should become pervasive; that is, every design team should use it in every project. To accomplish this, the organisation will have to spend significant resources on hardware, software, training and developing an internal library of BIM objects.

4.5.3 BIM for specialist consultants

Specialist consultants can benefit from BIM. For example, mechanical, electrical and plumbing consultants can beneficially adopt BIM in their design and analysis processes. In many cases this is becoming a necessity as more and more projects mandate the use of BIM. In the case of specialist consultants, the following major issues should be considered:

Figure 79: Indicative redistribution of effort in the design process



- Most specialist consultants rely on specialised design and analysis tools. One major bottleneck for these organisations is the lack of interoperability of mainstream BIM-authoring tools with the specialist design and analysis software that they use. Careful selection of software is needed to ensure that there is no disruption in the modelling process.
- Specialist consultants need to provide output in terms of models and documentation that link to downstream processes such as the production of shop drawings, selection of equipment and fabrication. Model development has to be performed in such a manner that these downstream activities can be supported.
- Work performed by specialist consultants depends on the model developed by upstream project team members. It is crucial that specialist consultants undertake model validation activity seriously.[135] Validation requires that the information needed as input by the specialist consultants is available in the model and can be retrieved by them.

Understanding these issues, along with appreciating information exchange protocols put in place on the project, is crucial.

4.5.4 BIM for constructors

Constructors play the following three important roles in the BIM environment:

1 they assist in the development of models by participating in the design wherever the project-delivery process allows

2 they fully utilise the models during the construction stage to perform tasks that are relevant during this stage of the project; and

3 they prepare models by enriching them with detailed as-built information as construction progresses so that the models can be used in the operation and maintenance phase of the project.

In most instances moving forward, constructors will receive the design model from the lead design consultant in a pre-agreed format, with the required level of development and at the prescribed phase of the project. While BIM implementation is maturing there are scenarios in which the constructor has to develop their own models for use in the construction phase in what is termed the 'lonely BIM' scenario. Functions such as health and safety planning, site planning, site logistics, supply chain management, procurement, production planning, monitoring and control are now being performed by constructors in a BIM environment. As these applications mature constructors will start seeing significant benefits stemming out of the model-centric approach.

4.5.5 BIM for project management consultants

BIM stands to change the role of the PMC (sometimes called the construction management consultant). As the operating system of the project changes to a model-centric system, functions that are typically performed by the PMC also change. Primarily BIM requires greater data-sharing and makes the role of PMC crucial. Using BIM, PMCs can perform their traditional role in an enhanced fashion by increasing collaboration, coordination and communication between stakeholders. The changes in the role of the PMC become clearer if their role is viewed in the following two scenarios:

1 the PMC plays the role of BIM management consultant in addition to their traditional role, on behalf of the owner; and

2 the PMC only performs their traditional role on behalf of the owner.

The traditional role of PMCs is impacted by BIM as shown in Table 7.

4.5.6 BIM for quantity surveyors

It has been predicted that the QS profession will become extinct due to the emergence of BIM. This has been caused by low awareness of BIM among QS professionals. This prediction is turning out to be wrong. It seems that BIM's capability of automating measurements through extraction of quantities directly from the model[136] gives QS professionals the opportunity to expend more attention on providing knowledge and expertise-intensive advice to the project team. A BIM-based cost planning process is described in Figure 57. The following main issues in the context of QSs are important to highlight:

1 QS professionals receive models developed by other project team members and are expected to perform their tasks using these models.

2 Given that the models are developed by other project team members, the first important task that QSs have to undertake is to review the model for accuracy and information richness. Many instances have been reported where the model does not have the required information to allow model-based measurements and quantity take-off.

3 It is important for the QS to ensure that the automatic model-based measurements and quantity take-

Table 7: Implications of BIM on the PMC's role

Stage	Role	BIM applications
Pre-construction	Feasibility analysis	Concept-stage BIM
	Value engineering	Options selection using BIM
	Design management	BIM information exchange
	Risk analysis	Simulation
	Scheduling	4D Modelling
	Constructability analysis	4D Modelling
	Procurement	-
Construction	Phasing and prototyping	4D
	RFIs and issue resolution	BIM information exchange
	Commercial and contract management	4D
	Change management	BIM information exchange
	Monitoring and control	4D and 5D
Project closure	Contract and financial closure	Record model
	Project closure	Record model
	Handover	Record model

off are compliant with locally accepted standard methods of measurements.

4 Classification systems adopted by the project team may have an impact on the work processes of the QS. Commonly adopted classification systems are RICS' NRM, OmniClass Construction Classification System, ICE CESMM, MasterFormat, UniFormat and CPIC Uniclass.

5 The LOD of the model must be clearly understood by the QS so as to ensure that cost planning is in accordance with the level of information that is available in the model.

6 Models can change frequently in the BIM environment. This has both positive and negative connotations. QS professionals/firms are able to provide better cost planning information to clients due to the model-based measurement and quantity take-off. However, frequent changes may disrupt the workflow normally expected by QSs.

4.5.7 BIM for facility managers

The ultimate benefit of BIM is its integration across the project life cycle and the seamless use of the model by facility managers. The model becomes the information source for computer-aided facility management (CAFM). CAFM is not replaced by BIM: through information exchange and sharing between BIM and CAFM, it becomes more effective. Obviously, to support the facility manager the as-built model has to provide the needed information in the correct format.

It is crucial to consider integration issues and standards to allow seamless use of BIM in FM. Currently COBie is the de facto standard for BIM and FM integration. Figure 80 shows FM in relation to BIM maturity levels. As shown in the figure, the current level of integration is low. Seamless integration of BIM and FM is anticipated as BIM evolves over time.

4.5.8 BIM for product manufacturers

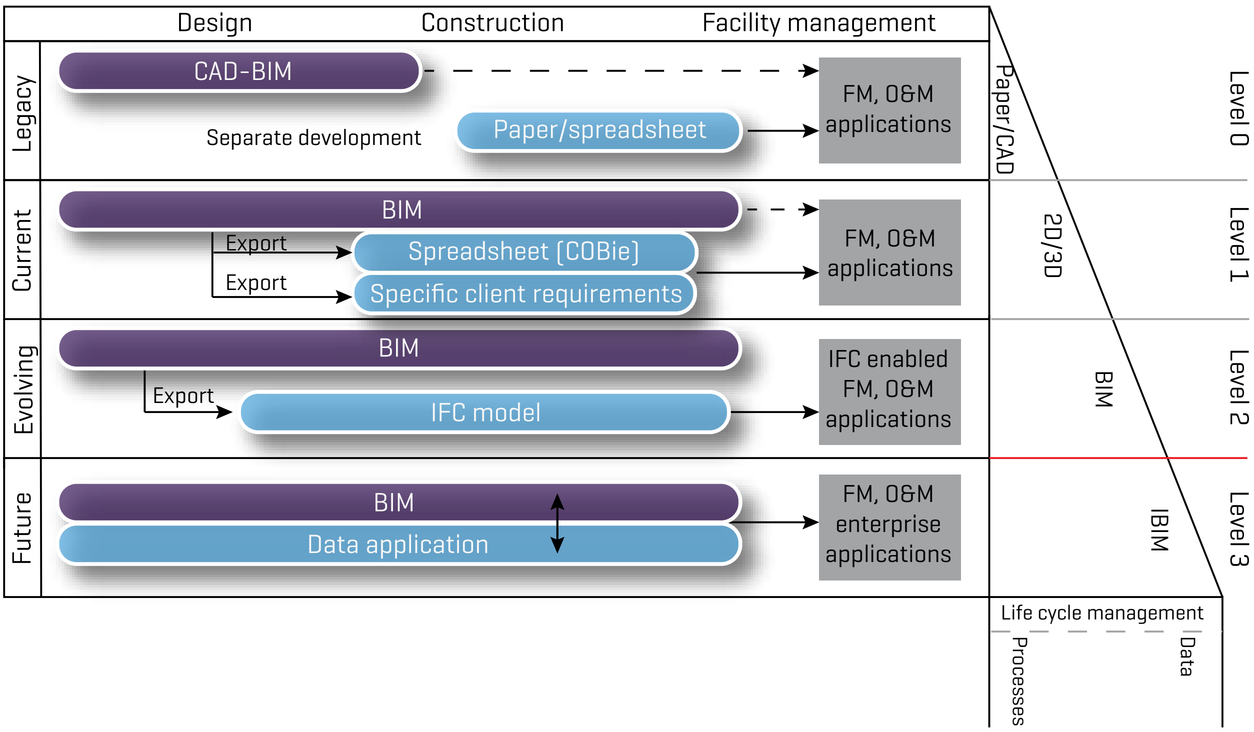
Product manufacturers can play a significant role in the increased adoption of BIM. As explained in subsection 2.4, model development requires what is termed BIM content in the form of (smart) objects. A majority of the objects come from product manufacturers who can provide actual models of their products which can be used by the project team to develop models. There are three primary sources of these objects (as shown in Figure 25).

Online (IFC compliant) objects can be produced and supplied by product manufacturers. Various platforms are available for product manufacturers to develop these objects and deploy them for use by various design consultants, engineering consultants and constructors. This provides a vast opportunity to product manufacturers to market and sell their products. Using these objects allows project teams to not only get pre-built modelling elements but also allows them to enrich the model with product information, including specifications.

4.6 Role of BIM management

On large and complex projects – both building and

Figure 80: FM and BIM maturity levels



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infrastructure – where BIM implementation is planned, BIM management services are needed. BIM management can be performed by one of the stakeholders. Loosely this entity can be called the BIM manager. BIM managers will play a significant role in BIM implementation both at the project level and at the organisational level. This is a new role that requires streamlining and clear articulation. It has two different connotations, one assuming the role as an individual and the other as an organisation. In any BIM implementation one of the organisations from the project will have to be nominated as the BIM management entity. The roles and responsibilities of this entity need to be clearly defined.

Some BIM guidelines introduce the role of an information manager which is different from a BIM manager. In this guidance note the term BIM manager is used to identify the project stakeholder (generally the lead design organisation) that will take on the following roles for the project:

1 developing, implementing and maintaining the BIM implementation/execution plan for the project

2 ensuring all project team members are in alignment with the plan

3 creating and maintaining a BIM coordination framework that is aligned with the overall BIM implementation/execution plan that in turn is linked to the project plan

4 maintaining the federated model created from the individual domain-specific models which are submitted by the project team

5 establishing BIM coordination meetings and reporting progress to the project coordination meetings

6 keeping a record of building information models and their status by stage of the project; maintaining various versions of the models with proper naming conventions

7 tracking the identity of the contributor to a model and the intended purpose of the model at every defined stage

8 establishing model quality control procedures and ensuring model quality in order to check that the models are accurate with the right LOD by stage of the project

9 identifying and documenting clashes between different discipline models using clash-detection software

10 administering the agreed document and model sharing/publication system (BIM collaboration procedures)

11 full responsibility and authority to issue instructions on BIM-related issues

12 coordinating the handover of the model and data at the agreed milestones in the BIM coordination programme

13 in the event that the project BIM coordinator transfers to another person, providing all associated documents and fully briefing incoming personnel on the protocols and history of the collaboration

14 having an understanding of legal, procurement and tendering issues; and

15 understanding the legal implications of BIM in terms of intellectual property, copyright, insurances and risk.

5 Conclusions and recommendations

BIM is a remarkable development that is challenging the built environment sector to consider systemic and holistic improvements in technology, work practices and processes. It is having an 'amalgamation effect', allowing the built environment to see the interconnectedness of paradigms such as lean principles, off-site technologies and green principles. Using this as a basis, many governments have set lofty medium-term goals for the built environment sector. For example, the UK government has prepared a BIM strategy for the Construction Client Group to reduce 'capital cost and carbon burden from the construction and operation of the built environment by 20 per cent'.[137] It is crucial that all constituents of the built environment sector work in unison to embrace far-reaching, sector-wide improvements that will pave the way for BIM adoption.[138]

The following challenges in BIM adoption still remain:

1. **Mindset issues**: implementing BIM requires changes in process and practice by all stakeholders. Resistance to change, turf issues and hesitancy in being the first to embrace change are some common mindset barriers that are slowing BIM adoption.
2. **Project-delivery network issues**: not all members of the project-delivery network are embracing BIM. Even in a perfect scenario, where a client and designer are willing to adopt BIM, lack of specialist consultants who are willing to use BIM makes implementation challenging.
3. **Technological barriers**: while software vendors boast seamless integration and interoperability in the tools they provide, there are still some technological issues that need to be resolved; this is especially an issue in the context of specialist consultants, contractors and vendors' software compatibility. Specialist software used by these project team members is still not compatible and interoperable, thereby fragmenting the BIM workflow.
4. **Availability of skilled resources**: lack of a BIM-savvy workforce remains one of the biggest challenges in BIM adoption.
5. **High hardware and software cost**: a roadblock in BIM adoption is the perceived price of hardware and software, especially from SMEs. Training costs and cost of disruption due to employee training programmes are making organisations think twice before embracing BIM.
6. **Legal and commercial hurdles**: issues pertaining to contracts, ownership of information encapsulated in models, fee schedules, deliverables and insurance are still not completely understood by industry players. This is hampering BIM adoption.

To overcome these barriers and to enhance the use of BIM in the built environment sector, the following broad structural changes may be needed:[139]

- broader vision and behavioural changes from all stakeholders to collaborate on the BIM platform with a 'whole of system' and a 'whole of industry' approach
- capacity building, education and training for BIM implementation
- better value proposition for all stakeholders (including the articulation of the value proposition)
- development of national standards and guidelines
- investment in research and development
- participation of the academic community in updating curricula
- process- and people-driven change and not technology-driven change; and
- a life cycle view for BIM implementation with strong integration with supply chain and asset management.

As the built environment sector moves forward, the following winds of change will have significant implications on the trajectory of BIM adoption and resulting benefits to the sector:

1. Digital fabrication: with the advent of 3D printers the built environment sector will see a significant shift towards the use of manufacturing, fabrication, prototyping and construction of assemblies and materials. Building products, materials and process will be governed by the ability to tap into the advanced 3D printing and contour crafting technologies.
2. Cloud computing: with access to elastic computing resources the built environment sector will be able to use the latest hardware and software technologies. Pervasive computing will become possible and construction sites will no longer struggle to receive and send real-time information.
3. Big data and analytics: with the advancement in the field of big data and business analytics the built environment sector will be able to utilise advanced analysis tools to develop support for decision

making during the life cycle of the asset. Simulation of various scenarios using vast amounts of data will allow meaningful risk management and advanced decision-making processes.

4 Smart cities: driven by urbanisation, smart cities will become a reality. The realisation of the benefits of smart cities will be dependent on the information available. This in turn will drive modelling of the built environment through BIM and associated geospatial technologies such as GIS.

5 Mobile platform: the built environment sector will be significantly impacted by the availability of BIM on mobile platforms making BIM to field and field to BIM possible. Coupling of mobile devices with sensor technology and laser scanning technologies will further make the ‘physical to digital’ and ‘digital to physical’ vision possible.

Appendix A: Definitions and terminologies

2D	Two-dimensional documentation in a traditional computer-aided design environment; in the context of BIM, all output/documentation in two-dimensional format.
3D	Three-dimensional space; in the context of BIM, a representation of a facility/asset in three dimensions (X, Y and Z coordinates).
4D	Model developed by addition of time dimension to a 3D model; also referred to as 4D simulation or 4D planning.
5D	Model developed by addition of cost information to a 4D model (or 3D model).
6D	Model developed by addition of sustainability information to a 5D (3D or 4D) model. In some parts of the world the term 6D is also used to describe a model for facility management.
AEC	Architecture, engineering and construction sector used to define professionals and professions involved in design, construction and operation of the built environment sector.
AIA	American Institute of Architects.
Architectural model	Model made up solely of architectural components/model elements.
As built	As built is defined as the record drawings and documentation that capture changes to the design in the finally constructed facility.
Asset information model (AIM)	Term used to describe the set of information (documentation, graphical model and non-graphical data) collected and collated over the entire life of the asset.
BIM execution plan (BEP)	Written plan to integrate the BIM tasks and information with all stakeholders and processes.
BIM implementation plan	The blueprint for integrating BIM into an organisation's working practices.
BrIM	Bridge information model.
BS 1192:2007	Collaborative production of architectural engineering and construction information. Code of practice.
BS 1192-4: 2014	Collaborative production of information - Part 4: Fulfilling employers information exchange requirements using COBie. Code of practice
bSDD-buildingSMART	Reference library for supporting improved interoperability in the building and construction industry.
bSI	buildingSMART International. A non-profit international organisation formerly known as International Alliance for Interoperability (IAI) focused on improving the exchange of information between software applications used for the built environment sector.
BSI B/555 Roadmap	British Standards Institution BIM Roadmap.
BSIM	Building services information model.
Building information management	Used in place of building information modelling to highlight the requirement to explicitly manage the information in a BIM environment.
Building information model	A digital representation of the physical and functional characteristics of a facility using a collection of elements or information that serves as a shared knowledge resource for design, construction, operation and retrofit/demolition of a built environment asset.
Building information modelling	Used to both describe the process and the philosophy that enables the input, sharing, maintenance and output of (electronic) information used in the built environment sector.
CAD	Computer aided drawing/drafting/design.
CAFM	Computer aided facilities management.
CAWS	Common arrangement of work sections.
CDE	Common data environment. A single source of information for any given project, used to collect, manage and disseminate all relevant project documents for multi-disciplinary teams.
CIC	Construction Industry Council.
CIM	Construction information modelling; BIM during the construction process.

CityGML	City Geography Mark-up Language.
Clash detection	Process of identifying or detecting possible collisions between elements in a building information model generally from two different disciplines (sometimes all referred to as collision detection or coordination).
COBie	Construction Operation Building information exchange. A structured facility information for the commissioning, operation and maintenance of an asset.
CPIC	Construction Project Information Committee.
CPIx Protocol	Construction Project Information Committee BIM Protocol and templates.
Data drops	Digital equivalent of 'stage reports' where information is delivered from the building information model to the client.
Design intent model	An initial stage model of the project sometimes called the concept model.
Design model	A model of those aspects of the facility/asset/project that are designed and expressed by an architect/engineer.
EIR	Employer's information requirements is a document setting out the information to be delivered, and the standards and processes to be adopted by the supplier as part of the project delivery process (defined in PAS 1192-2:2013).
EXPRESS	EXPRESS data modelling language.
Fabrication model	Building information model which incorporates components that are suitable for (digital) fabrication.
Federated model	Building information model consisting of linked but distinct component/disciplinary models.
FIM	Facilities information model.
FTP	File transfer protocol: standard network protocol for transferring computer files from one host to another through the Internet.
gbXML	Green Building Extensible Mark-up Language. Open file format to exchange (green) building design data.
GIS (Geographic information system)	Computer tool designed to capture store, manipulate, analyse, manage and present all types of geographical data.
GSA	US General Services Administration.
GSL	UK Government Soft Landings.
Horizontal/civil/ heavy BIM	Building information models used for infrastructure projects.
IAI	International Alliance of Interoperability (former name of buildingSMART International).
iBIM	Integrated BIM (defined as Level 3 in the UK BIM maturity levels).
ICE	Institution of Civil Engineers.
ICT	Information and communication technology.
IDM	Information delivery manual.
IFC	Industry foundation classes.
IFD	International framework dictionary.
Interoperability	The ability of two or more (computer or software) systems or components to exchange information and to the use the information that has been exchanged.
IPD	Integrated project delivery.
ISO 159261:2004	A standard to facilitate integration of data to support the life cycle activities and processes of facilities engineering, construction and operation – explicitly for process industries but with wider applicability.
ISO 16739:2013	A standard to define industry foundation classes (IFC) for data sharing in the construction and facility management industries.
ISO/CD 16757	Product data for building services systems model.
ISO/DIS 16757-1	ISO standard for data structures for electronic product catalogues for building services (Part 1): Concepts, architecture and model.
Kaizen	Continuous improvement.

LandXML	Land extensible mark-up language.
LCCP	Life cycle cost plans.
Level of maturity	A metric of the ability of the construction supply chain to operate and exchange information.
LOD	Level of detail/level of development.
LOD (Level of detail)	This is the specific resolution of graphical information required for a particular element at a particular phase of the project.
LOD (Level of development)	This is the specific resolution of graphical and non-graphical information required for a particular element at a particular phase of the project.
LOI (Level of information)	A term to indicate stages of non-graphic information requirement throughout the project.
MEA (Model element author)	Party responsible for developing the content of a specific model element to the level of development (LOD) required for a particular phase of the project.
MEP	Mechanical, electrical and plumbing disciplines.
MEP model	BIM design model focusing on mechanical, electrical and plumbing services of a building project.
Model element	Portion of the building information model representing a component, system or assembly within a building or building site.
MVD (Model view definition)	The subset of IFC data model necessary for supporting the specific data exchange requirements of the AEC industry during the life cycle of a construction project.
NBIMS	US Project Committee National BIM Standard.
nD	Denotes model that has all possible information added to it.
NIBS	US National Institute of Building Sciences.
NIST	National Institute of Standards and Technology.
NRM	New rules of measurement.
Off-site construction	Refers to structures built at different locations than the location of use or installation.
OmniClass	Classification system as used in the USA similar to (but not directly interoperable) with UniClass.
OpenBIM	A universal approach of collaborative design, realisation and operation of buildings based on open standards and workflows.
OSCRE	Open Standards Consortium for Real Estate.
Parametric objects	A digital representation of a physical object using set of parameters.
PAS 1192	Parts 2 and 3 of a publicly available specification (PAS) sponsored by the Construction Industry Council (CIC) in support of BS 1192:2007 – also includes excellent glossaries of terms.
PBO	Project-based organisation.
PIM (project information model)	Term used to describe the set of information (documentation, graphical model and non-graphical data) compiled for a project.
PMC	Project management consultant.
Point cloud	A point cloud is a set of data points in a specific coordination system. In a three-dimensional coordination system these points are usually defined by X, Y and Z coordinates.
QS	Quantity surveyor.
RACI	Framework used in project management practice to define responsibility assignment matrix and can be illustrated as 'R' for responsible party, 'A' for accountable party, 'C' for contributing or consulting party, and 'I' for party(s) to be kept informed.
RAM	Responsibility assignment matrix
Record model	Building information model that has as-built information.
RFI	Request for information.
RIBA	Royal Institute of British Architects.
RICS	Royal Institution of Chartered Surveyors.
SIM	Structural information model.

SME	Small and medium enterprises.
TPS	Toyota Production System.
UniClass	Unified classification for the Construction Industry classification system used in the UK and owned by CPIC.
VA BIM Guide	US Department of Veterans Affairs Office of Construction and Facilities Management (CFM) Guide to Building Information Modelling.
Vertical BIM	Building information model used for vertical structure construction such as buildings.
XML	eXtensible Markup Language. A mark-up language defining set of rules for encoding documents in a format both human readable and machine readable.

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