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Bruno Emanuel Araújo Caires

BIM as a tool to support the collaborative project between the Structural Engineer and the Architect
BIM execution plan, education and promotional initiatives

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Escola de Engenharia

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Msc Dissertation
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Supervised by:
Engineer José Carlos Lino
and
Professor Miguel Azenha

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"The future belongs to those who believe
in the beauty of their dreams"

(Nelson Mandela)

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ABSTRACT

Building Information Modeling (BIM) is considered to be one of the emerging trends in the architecture, engineering and construction (AEC) industry, being expected to decrease the inefficiencies concerning the project delivery process. This concept provides an innovate holistic methodology on executing projects, by integrating a set of collaborative policies and technologies which enable to materialize the managing of the building design and project data through a digital format throughout the building´s lifecycle. Over the last few years, various governments have traced strategic implementation approaches to effectively introduce the BIM methodology under a collaborative environment for all national projects, foreseeing the paramount impact of its applicability in the construction sector. The uprising request of BIM allied with the current process of globalization for the construction sector have aroused the AEC firms to the inevitability of implementing BIM in their work procedures, to enhance their international competiveness. However, several barriers have been detected contributing to the slower adoption of BIM, where the lack of personnel with BIM competencies is considered one the most significant constraints. Furthermore, although many standards relevant to BIM exist, it is suggested that there is an absence of implementation guidelines into which those standards could be incorporated for project teams to follow.

Acknowledging these needs, the present work has the generic aim to contribute to the implementation of the BIM methodology among the stakeholders of the AEC industry. Its core ambition is the proposal of a BIM Execution Plan (BEP) framework in which a set of methodologies are compiled to enable project teams on strategizing the implementation of a BIM collaborative working procedure throughout the whole project process. The suggested BEP framework is based on a rigorous process of benchmarking regarding the most reputable BIM standards/execution plans and established interviews with distinguished AEC professionals regarding the fields of architecture, engineering and BIM. In addition, a case study was performed where the practical application of the proposed implementation methodologies regarding the collaborative workflows in BIM between the architect and structural engineer, were analysed. Complementary to the produced BEP framework, a series of initiatives concerning the promotion of the BIM concept and a BIM curricular unit, which are integrated in the strategy assumed by the University of Minho, are developed and analysed with the intent to demonstrate the importance of education as an active agent on BIM implementation.

Keywords: ***Building Information Modeling (BIM); collaborative project; BIM Execution Plan (BEP); BIM education.***

RESUMO

Building Information Modeling (BIM) está considerado como uma das tendências emergentes na indústria da arquitetura, engenharia e construção (AEC) sendo expectável que diminua as ineficiências relacionadas com o processo de execução de projetos. Este conceito proporciona uma metodologia de realização de projetos holística e inovadora integrando um conjunto de tecnologias e políticas colaborativas que permitem apoiar a gestão do projeto de construção e o acesso aos seus dados, através de um formato digital durante todo o ciclo de vida do edifício. Durante os últimos anos têm sido elaboradas estratégias de implementação BIM para impor a introdução efetiva desta metodologia sob um ambiente colaborativo, por vários governos, para todos os projetos nacionais, prevendo o seu impacto significativo no sector da construção. A crescente solicitação de BIM, aliada ao atual processo de globalização do sector da construção, tem alertado as empresas da indústria AEC para a inevitabilidade de implementar esta metodologia nos seus procedimentos de trabalho, reforçando a sua competitividade. No entanto são vários os obstáculos que têm contribuído para uma morosa adoção do BIM, entre as quais se destaca a falta de profissionais com competências BIM. Além disso, embora existam já normas nacionais referentes ao BIM em vigor, constata-se ainda a falta de orientações para a sua implementação, de um modo integrado com essas normas, para apoio às equipas de projeto.

Reconhecendo essas necessidades, o presente trabalho tem como objetivo genérico contribuir para a implementação da metodologia BIM entre os atores da indústria AEC. O seu principal objetivo é a elaboração de um guia para traçar um *BIM Execution Plan* (BEP), em que um conjunto de metodologias é compilado de forma a auxiliar as equipas de projeto na elaboração das melhores estratégias para implementar um processo de trabalho colaborativo em BIM, durante todo o processo de execução do projeto. O guia sugerido é baseado num rigoroso processo de revisão das normas mais conceituadas de BIM/BEP existentes e em entrevistas efetuadas a profissionais distinguidos da indústria AEC, relativamente às áreas de arquitetura, engenharia e BIM. Adicionalmente foi realizado um caso de estudo onde foi analisado a aplicação prática das sugeridas metodologias de implementação em relação aos fluxos de trabalho colaborativo em BIM entre o arquiteto e o engenheiro de estruturas. Complementarmente foram desenvolvidos e analisados um conjunto de iniciativas relacionadas com a promoção do conceito BIM e uma unidade curricular BIM, ambos integrados na estratégia assumida pela Universidade do Minho, com o desígnio de demonstrar a importância da educação como um agente ativo na implementação do BIM.

Palavras-chave: ***Building Information Modeling (BIM); projeto colaborativo; BIM Execution Plan (BEP); educação BIM.***

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LIST OF SYMBOLS AND ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
AEC	Architecture, Engineering and Construction
AEC/FM	Architecture, Engineering, Construction and Facility Management
AIA	American Institute of Architects
APIs	Application Programming Interfaces
BCA	Building and Construction Authority
BCF	Building Collaboration Format
BEP	BIM Execution Plan
BIM	Building Information Modeling
BIM-FM	BIM facility Management
BIT	Building Information Technologies
BPMN	Business Process Modeling Notation
bSa	buildingSMART alliance
CAD	Computer-aided-design
CDE	Common data environment
CIC	Computer Integrated Construction
CIS/2	CIMsteel Integration Standard Version 2
COBIM	Common BIM Requirements
C.U.	Curricular Unit
DB	Design-Build
DBB	Design-Bid-Build
ER(s)	Exchange requirement(s)
FAUP	Faculdade de Arquitetura da Universidade do Porto
FAUTL	Faculdade de Arquitetura da Universidade Técnica de Lisboa
FEUP	Faculdade de Engenheira da Universidade do Porto
FPs	Functional Parts
GC	General Contractors
GUID	Globally unique identifier
HVAC	Heating ventilation and air conditioning
IAI	International Alliance for Interoperability
ICTs	Information and communication technologies
IDM	Information Delivery Manual
IE	Information Exchanges
IFC	Industry Foundation Classes
IFD	International framework of dictionaries
IPD	Integrated Project Delivery
IPL	Instituto Politécnico de Leiria

IPV	Instituto Politécnico de Viana do Castelo
ISO	International Organization for Standardization
IST	Instituto Superior Técnico
LOD	Level of Development
LNEC	Laboratório Nacional de Engenharia Civil
OOP	Object-oriented programming
MEP	Mechanical, Electrical and Plumbing
MVDs	Model View Definitions
NBIMS	National BIM Standard – United States
NIBS	National Institute of Building Sciences
PLM	Product Lifecylce Management
PLPs	Project lifecycle phases
PM(s)	Process Map(s)
PTPC	Plataforma Tecnológica Portuguesa da Construção
PPP	Public Private Partnership
QTO	Quantity Take-off
ROI	Return on investment
RnD	Research and development
SLS	Service Limit State
UC	Universidade de Coimbra
UK	United Kingdom
UL	Universidade Lusófona
ULS	Ultimate Limit State
UMinho	Universidade do Minho
US	United States
USP	Universidade de São Paulo
WIP	Work in Progress

CHAPTER 1

1 INTRODUCTION

1.1. Subject Background

Over the last decades, architecture, engineering and construction (AEC) industry has shown economical inefficiencies, when compared to other prime industries. During the last four decades, evolution analyses have shown that, even with technological progress, the AEC industry has presented a decrement, regarding the productivity index when compared to other industrial sectors, where their values have more than doubled (Martins, 2009, Eastman et al., 2011) (see figure 1.1). In fact, over many decades, this sector is the industrial activity that represents the largest consumption of material and human resources (Construction, 2009) (see figure 1.2). Furthermore, in most developed countries around the world, this sector embodies a vital slice of their economies (Macdonald, 2011), working as an important indicator of their economic performance.

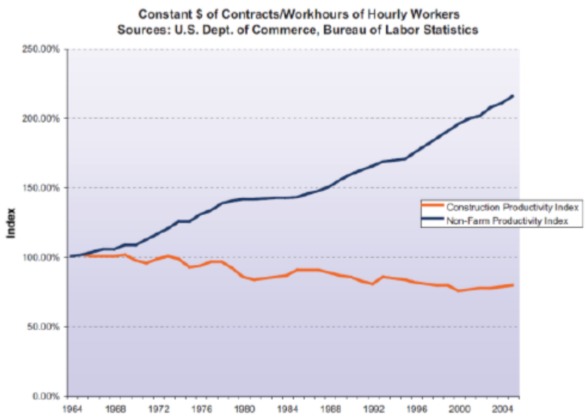


Figure 1.1 – Construction Productivity Index *vs* Non-Farm Productivity Index, evaluated in the US (NIBS, 2007).

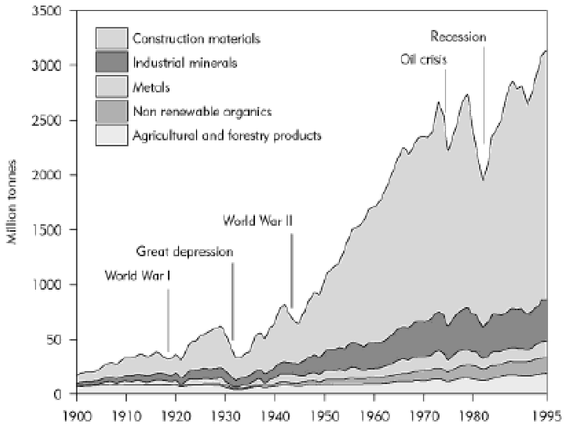


Figure 1.2 – Evolution in the consumption of raw material resources (Wagner, 2002).

The information and communication technologies (ICTs) have modernized many sectors of the economy, being the primarily reason that justifies the growth of several industrial activities (Martins, 2009). The focal purposes of these technological tools are to optimize the transmission of information between stakeholders, enabling to nurture a consistent set of solutions that support a collaborative project (creation, management, dissemination and use of information) throughout the lifecycle of a certain project/process (Shen et al., 2009).

Studies have indicated that the main reason that differentiates the AEC industry from other sectors in growth (e.g. automotive and aviation), consists on the inaptitude of accepting and implementing advanced ICTs applications and consequently modernizing their work methods (Eastman et al., 2011). However, the optimization of the construction sector is a more complex procedure when compared to other industries due to the elevated number of stakeholders that are involved and to the complexities associated in the development of building designs.

Fragmentation among the various stakeholders is appointed as the main insufficiency of the current construction industry (Isikdag and Underwood, 2010). Therefore, there has been a need to enhance the communication infrastructure, based on interoperable ICTs that facilitate information exchanges among the involved stakeholders and across the stages of the project lifecycle (Hammad et al., 2012). As a response to the increasing complexibility of the current projects and the disintegration between AEC stakeholders, ICTs have been developing at a very fast pace over the few years. The idea is to adapt triumphant technologies and methodologies that have been successfully implemented in other production industries in the AEC sector, namely the philosophies of *lean* and Product Lifecycle Management (PLM) (Martins, 2009). Economic efficiency, constructability, structural safety, performance, cost, sustainability, information interchange and effective team collaboration have been presented as key factors for construction productivity in the AEC industry (Lee et al., 2012, Ren et al., 2011).

In the recent years, a major shift in ICTs for the construction industry has been the proliferation of Building Information Modeling (BIM) as the new CAD paradigm (Bryde et al., 2012). BIM is one of the most promising developments in the AEC industry (Eastman et al., 2011), considered to be the new way of approaching the design, construction and maintenance of buildings (Azhar et al., 2009). In brief, BIM simulates the construction project in a virtual environment, by employing BIM ICTs, an accurate and integral 3D virtual model of the building, is digitally constructed and when completed these models contain all the necessary information in the form of data repository, which, consequently, supports the decision making of the stakeholders throughout the lifecycle of the project (Azhar, 2011, Gu and London, 2010).

Currently, there are already governments that have traced strategic implementation approaches to effectively introduce the BIM methodology under a collaborative environment for all projects in their countries, foreseeing the paramount impact of its applicability in the construction sector (Eastman et al., 2011). The uprising request of BIM allied with the current process of globalization of the construction sector have aroused the AEC firms to the inevitability of implementing BIM in their work procedures, to enhance their international competiveness. However, several constraints have been detected and contributed to the slower adoption of these new procedures (Lino et al., 2012, Construction, 2009). BIM represents a new paradigm shift within AEC industry, one that encourages integration of the roles of all stakeholders in a project (Azhar, 2011), where the lack of personnel with BIM competencies is a significant constraint retarding the implementation process (Sacks and Barak, 2010). Furthermore, although many standards relevant to BIM exist, it is suggested that there is an absence of implementation guidelines into which those standards could be incorporated for project teams to follow (Ahmad et al., 2012).

1.2. Dissertation’s scope and objectives

There is a consensus that more and more professionals of the AEC industry will need to acquire knowledge and skills to collaborate and cooperate through a BIM environment, which necessarily will include the curricular education developments, sanctioning the academic formation of BIM competencies to engineers/architects (Lino et al., 2012, Sacks and Barak, 2010). Equally important, is the development of implementation strategies, such as guides that enable the formulation of a BIM Execution Plan (BEP), which assimilate the current BIM standards and methodologies to help plan how to use BIM in collaborative projects. Acknowledging these needs, this thesis has the generic aim to contribute to the implementation of the BIM methodology among current and future stakeholders of the AEC industry, under a collaborative logic and embracing the latest developments and technologies in this field. Therefore, this work shall attend to three inter-related domains which are essential to foment a balanced implementation process, being described their objectives in following paragraphs.

The promotional initiatives of the BIM concept have the objective to announce and aware students (undergraduate/graduate), professors of civil engineering and architectural departments and even professionals of the construction sector, about the future challenges and trends of the AEC industry, explaining the importance of acquiring BIM competencies to match the proximate future requirements of the market. In some of these promotional initiatives it will be still intended to lecture the essential BIM concepts and demonstrate practical applications of this methodology. All promotional events presented in this dissertation had the contribution of the author and fall within the strategy assumed by the University of Minho, concerning the promotion of the BIM methodology among its students/teachers.

The second domain addresses the BIM curricular education initiatives, where the author of this thesis had the role of supporting the preparation and development of a curricular unit exclusively dedicated on BIM that was carried out at the University of Minho. The lecturing team was formed by professors and invited speakers that represented the diversified fields of the AEC industry with the aim to develop a comprehensive programme in order to convey the main concepts of BIM, to prepare the students with the necessary intellectual tools to be able to implement BIM in AEC projects, under a collaborative logic. Tacking advantage of Active Learning Methodologies it was intended that the students should develop a case study that matches the practical work that will be needed at a professional level.

The last domain and the core proposition of this MSc´s dissertation resides in the analysis of the collaborative BIM process. The main objective to achieve from this work consists in developing and presenting a set of methodologies that are capable to support and facilitate the implementation of a collaborative working procedure among the stakeholders of a project team to ensue throughout the project delivery, based on the BIM methodology and supported by interoperability. In parallel, it shall be performed a case study being analysed the practical application of the proposed implementation methodologies regarding the collaborative workflows that unfolds among the architect and structural engineer in a BIM project.

To be able to attain this core objective, a BIM Execution Plan (BEP) framework that incorporates the proposed implementation methodologies, intended to assist the Portuguese AEC firms on performing collaborative projects in a national/international scale will be developed. With this BEP framework the following topics shall be addressed:

- Process mapping procedure for planning the collaborative BIM workflows among the involved stakeholders during the phases of the project;
- Determination of the information exchange requirements and corresponding LOD classification attribution that occurs during the lifecycle of the project;
- BIM data management under a collaborative working procedure;
- BIM model management;
- Quality assurance checks of the BIM models.

By culminating these three domains a series of interacting relations are awaited to surface (see figure 1.3), such as the recognition that BIM is a collaborative methodology that is holistic to all members and disciplines of a project, where it is imperative the acquisition of knowledge regarding the essential concepts of BIM to prepare the current and future stakeholders in performing multi-disciplined collaborative BIM projects.

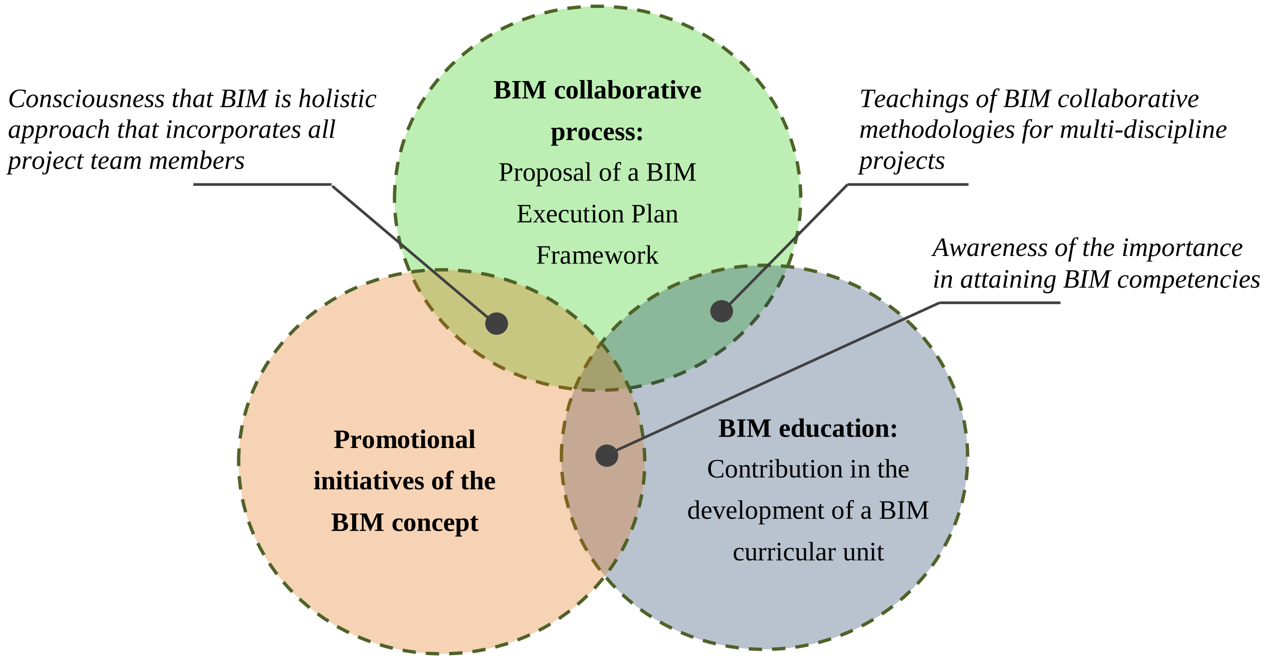


Figure 1.3 – Three work domains outline of the present MSc dissertation.

It must be given relevance that the work developed in this dissertation was elaborated at the engineering office NEWTON – Consultores de Engenharia, Lda (NEWTON-C) were the application of the BIM methodology is already a reality. The partnership between the University of Minho and NEWTON-C and posteriorly the interviews/collaborative work held between NEWTON-C and Atelier Nuno Lacerda Lopes (CNLL) were core features that promoted the opportunity to develop this dissertation project granting a valuable scientific interest.

1.3. Chapter outline

This dissertation is organized in five chapters, the first of which consists of this introduction.

The literature review present in **Chapter 2** embarks with the definition of the BIM concept and its potentialities, going onto aspects related to its implementation, where concretely the main barriers of implementation, possible strategies that can be undertaken to facilitate its adoption and the acknowledgment of the current worldwide status of BIM were nominated. In this literature review the description of the collaborative process in BIM is given great relevance, namely discussing its future trends, the current delivery contractual agreements and its relations with the BIM methodology. Furthermore, the data management characteristics that occur in a collaborative BIM working project, the interoperability aspects that are intrinsic in a BIM environment and brief description of the main BIM standards and construction classification systems generally applied in BIM specifications are delineated. To conclude, the most significant features that are commonly inherent in guides that formulate BIM Execution Plans are outlined.

Chapter 3 performs a summary of the promotional initiatives and the curricular unit of BIM that were carried out during the period of this dissertation work. For all initiatives that were held at the University of Minho, detailed information will be given about its description, objectives and tasks performed by the author. In addition, each initiative under study has a concluding point that analyses and discusses the acquired results.

Chapter 4 presents the proposed BIM Execution Plan (BEP) framework and concurrent analysis of the performed case study. This chapter commences by describing the investigation methodology followed to formulate the set of methodologies that are presented throughout the suggested implementation guide. During the chapter several fundamental issues regarding the planning strategy of a BIM collaborative working procedure are studied, being outlined a six stage method to strategize a detailed BIM Execution Plan for the involved stakeholders to follow during the project delivery. In each stage a theoretical explanation and the particular considerations admitted are indicated, followed by a practical exemplification through a case study that incorporates the collaborative project between the architect and structural engineer.

To conclude, **Chapter 5** provides a summary of the main conclusions, together with some suggestions for possible extensions of the conducted work.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Building Information Modeling

2.1.1. The BIM concept

Building Information Modeling (BIM) is changing the construction industry (Barak et al., 2009), by embracing a 3D graphical representation to improve project members workflows, communications, collaborations and data exchanges.

BIM consists of a set of interacting policies, processes and technologies that generate a work methodology that is able to manage, the building design and project data, in a digital format throughout the building´s lifecycle (Succar, 2009a) (see figure 2.1). BIM resides on the virtual construction of a building in a 3D digital model, known as a building information model, were simultaneous simulations associated with design and construction can be automatically generated by architects, engineers and contractors giving them more support in developing more efficiently projects. BIM is able to provide a holistic and more interactive vision of the project, making explicit the interdependencies that prevail between the various project specialties of a building (architectural, structural, and mechanical, electrical and plumbing (MEP) layouts) by technologically coupling the involved stakeholder's designs (Love et al., 2011) (see figure 2.2). Throughout the virtual construction of the digital model, the various stakeholders are constantly redefining and optimizing their discipline projects, hence updating the digital model under a collaborative logic (Carmona and Irwin, 2007).

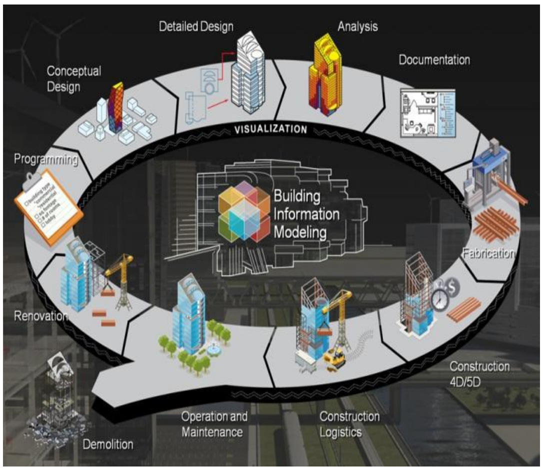


Figure 2.1 – BIM present in the project lifecycle of a building (Mienr, 2012).

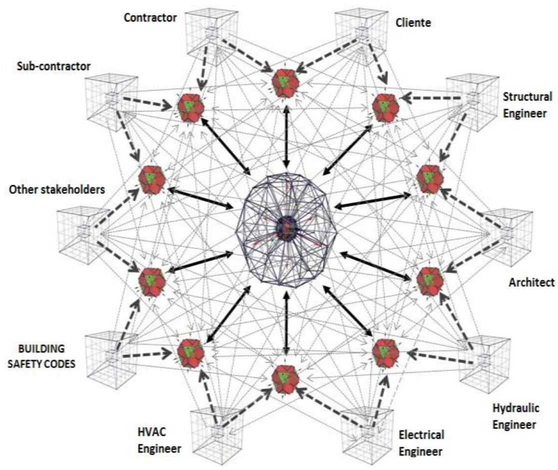


Figure 2.2 – Collaborative BIM methodology of sharing a virtual model, adapted (Musayelyan, 2009).

The definition of BIM has multiple understandings which are dependent on the value that the specific stakeholder wants to withdraw from this methodology. The contractor's perspective of BIM can be put in terms of its technical aspects as a model or documentation tool, serving as a project instrument to support the decision making and risk assessment throughout the construction and operation phase (Construction, 2009). Architects, structural engineers and MEP engineers who are more associated to the design phase, consider that BIM is an intelligent 3D virtual building model that can be constructed digitally by containing all aspects of the building information into an intelligent format that can be used to develop optimized building solutions with reduced risk and increased value before committing a design proposal (Barlish and Sullivan, 2012).

Summing up, the BIM concept essentially lays on a methodology of sharing information between all the stakeholders which is carried out during the lifecycle of the building, and materialized, by the use of specialized software, in the virtual construction of a 3D digital model (Lino et al., 2012). This 3D model in addition to containing the geometrical characteristics of the elements that constitute the building, it additionally clusters the properties and attributes of those building components, acknowledging the parametric relationships between those various elements (Lino et al., 2012).

2.1.1.1. The main fundamentals of BIM

BIM introduces a shift in the current work methodology undertaken in the construction sector, being transversal to all the actors involved, by changing the base documentation used in construction from one that is only readable by humans to new representations that are machine readable (Joeng et al., 2009). This innovated methodology enables a complete and accurate communication of engineering information without the need for detailed drawings (Sacks and Barak, 2010). BIM is fundamentally different from the traditional methodology (CAD), by being able to model the form, function and behaviour of the buildings components (Sacks et al., 2004). In the following paragraphs the main fundamentals related to the functionality of BIM shall be analysed.

- **Object-Oriented Modelling**

The research and studies performed in computer-aided design (CAD) field can be grouped into two main lines of development. The traditional CAD that is highly known to the AEC sector is designated as entity-based CAD, which consists of a geometric representation that present any element by using points, lines and areas. The other line of development, and the one that is adopted by BIM, is entitled as object-based or object oriented CAD (Mattei, 2008), where the object-oriented modelling approach is adopted to represent project design.

The object-oriented modelling is based on the concepts of object-oriented programing (OOP). In simple terms, OOP is a type of programming where everything is coupled as self-sustainable “objects/elements” (Nirosh, 2011), where in the case of BIM consists in representing the building design by its elements (objects – footings, beams, columns, slabs, wall, among others) (see figure 2.3). It is perceptible the similarity between the real sequence of construction and the virtual construction that is performed in this manner of modelling, giving the stakeholders a better vision of the real construction. This form of modelling stands out from the traditional CAD, because each element is usually a digital representation of the physical and functional characteristics of an actual building component to be used in a project (BCA, 2013f). Furthermore, each element has the ability to contain geometric (volume; shape; height; orientation; among others) and non-geometric (system data; performance data; mechanical characteristics; cost; among others) information.

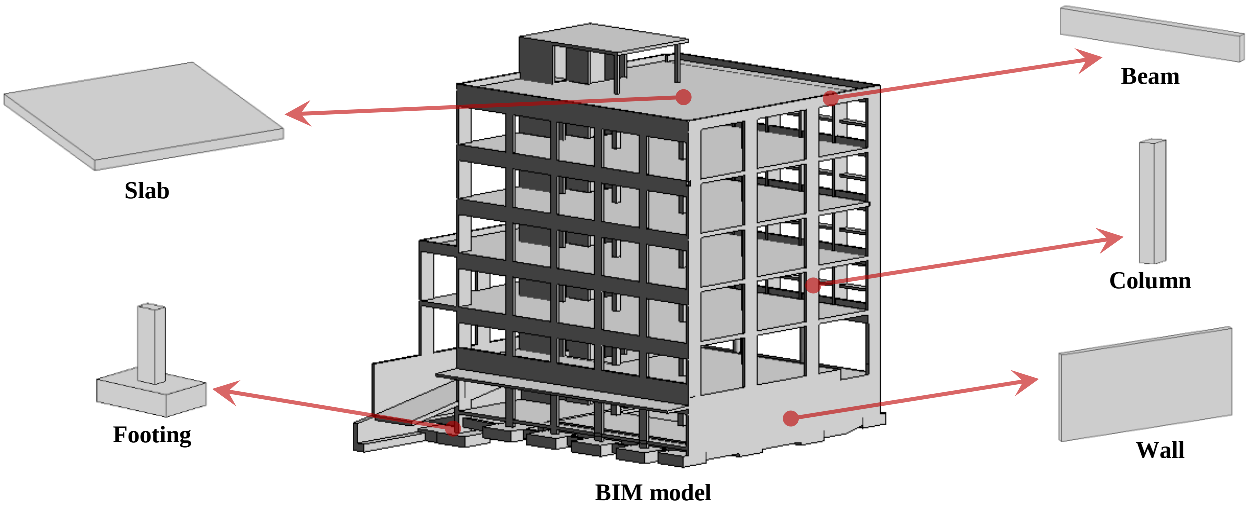


Figure 2.3 – Object-oriented modelling, adapted from (NEWTON, 2012).

- **Parametric 3D Digital Modelling and Parametric Relationships**

Parametric 3D digital modelling consists on a modelling approach that is totally guided by parameters, based on algorithms that are pre-defined by the user (Azenha et al., 2013a). It is a technology in which all objects are using rules and parameters that define its geometry and behaviour, as well as some non-geometric features and properties (Henriques, 2012). Hence, all the geometry can be controlled by a small number of key parameters (Azenha et al., 2013a). In figure 2.4 a practical example of parametric modelling is shown, in which an application named Grasshoper3D, defined as a graphical algorithm editor was applied, enables to control the behaviour of the form by selecting key parameters. In this case it is illustrated the integration of the parametric model with a structural analysis software, with the intent to optimize the structural design.

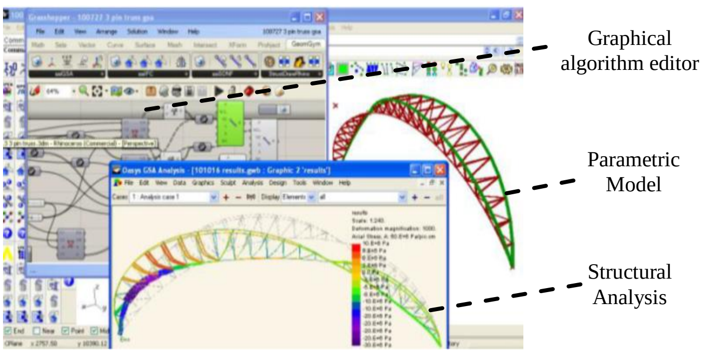


Figure 2.4 – Structural analysis extraction from Grasshopper3D (Mirtschin, 2012).

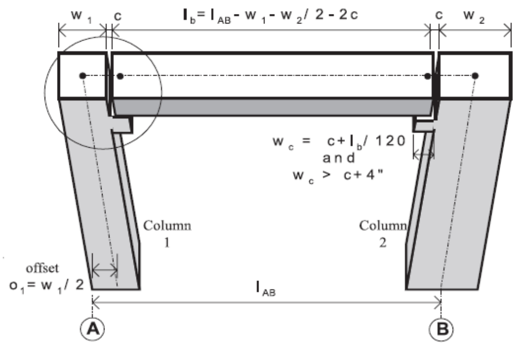


Figure 2.5 - Parametric relationships between beam and column, adapted (Sacks et al., 2004).

A key characteristic considered in parametric models is the ability to define the interactions between the elements incorporated in a model. The parametric relationships are defined by a series of rule sets that characterize the connecting relations among the building components (see figure 2.5), defining the possible constraints and implications between the respective objects (FEUP, 2011). These parametric relations are a core characteristic of BIM models being responsible for many of its key features. However, the definition between objects is also one of the biggest challenges for BIM software producers since there are numerous forms for two or more elements to relate to each other (Ferraz and Morais, 2012).

- **Information Model**

The usage of parametric object-oriented modelling enables the creation of elements "rich" in data and, consequently, the resulting virtual model can be defined as a 3D model of digital information. In other words, the building model is a repository of information which is developed and maturated by the involved stakeholders throughout the lifecycle of a building. The way on how a BIM model organizes and displays its data, in terms of software engineering is called a data model structure (FEUP, 2011). For a better understanding, figure 2.6 illustrates the data model structure regarding a column, demonstrating how the information relating to that component could be organized.

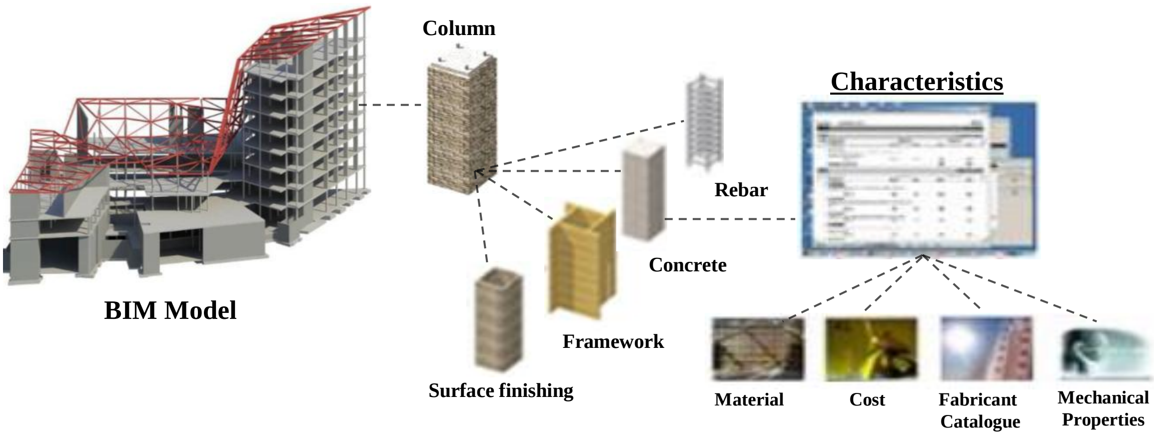


Figure 2.6 – Organization of the information in the BIM model, adapted from (Autodesk, 2011, Meireles, 2009).

Another key advantage of OOP when relating to BIM, is the ability of programmers to create "modules" within an information model that do not need to be altered when adding new types of objects (Lewis and Loftus, 2008, Shen et al., 2009). Users can simply create a new component of a building that inherits many of its features from existing similar objects. This introduces the concepts of "classes" or "parametric families" and "heritage" between classes which are essential aspects of the data management of a BIM model. In BIM models all the objects are organized according to different levels of classes. For an example, if the user wants to create a "metallic HEB 300 column", this BIM object will be part of the following classes: initiating by its superclass "columns", then "metallic columns", following "metallic HEB columns", and finally the class "metallic HEB 300 columns" is included. Only when applying the "final class" in a BIM model does it become a BIM object.

- **Interoperability**

As mentioned throughout the above topics, information and its management in the BIM models are key aspects of the BIM methodology. The ability to communicate, re-use and share data, efficiently, without loss or misinterpretation between stakeholders that use different software applications is an essential requirement that needs to be matched (AEC-UK, 2012a), in order to integrate the collaborative procedures with the technologies that are inherent to the BIM concept.

Interoperability in a BIM context can be defined as the capability of transmitting data between applications, as well as the ability of multiple applications working together (Eastman et al., 2011). The software applications used in BIM can be grouped as BIM tools or BIM platforms. A BIM tool can be defined as task-specific application that produces a specific outcome (Eastman et al., 2011). For example, tools can generate cost estimation, clash detection, structural analysis, energy analysis, renderings, among other uses. A BIM platform is an application that generates data for multiple uses (Eastman et al., 2011), allowing the creation and editing of the information relevant to the BIM model, containing the definition of classes and parametric relationships (Azenha et al., 2013a). Most BIM platforms, also internally, incorporate tool functionality such as drawing production and clash detection (Eastman et al., 2011).

In BIM, interoperability can be completed in multiple levels (Azenha et al., 2013a):

- Interoperability between a BIM platform and a BIM tool;
- Interoperability between a BIM tool and a BIM tool;
- Interoperability between a BIM platform and a BIM platform.

In these three levels the interoperability between the various applications can be obtained through a direct or an indirect link. The direct link is defined as a singular connection between two software applications, e.g. via an Application Programming Interface (API). The API is an interface implemented by a software application that enables the interaction with other applications (tools/platforms) (Eastman et al., 2011, Nielson and Madsen, 2010). On the other hand, the indirect link consist on using information exchange standards like the *Industry Foundation Classes* (IFC) – for building planning, design, construction and management, or *CIMsteel Integration Standard Version 2 (CIS/2)* – for structural steel engineering and fabrication (Eastman et al., 2011), among other data exchange standards.

- **Abstractions**

Abstractions in the BIM methodology are a concept that is associated with the management of the information when modelling. Generally, an abstraction corresponds to a vision of a reality where it is supressed a set of information that are considered unnecessary for the purpose in mind (Martins, 2009).

The concept of abstraction in BIM models are directly related to the sharing of information, where the abstractions can be defined as high or low (Esteves, 2012). When assisting to a high level of abstraction the sharing of information is censured generally only presenting the object. On the contrary, when there is low or no abstractions involved, a complete sharing of information is conceived. As a result, the abstraction considered will have an effect on the modelling detail (geometrical and non-geometrical) of the objects during the collaborative process.

The level of abstraction considered by the stakeholders during the collaborative BIM process can be used to consider possible restrictions on collaboration, namely to protect the intellectual property of the actors of the project team. These intellectual properties can be exemplified as libraries of objects that are developed by companies.

2.1.1.2. Features and potentialities

BIM is currently capturing the interest of the AEC industry due to the innovated potentialities and diverse applications that can be applied during the phases of the project (Love et al., 2011, Azhar, 2011, Bryde et al., 2012). The subsequent points, present the main features (general and specific) of BIM that are commonly applied in practical cases, according to the literature review (Kim, 2011, Azhar, 2011, FEUP, 2011).

- **General Features**

The following general features are transversal to all the specialities that are involved in a construction project. In brief, these general features are:

- Rapid visualization of the 3D model and the information of the project;
- Automatic generation of the technical documents;
- Automatic Quantity Take-off (QTO);
- Data sharing and coordination between the involved stakeholders.

The rapid visualization of the BIM model is the simplest feature of its technology, enabling an enhanced visual comprehension by the stakeholders throughout the lifecycle of the building (Joeng et al., 2009). Visualization helps to make the process management more transparent. In other words, the 3D BIM model can easily be manually inspected to verify what has been and has not been included in a given area or discipline of a project (Hammad et al., 2012). Furthermore, as the objects that constitute the BIM model are parametrically relatable, it enables the user to determine, freely, the view to be automatically generated (plans views, section views, elevation views, 3D views and construction details) (see figure 2.7).

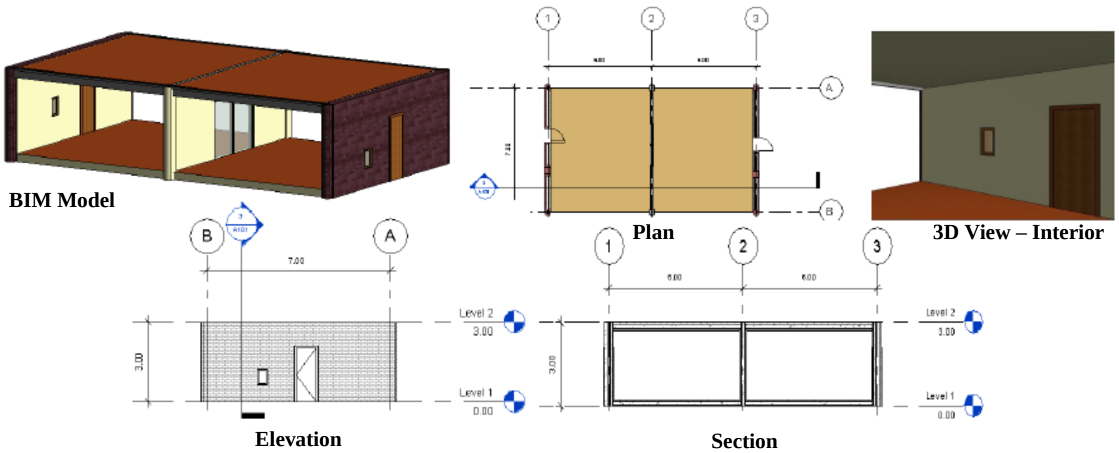


Figure 2.7 – Automatic production of views generated in a BIM model (Azenha et al., 2013a).

As recognized, the production of technical documents is one of the most arduous activities of the construction industry, both in terms of design documentation for licensing, procurement or construction documents (Monteiro and Martins, 2011). In the traditional methodology, whenever it is needed to be performed a design change it would imply extending all the alterations to the design documents associated to the specific views that are involved. When using BIM, the process of technical document production is automatized, implying that any modification to the project will be automatically verified in all the types of documentation that are involved (drawings and/or schedule documentation, for instance quantity take-off (QTO)) (Eastman et al., 2011). This potentiality is considered to be one of the main features of BIM (Fontes et al., 2010), because it allows all the stakeholders to remain updated to all the changes that occur in the shared model, being essential to achieve an efficient collaborative process.

Another general feature consists on the elaboration of a QTO schedule, which is considered to be one of the most time fulfilling and responsible activities in the construction sector (Eastman et al., 2011). As already mentioned parametric object-oriented modelling requires the specification of parameters regarding each object. With those parameters, namely the geometric (length, height, thickness) it is possible to retrieve from the model, instantaneously and automatically the quantification of each element that composes the building, attaining the bill of quantities (Eastman et al., 2011, Fontes et al., 2010). The QTO tool enables each stakeholder to test various solutions, rapidly, and support the decision making during the lifecycle of the building.

The sharing of data through the models of the involved stakeholders of a project, enables the work to be elaborated from the same data environment, which reduces possible errors and omissions when exchanging information documents (BCA, 2013f).

Another two key aspects consist on the accessibility to the project´s information and the ability to perform the compatibility checks between the disciplines that are involved. The coordination between the various stakeholder´s models enable to verify the possible conflict detections that occur between each discipline and indirectly assist on the evaluation of possible alternative solutions (Eastman et al., 2011). It should be noted that, the interference checking is customarily elaborated by the architect, but with BIM it is recommended to be performed occasionally by each actor of the project, granting more quality to the project design procedure (BCA, 2013f, AEC-UK, 2012a, COBIM, 2012c).

- **Architectural BIM features**

The main potentialities that can be delivered from BIM applications for an architect are (BCA, 2013a, Eastman et al., 2011):

- Mass Modelling enables the architect to study possible forms of the building´s architecture considering the landscape integration and initial QTO analyses. It should be noted that, mass modelling is only suggested to be considered in the initial phases of the architectural design;
- Sun studies are a significant benefit to determine the orientation, location and functional distribution of the various rooms of a building (see figure 2.8);

- Automatic integration with energy analysis applications;
- Animated 3D visualization and renderings (see figure 2.9);
- Production of detailed design layouts and detailed drawings (see figure 2.10);
- Automatic spatial validation, analysing automatically whether the architectural design is in conformance with the spatial program requirements (GSA, 2007).

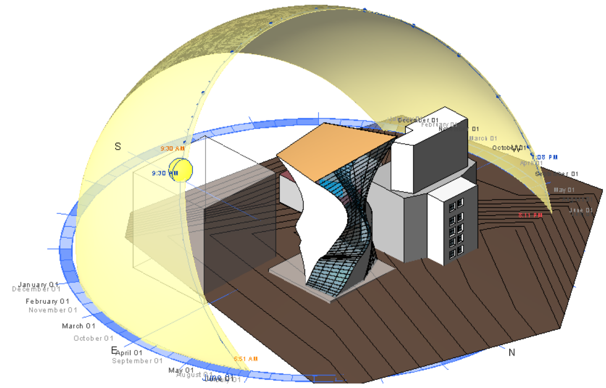


Figure 2.8 – Architecture BIM features: Sun study (Simmons, 2011).

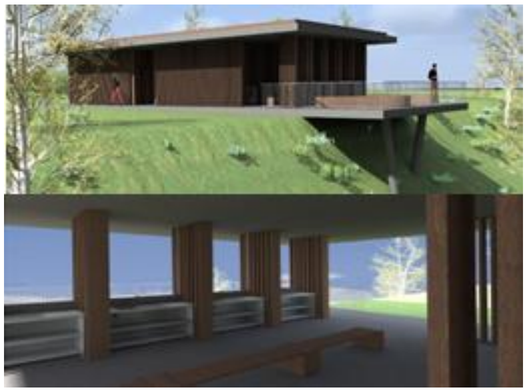


Figure 2.9 – Architecture BIM features: Renderings (Fonseca et al., 2013).

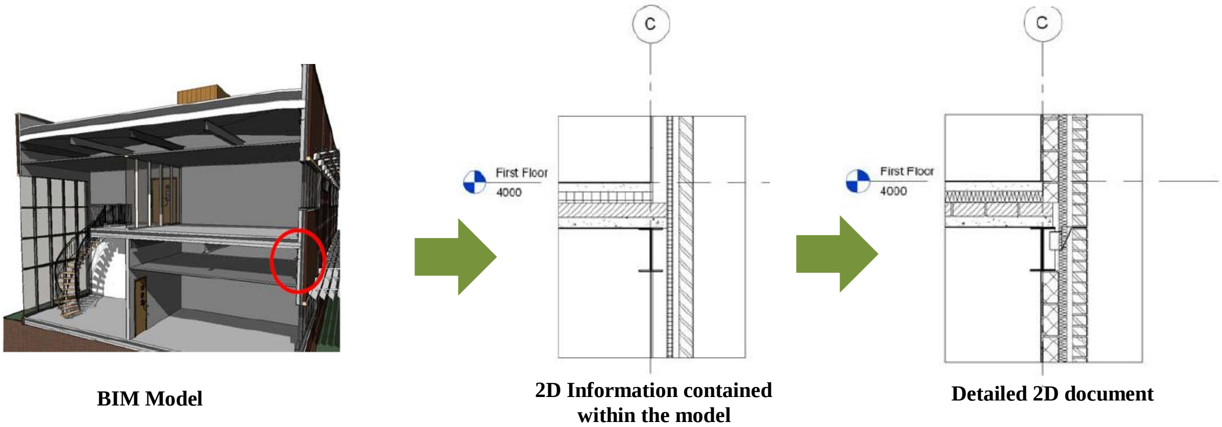


Figure 2.10 – Architecture BIM features: Production of detailed 2D drawings, adapted (AEC-UK, 2012a).

- **Structural Engineer BIM features**

The main potentialities that can be delivered from BIM applications for a structural engineer are (Joeng et al., 2009, BCA, 2013c, Nielson and Madsen, 2010):

- Automatic calculation of the earthworks – excavations and landfills;
- Automatic integration with structural analysis applications;
- Structural erection (sequential planning – 4D BIM);
- Structural detailing with respective QTO analysis – reinforcement concrete (see figure 2.11); steel connections; among others;
- Structural shop drawings (see figure 2.12);
- Automatic verifications of structural regulations and standards;
- Structural monitoring (Ferreira, 2011);

- Integration with the fabrication and construction phases.

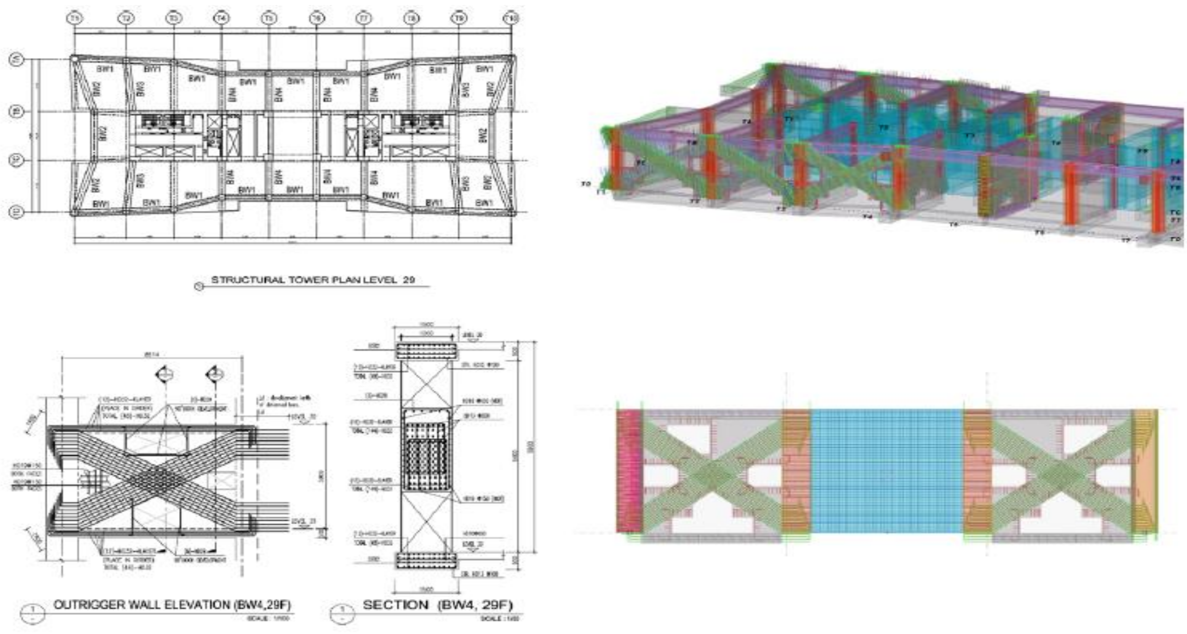


Figure 2.11 – Structural reinforcement detailing with production of 2D detailed drawings (Lee et al., 2012).

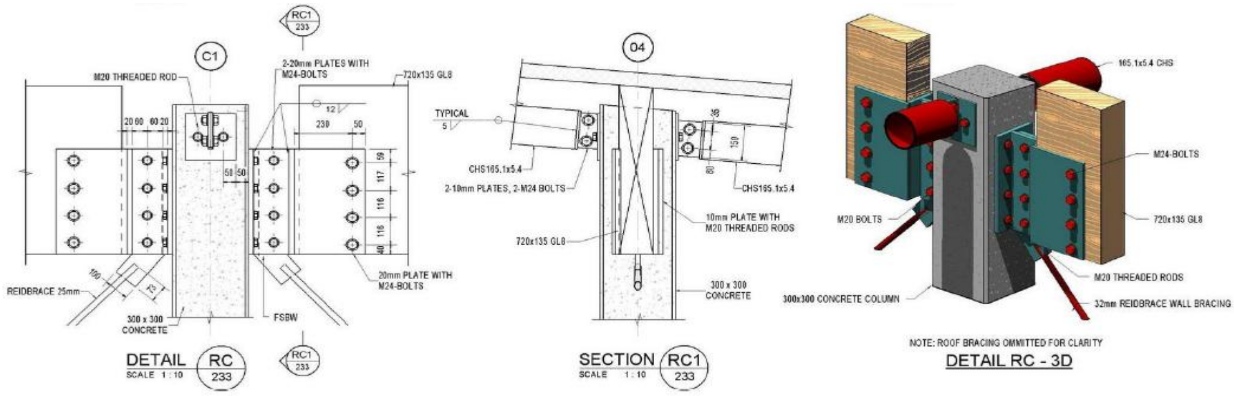


Figure 2.12 – Structural steel connections – shop drawings (BCA, 2013c).

- **MEP Engineer BIM features**

For MEP engineers the main features to retrieve from BIM applications can be, briefly, listed as (Eastman et al., 2011, BCA, 2013e):

- Class detection between the various systems involved in a MEP engineers workflow (Heating, ventilation and air conditioning (HVAC); water supply and sanitary plumbing; electrical circuits and mechanical equipment) (see figure 2.13);
- Detailed drawings – shop drawings;
- Automatic design and tracing – By entering the parameters that define each equipment/object of a certain system of the building (e.g. the exit flow rate of lavatory), a MEP BIM application is capable to determine automatically the sizing of the diverse pipes or ducts that constitute the system and present a set of alternative layouts intended to be the most economic;
- Automatic verifications of regulations and standards (Martins and Monteiro, 2013);

- BIM facility management (BIM FM or BIM 6D) – With BIM FM applications allow to extend the capabilities of BIM for phases of operation and maintenance of the building (Khemlani, 2007), enabling to maintain and control the various MEP systems (see figure 2.14).

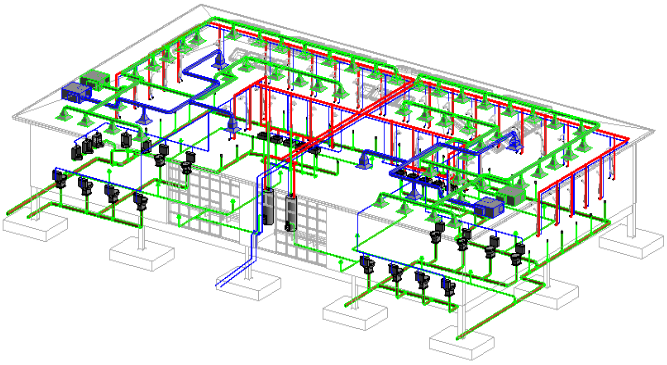


Figure 2.13 – BIM MEP model.

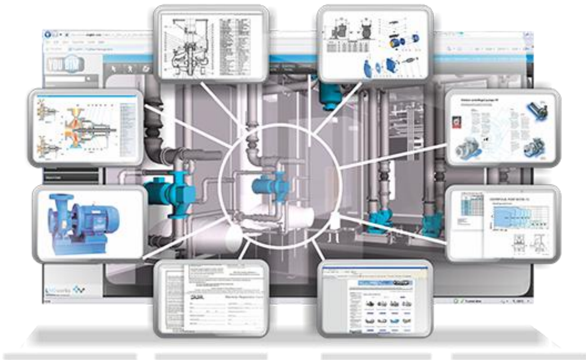


Figure 2.14 – BIM capabilities applied in facility management (YouBIM, 2013).

- **Contractor BIM features**

The main potentialities that can be delivered from BIM applications for contractors are (BCA, 2013d, Hergunsel, 2011, Eastman et al., 2011):

- Site planning – Logistic planning of the construction site;
- Construction coordination and quality assurance checks – This potentiality consists on evaluating the quality of the architectural, structural and MEP models, verifying if there is missing elements/information and detecting constructability issues;
- Construction documents – Preparation of the shop drawings for construction;
- Sequencing the construction (BIM 4D) – Temporal planning of the construction activities;
- Cost estimation (BIM 5D) – Planning of the cost flow throughout the period of construction;
- Risk assessment – By correlating the temporal and cost planning that are followed throughout the construction phase, it is possible to determine the risk that is involved regarding development of the construction;
- Construction monitoring – 3D laser scanning can be used to monitor the progress of the real construction when compared to the planned, by scanning and registering point clouds of geospatial information which then can be introduced in the contractor´s BIM model and compared manually the progress of the construction (Hergunsel, 2011).

2.1.2. BIM Implementation

2.1.2.1. The main issues of implementation

The barriers and limitation on the adoption of BIM by companies of the AEC industry can be divided into two broad categories: legal/social barriers and the technical/technological issues (Arayici et al., 2009, Azhar, 2011). In the following paragraphs, the main issues of each category, according to Love, Eastman, Ashcraft and others, are briefly discussed (Love et al., 2011, Eastman et al., 2011, Howard W. Ashcraft, 2008):

- **Legal/personnel barriers**

-Lack of skilled manpower: The lack of staff with expertise in BIM and BIT (Building Information Technology) is one of the main barriers that prevent the implementation of BIM in the professional AEC industry (Sacks and Barak, 2010). For there to be collaboration between the stakeholders of the project it is necessary for their modellers to have technical skills in order to enter and manage correctly the information in the shared model;

-Expensive investment: The purchasing of software licenses, training and formation of the work staff, and as well as the possible purchase of new hardware will be necessary to require this methodology;

-Productivity loss during the adaptation phase: The fall of productivity when implementing BIM in a company can be in many cases unsustainable due to the elevated investment made and the resulting reduced index of productivity obtained in the initial phases of adaptation;

-Involvement of all stakeholders in the project: Currently, BIM is in a phase of experimentation and implementation, with only part of the actors who are willing and able to use this methodology. Consequently, there is an incomplete collaborative process withdrawing one of the main potentialities of BIM, which is the collaborative integration;

-Ownership of the BIM model: The lack of contractual documents that determine ownerships rights prevent stakeholders to maximize the potentialities of their BIM models, due to the possibility of sharing internal intellectual property of their company with other project members;

-Lack of contractual responsibility: When working in such an open data environment, results, to some extent, in the dilution of responsibilities for the actors involved, which may result in dangerous consequences. Therefore, it is necessary to implement a contractual responsibility agreement, based on trust, among all stakeholders, in order to achieve the necessary deliverables throughout the collaborative process by each actor, without compromising copyright issues.

- **Technical barriers**

-Lack on application integration (interoperability issues): Interoperability is claimed to be the main technological barrier. It is essential to verify communication (import/export of information) between software applications with different data model structures. Nevertheless, several investigations are in pursuit to assess this difficulty;

-Lack of standardization of practical methods and processes: Due to the lack of the sharing of internal and external business processes by the companies of the AEC industry, the organizations responsible for standardization are having difficulties to map the collaborative processes that identify the information exchanges between stakeholders. Consequently, this issue delays the improvements of software applications and methods to facilitate the implementation of BIM.

2.1.2.2. Learning curve

A company of the AEC industry that intends to implement BIM in their work processes must balance a correct definition of their expectations during the process of implementation, which is very important in managing the usages to retrieve from BIM during projects (FEUP, 2011). The promotion of the concept Building Information Modeling is the target of a large advertising process (marketing), which has positive and negative outcomes. The positive outcome is the incentive to implement and use it as a mean to develop projects. The negative outcome is the tendency to hide the excessive effort that the company will incur to achieve an effective implementation of BIM, in order to take advantage of the features and capabilities provided by this methodology. In other words, this last aspect consists on a concept related to BIM called “BIMwash”, which resides on the attempt to hide imperfections (limitations of BIM), while at the same time, promoting an inaccurate view of one´s BIM capability or credentials (Succar, 2011).

The learning curve is a practical indication that illustrates the estimated evolution of the company´s progress in acquiring capabilities/competencies in BIM (see figure 2.15).

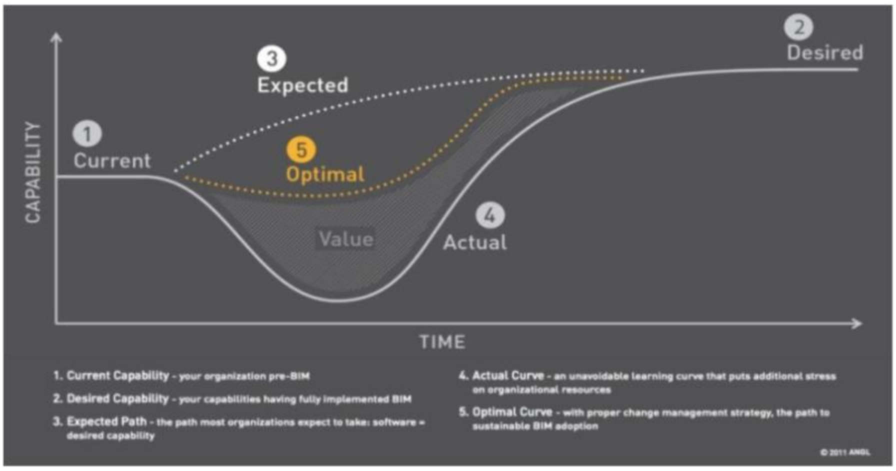


Figure 2.15 – Estimated learning curve of the AEC firms in BIM capabilities (ANGL, 2011).

Based on the learning curve shown in the figure 2.15, it is preferable that firms of the AEC sector begin with a slow and realistic objective process of implementation of BIM (Oakley, 2012), hence nurturing a sustainable growth and maturation in BIM skills rather than inflating their expectations. Several studies and practical cases sustain this argument (Construction, 2010).

2.1.2.3. Implementation strategies

Replacing the traditional methodology (entity based CAD – 2D and 3D) for a set of BIM models involves more than the acquisition of software, training and hardware. It consists in understanding the work philosophy and the technology intrinsic to BIM and create an implementation plan prior to the transition (Eastman et al., 2011).

Accordingly to (Hammnd, 2007, Howard W. Ashcraft, 2008, Eastman et al., 2011, Succar, 2012) and several case studies, the generic recommendation strategies that should be considered to achieve a sustainable implementation process in BIM are presented below:

1. The responsibility for developing a implementation plan of BIM should be attributed to the higher level of the business management hierarchy, in order to involve all areas of business and

understand how the proposals will affect the various internal departments, external business partners and customers;

2. Create an internal team of managers responsible for coordinating the BIM implementation plan. This team should be conditioned with budget margins, timelines and performance expectations;
3. The first contact with BIM in practical terms should commence with a set of small projects. In these pilot projects the BIM methodology alongside with the traditional methodology should be executed, with the objective to compare the same project outputs (e.g. traditional 2D documents). Hence, this implementation strategy helps to alert where there are inconsistencies in the BIM methodology that need to be improved or adapted. Normally these inconsistencies refer to output capabilities and interoperability issues with applications for analyses;
4. A second aspect to retrieve from the set of simple pilot projects consists on the development of internal processes and standards. This implementation strategy is a key aspect to follow in order for the companies to progress in implementing BIM. It is fundamental that a firm learns and registers the mistakes committed, workarounds and methods used in each pilot project. Equally important, the companies must develop internal routines (modelling guidelines and work processes) and be able to evaluate the efforts of modelling needed to obtain certain deliverables of a project. This last aspect is greatly important to enhance the productivity of the company when using the BIM methodology;
5. The company's management board should be continuously informed about the progress, problems and opportunities that arise during the implementation process. It should be noted that, this measure has the objective to avoid fragmentation within the company, but it is essential that the management board has an open mind and insistent approach;
6. When developed the internal routines to an acceptable level, companies should extend the usage of BIM to collaborative projects and initiate integrated work with other firms, with the objective to develop collaborative approaches that optimize integration and information sharing through a BIM model, and learn new approaches to optimize the internal routines of the company;
7. Periodically the BIM implementation plan should be revised and improved considering the benefits and problems observed. Ultimately, it should be imposed new goals (performance, timelines and budget limitations) for the internal managers responsible for its execution. In addition, companies should develop analyses to measure their state of implementing BIM, namely by performing return on investment (ROI) studies;
8. It is recommended that companies stay updated to the latest scientific/professional research and developments (RnD) in the diverse fields related to BIM and to the recent developments in the software industry. This can be done by attending international/national conferences, seminars, webinars and workshops.

A scale that can assess the individual competency of the staff in BIM can be generally defined into levels of knowledge. These levels of BIM competencies are distributed considering the theoretical and practical understandings that are needed to perform a well-defined activity or task using this methodology (Succar, 2012) (see figure 2.16).

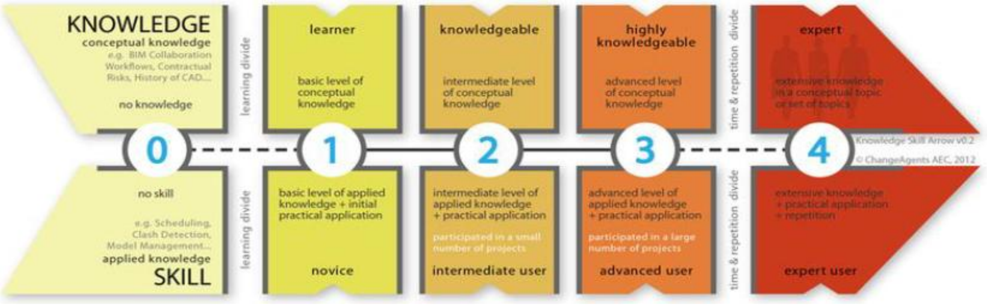


Figure 2.16 – Individual BIM Competency – the Knowledge Skill Arrow (Succar, 2012).

According to Bilal Succar, the scale of individual competency in BIM is defined in five distinct levels.

- **0- None**: lack of competence in any topic related to the concept;
- **1- Basic**: an understanding of concepts and fundamentals with some initial practical application;
- **2- Intermediate**: a solid conceptual understanding with some practical application;
- **3- Advanced**: significant conceptual knowledge with practical experience in performing a defined activity/task at a consistently-high standard;
- **4- Expert**: extensive knowledge, perfected skill and prolonged experience in performing a defined activity/task at the highest standard.

2.1.2.4. Worldwide status of BIM

BIM is being integrated rapidly into the work processes of AEC firms worldwide (Succar, 2009a). For a better understanding of the significance of the implementation of BIM and how it is being adopted in the global domain, it is useful to have a simple method to capture the different levels of sophistication (maturity levels) in which BIM is practised (Langdon, 2011). Figure 2.17 illustrates the various levels of maturity that are related to the implementation of BIM.

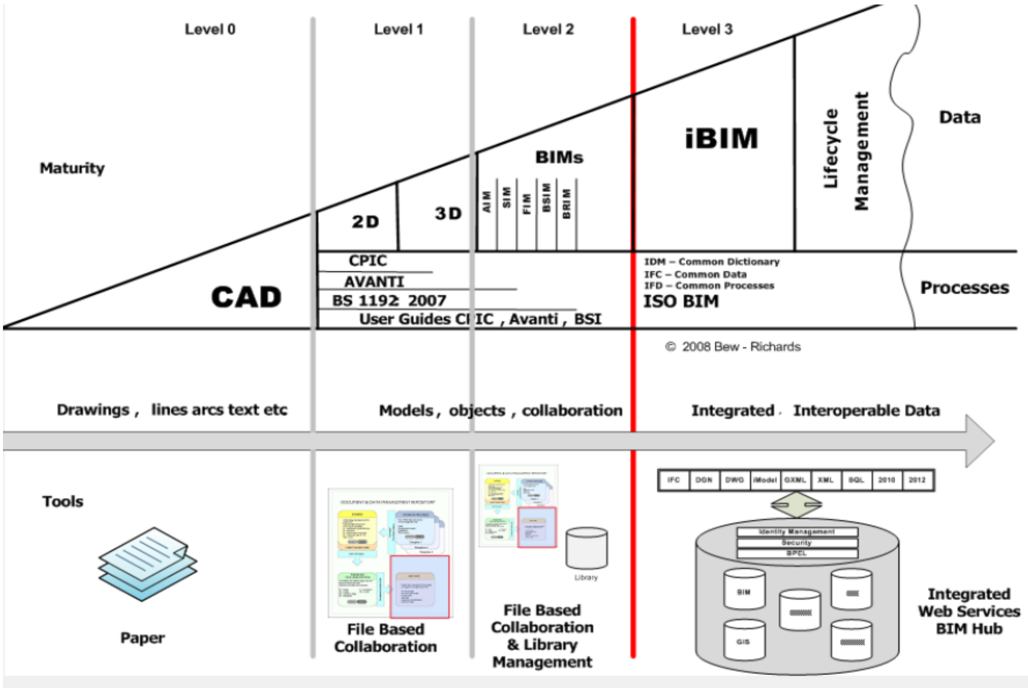


Figure 2.17 – BIM maturity levels (Group, 2011).

The different levels of maturity can be defined as follows (Succar, 2009b, Langdon, 2011):

-Level 0: Traditional methodology (entity-based CAD) without any information system, using a 2D format on paper or "electronic paper" as the main exchange system;

-Level 1: Traditional methodology (entity-based CAD 2D and 3D) used in a collaborative logic (extranet), by creating an environment of data exchange. Possibly using some standardized formats and data model structures. Additionally in this level BIM models can be developed but applied under isolated manner not verifying model sharing among the actors of a project;

-Level 2: The BIM models are incorporated in a collaborative environment structured in different project disciplines that allow sharing and management of the data between the various BIM models. Furthermore, in this approach it can be included BIM 4D and BIM 5D applications;

-Level 3: Fully integrated collaborative process characterized by employing a central model server that is holistic to all involved stakeholders and activities throughout the lifecycle of the building.

Several anchor world economies have taken concrete steps so that BIM becomes definitively a part of the processes that are inherent to their construction industry, namely through e-procurement, automatic licensing or support for electronic budgeting, among other necessary activities (WSP, 2012). The following paragraphs describe the world´s panorama regarding the status of the BIM implementation, considering the main countries that have invested in this methodology.

A first glance of the international scenario reveals that there is a greater relevance of the Nordic countries (Finland; Sweden; Norway; Denmark) in the adoption and use of BIM. These countries are considered as the precursors in the adoption of this concept, continuing to maintain a leadership status (WSP, 2012). These countries are home to some key AEC software vendors of BIM, such as Tekla and Solibri and have also pushed for interoperability and open standards in AEC technology (Khemlani, 2012). The early deployment of BIM in these countries is justified due to the rigorous climate conditions, which made prefabrication in buildings very common. Consequently, due to the elevated automation needed in prefabrication, this enhanced the natural implementation of BIM (Khemlani, 2012). Common BIM Requirements (COBIM), Stastbygg BIM Manual and Senate Properties BIM Requirements are just some of the national standards of BIM that have been developed.

Singapore, alongside with the Nordic countries of Europe are considered to be one of the earliest countries that recognized the potential of the model-based design (BIM) (Khemlani, 2012). The Building and Construction Authority (BCA) is the main organization governing the construction industry in Singapore, which had a project named CORENET that consisted on a system for automatically code-checking a design (Wong et al., 2009). In order for this system to be successful, it was necessary to represent the building by using a model rather than drawings, which aroused the interest of Singapore to adopt BIM (Khemlani, 2012). Currently, BIM has taken off in Singapore, where the BCA has developed a roadmap for the effective implementation of BIM that impulses its construction industry to be using this methodology widely by 2015 (BCA, 2013f). According to the Singapore BIM Roadmap, in this present year (2013) it is mandatory the implementation of BIM in important public projects. The Singapore BIM guide is one of the national BIM standards produced by the BCA, which is currently on its second version.

In the United Kingdom (UK), the UK Cabinet Office published a strategic document named the "Government Construction Strategy" that has an entire section on "Building Information Modeling". This document specifies that the government will obligate a level 2 BIM maturity level (see figure 2.17) for all projects in the UK as a minimum requirement by 2016 (AEC-UK, 2012a). To achieve this goal the UK government has elected a committee to develop a national standard of BIM and other protocol documents to facilitate its implementation under the collaborative logic (Khemlani, 2012). Currently, the AEC (UK) BIM Protocol is a national BIM standard, which is already on its second version.

The United States is one of the leading countries which develop the greatest number of BIM initiatives, being notorious the partnerships between professional AEC firms, universities and national organizations. From these various research projects there have been developed many documents that support the implementation of BIM in collaborative projects, namely outlining modelling guidelines, project requirements and projects processes (Saluja, 2009).

Australia is highly accepting the implementation of BIM in the industrial and academic contextual. Noteworthy, is the significant work done in the phases of operation and maintenance when using BIM as an approach for facility management (BIM-FM). The National Guidelines and Case Studies for Digital Modeling corresponds to a national guideline document produced by the Cooperative Research Centre for Construction Innovation which is a government research organization regarding the construction sector (CRC, 2009).

There are also a number of countries, such as India, China and South Africa that intend to implement BIM. As an illustration, India is already known for its outsourcing in BIM, namely in modelling services (WSP, 2012).

Currently in Portugal the implementation of BIM is in its foundational stages. Hence there is a lack of BIM adoption and awareness among the students (undergraduate and graduates), the professionals and other players of AEC industry (Monteiro and Martins, 2012). Nevertheless, one can already find several initiatives across the national companies, government organizations and universities, which seek to study best practices that may serve as initial orientation for the implementation of BIM (Lino et al., 2012). Two of the main organizations responsible for leading these initiatives are BIMFORUM Portugal and the BIM work group of the Portuguese Construction Technology Platform (PTPC), where the main national firms and universities are joint members of these organizations.

2.2. Collaborative process in BIM

2.2.1. Roadmap of the collaborative process

The coordination between the activities of the architecture, engineering, construction and facility management (AEC/FM) fields are complex processes that continues to grow in complexibility because of the increase in specialist knowledge (Moum, 2010). The projects produced in the AEC industry are currently characterized, as a result of extensive collaborative work from several domains (Singh et al., 2011), where a continuous exchange and refinement of information and knowledge proceed among the various stakeholders (Gray and Hughes, 2001).

BIM is considered to be a solution that fulfils the future requirements of the construction sector, by fostering the integration of processes between the stakeholders in a collaborative project. Contrary to the traditional method, that adopts a fragmented and sequenced collaborative method (traditional) (see figure 2.18).

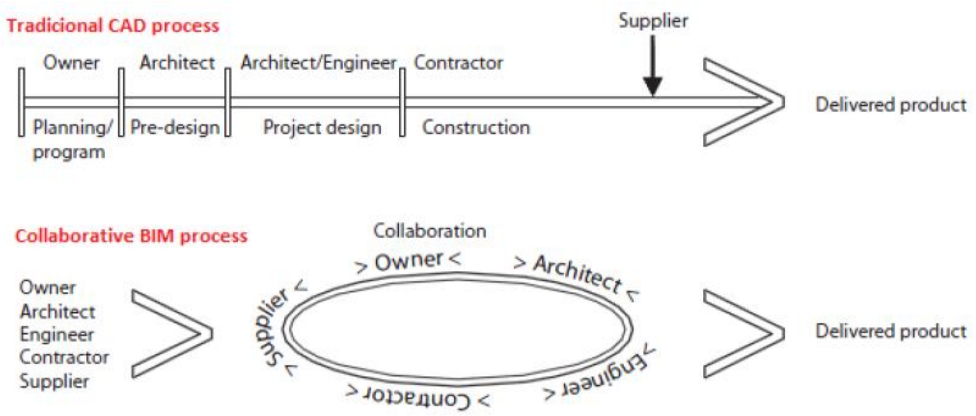


Figure 2.18 – Traditional CAD collaborative process *vs* collaborative BIM process (Thomassen, 2011).

According to (Löhnert et al., 2003) (see figure 2.19), the traditional ideal collaborative procedure is considered to be a linear procedure, however it does not allow for design optimisation. If a design needs to be improved it requires iterations, which originates the iterative collaborative procedure (see figure 2.19). Both procedures represent weaknesses. The traditional procedure fault is of not being able to embrace improvements to the design and the iterative procedure flaw is of being difficult to control because the extent of iterations can easily cause the design to diverge from its original objectives (Treldal, 2008). The integrated collaborative procedure (see figure 2.19), incorporates the two previous procedures mentioned, were at each iteration it is intended to create a basis for taking decisions, considering the goals of the project, possible constraints or influences and acknowledging the recommendations suggested by the diverse specialists of the design team (Treldal, 2008) (see figure 2.20).

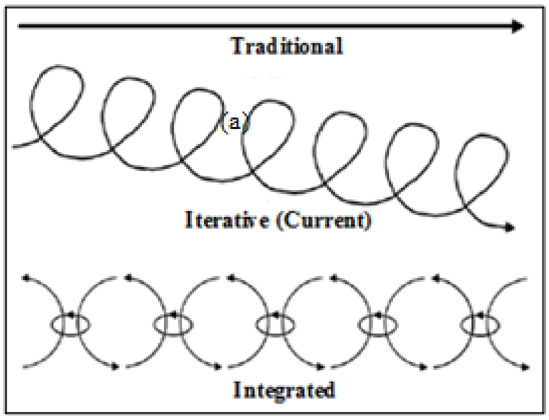


Figure 2.19 – The linear, iterative and integrated collaborative procedures, adapted (Löhnert et al., 2003).

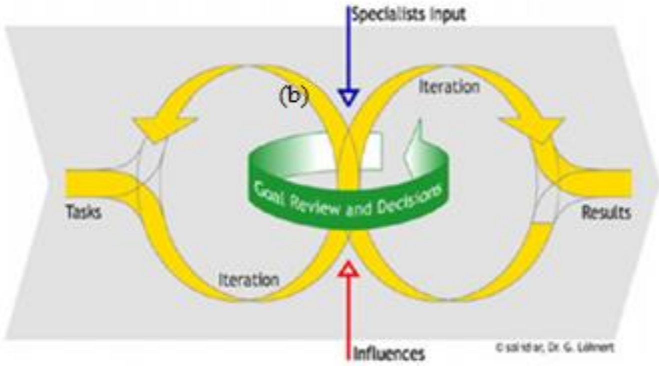


Figure 2.20 – The decision making process in the integrated in the integrated collaborative procedure (Löhnert et al., 2003).

The process of BIM implementation, which in return indicates the level of maturity of the project, is intrinsically related to the collaborative procedures adopted. According to the Australian Institute of Architects, the evolution of the collaborative BIM process implementation is described by the diagram "Towards Integration", which simply demonstrates, a very complex process (see figure 2.21).

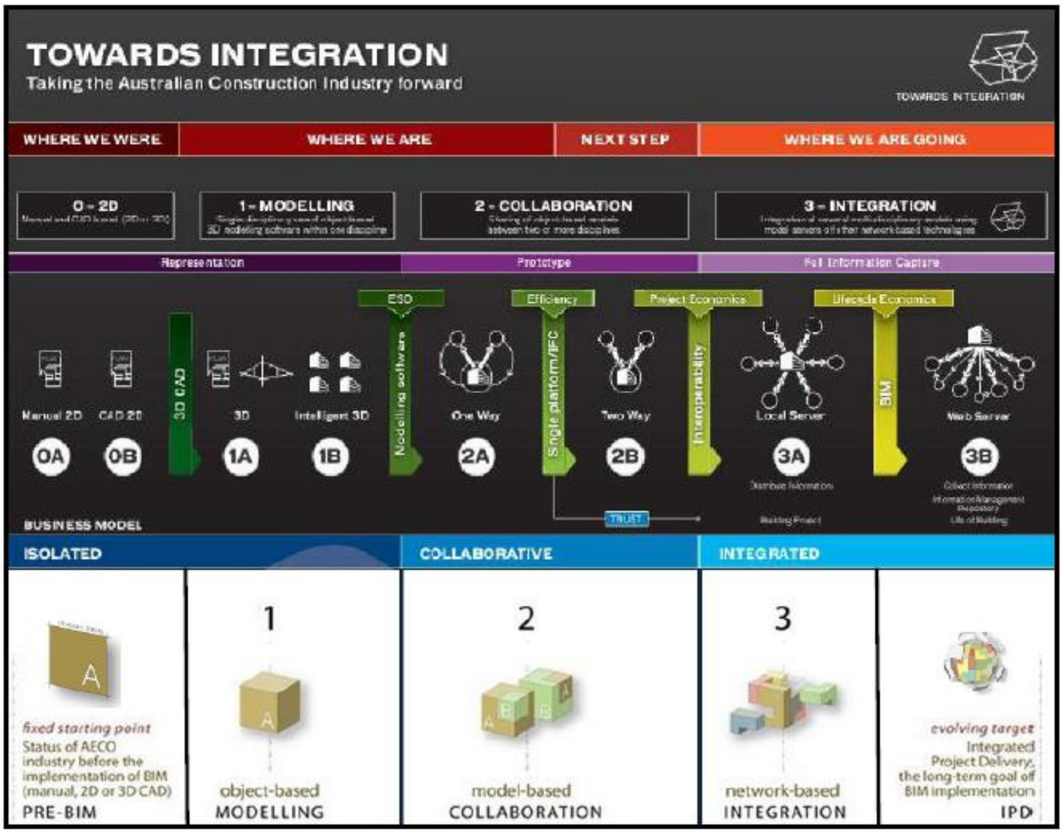


Figure 2.21 – Course of the progress in the integration and BIM collaborative implementation, adapted from (CRC, 2009, Succar, 2009a).

According to the CRC for Construction Innovation and (Succar, 2009a), the implementation evolution of the collaborative BIM process implementation can be subdivided into four stages:

- Stage 0: Pre-BIM;
- Stage 1: Object-based modelling;
- Stage 2: Model-based collaboration;
- Stage 3: Network-based integration.

Most of the current methodologies that are used in the communication and collaboration among the actors of a construction project lie in stage 0 – Pre-BIM. The contractual agreements mainly depend on 2D documents (manual drafting – OA or CAD 2D drafting – OB, see figure 2.21) to describe a 3D reality. Furthermore, the collaborative workflow is characterized as being sequential (Succar, 2009a).

With the advances in technology there has been, in parallel, an evolution of the modelling methodology, firstly with the adoption of 3D entity-based CAD modelling and secondly with the adoption of object-based modelling, where the model developed is considered to be a parametric intelligent 3D model (CRC, 2009) (see figure 2.21, 1A and 1B, respectively). Thus, in stage 1 – object-based modelling, the collaborative practice is characterized of not verifying significant model-based interchange among the different specialities and the work process of the actors of each discipline are executed separate from one another. Only when finalizing do the stakeholders discuss the work developed (Succar, 2009a).

In stage 2 – model-based collaboration the stakeholders actively collaborate with other disciplinary actors by using BIM models (Succar, 2009a). The implementation process of employing BIM models as collaborative virtual databases is done through two phases of adoption. The first phase consists in the creation and the entry of information in a BIM model, being characterized exclusively by the importation of data to the model for the other actors of the collaborative process to be able to view, communicate, analyse and simulate (CRC, 2009) (see figure 2.21 – 2A). The “feedback” from other actors is performed by using traditional methods, namely by digital/paper drawings, email, among others. In the second phase (see figure 2.21 – 2B), which is fundamental for the effective implementation of this methodology in the collaborative project, the BIM model is shared by two or more project stakeholders in an iterative collaborative process. Hence, this collaborative method is characterized by import and export of data interchanges among the involved actors, which translates into a greater integration among the various specialities of a design team (CRC, 2009).

Evolving to stage 3 – network-based integration, this stage can only be achieved if all stakeholders embrace BIM in the project delivery process. Stage 3 initiates with a collaborative method designated “consolidated models” (see figure 2.21, 3A). This collaborative method produces a project which is composed by a set of BIM models (partial models) that when combined, represent all the disciplines of the project (CRC, 2009). During the virtual construction of the building each actor interacts with a shared platform/server by updating their respective BIM models and retrieve relevant information from other BIM models.

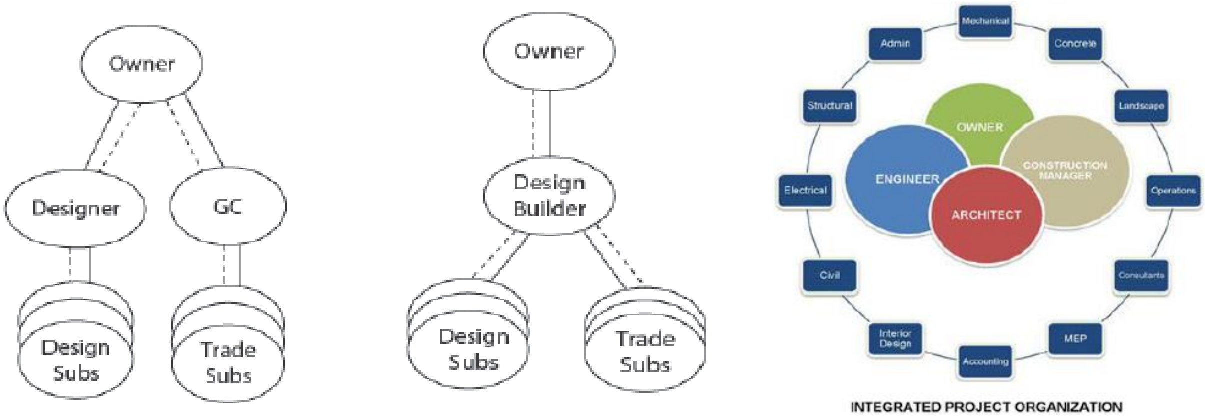
The final trend of the collaborative BIM implementation consists on obtaining full integration among the project team throughout the lifecycle of a building (see figure 2.21, 3B). In short, this project delivery approach is characterized by involving people, systems, business structures and practices into a process that collaboratively promotes 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 (Succar, 2009a).

2.2.2. Delivery process contractual agreements

BIM is only a mean to support the design, construction and facility management phases of a building, which needs to be sustained by agreements on project responsibility between the stakeholders of a project (Thomassen, 2011). In the AEC industry there are several project delivery agreements that are based upon the interests of the involved stakeholders (specially the client´s requirements), the type/scale of the project and trustworthiness between the actors.

The current project delivery agreements that are practised can be divided in two categories. The traditional delivery agreements like the design-bid-build (DBB) and the design-build (DB), which are currently the most applied agreements in the construction sector (Eastman et al., 2011). These agreements are related to a construction flow where the members of the project hand over their work in phases (Thomassen, 2011) (see figure 2.23). There have been applications of newer delivery agreements such as the Partnering, Public Private Partnership (PPP) and the Integrated Project Delivery (IPD) that are based on more integrated relationship between the processes of collaboration with the objective to induce more efficient designs (Eastman et al., 2011).

In the subsequent sections the DBB, DB and the IPD project delivery agreements will be described with higher detail (see figure 2.22). The selection of the indicated delivery agreements are justified due to their respective applications in the AEC Portuguese Industry. It should be noted, that the following descriptions acknowledge the interviews established with experienced professionals of the AEC Portuguese industry, namely Arch. Nuno Lacerda Lopes, Arch. Vanessa Tavares and Eng. José Carlos Lino. The results retrieved from the performed interviews have great similarities with the statements uttered by Chuck Eastman, Paul Teicholz, Rafael Sacks and Kathleen Liston (equally experienced professionals of the AEC industry under an international context) (Eastman et al., 2011), regarding the generic approach of each delivery agreements under analysis. This last, is an indication that the delivery agreements practiced in the Portuguese AEC industry are easily adaptable to those that are practised in an international scope.



a) b) c)

Figure 2.22 a), b) and c) – Project delivery agreements: Design-Bid-Build (DBB); Design-Build (DB); Integrated Project Delivery (IPD), respectively (Eastman et al., 2011, J.P. Cullen & Sons, 2008).

2.2.2.1. Design-Bid-Build (DBB)

In the DBB delivery agreement (see figure 2.22 a)), in a first stage, the client hires an architect, who develops a base program that considers a list of building requirements and establishes the project´s design milestones. Then the architect either hires employees or contracts specialized consultants to assist in designing the structural and MEP discipline designs of the building. The design team proceeds through several design phases: schematic design, design development and the detailed design. At each phase, the design documents of each discipline are recorded, which must then be coordinated to avoid incompatibilities. Finally in the phase of detailed design, the final set of drawings and specifications must contain adequate detail to facilitate the contractor´s bids.

In a second stage, starts the bidding process, where the owner and architect may determine which general contractors can participate in the bidding procedure. Each general contractor (GC) must be sent the design detailed documents (final drawings and specifications) obtained in the final design stage, which are then used to perform QTO analyses. These QTO analyses allied with the bids of subcontractors are then used to determine their cost estimation. Some GCs perform cost and temporal construction planning, with the objective to evaluate the risk assessment in performing the construction.

The winning GC is normally the contractor who performs the lowest bid, and before initiating the construction works it is often necessary to redraw some of the drawings to reflect the construction processes and the sequence of work. These documents are called the general arrangement drawings (construction documents). The sub-contractors and fabricators must also produce their own shop drawings, which are highly accurate and detailed drawings. If these drawings (general arrangement drawings and/or shop drawings), are inaccurate it can, consequently, provoke significant delays and unnecessary costs.

In cases where the bidding offers are too expensive, the design team must revise the design project and reduce features to bring down costs. In certain cases, the owner appoints a GC to accompany the design team to assist with cost reduction.

The main advantages of the DBB approach consists on the impartiality of the design team, where they look out for the owner´s interest in the project during the phases of design and construction (Thomassen, 2011). Furthermore, with this approach there is more competitive bidding in order to achieve the lowest possible price and there is less political pressure in selecting a given GC. As disadvantages, this approach has a greater tendency for the occurrence of errors and omissions in project documents (Azenha et al., 2013a), due to the elevated fragmentation of the collaborative process. Furthermore, the DBB contractual agreement requires that the procurement of all materials is to be held until the owner approves the bid, which translates larger waiting periods relatively to other delivery agreements, such as DB (see figure 2.23).

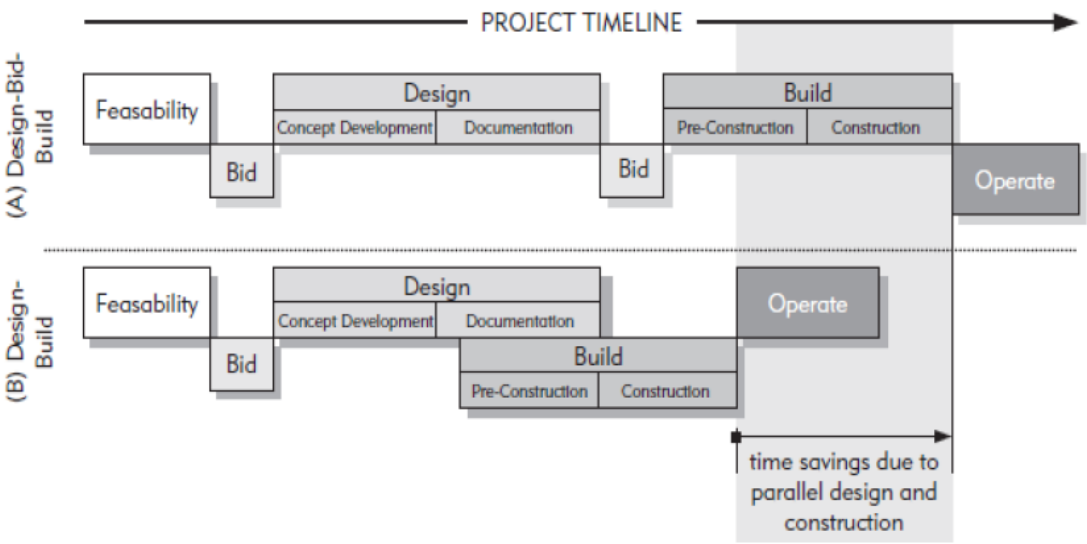


Figure 2.23 – Comparison between the Design-Bid-Build (DBB) and the Design-Build (DB) delivery-agreements (Eastman et al., 2008).

2.2.2.2. Design-Build (DB)

In the DB delivery-agreement (see figure 2.22 b)), the owner only contracts with one single entity, which generally is the contractor with design capability. The DB contractor is to develop a well-defined base program and a schematic design that meets the owner´s requirements. Still in the planning phase the contractor indicates the time needed and the cost associated with de design and construction of the building to the owner. When implemented all the alterations requested by the client and the schematic design is approved, the final budget is established.

Hence, the responsibility of the project is attributed to the contractor, whom includes a team of architects and engineers in the phases of design and construction to manage the various disciplines of the project. The contractor, as the risk taker and main stakeholder involved needs to control the design and construction phases, focussing on the cost/benefit interests that are involved (Thomassen, 2011).

The advantage of this delivery agreement is that the main alterations and decisions are made to the building´s design in its early phases where the costs of alterations have a minimal impact, due to the enhanced integration among the various disciplines of the project, relatively to the DBB contractual approach. Another important feature is the possibility to reduce the schedule of delivery process by overlapping parts of the design and construction phases (Thomassen, 2011) (see figure 2.23). As disadvantages, there is little flexibility for the owner to make modifications after the initial design is approved and a budget amount is established. Most important of all, is that, during the design and construction phases, no actor of the design team is safeguarding the interests of the owner, focusing solely on profiting.

2.2.2.3. Integrated Project Delivery (IPD)

Generally, the integrated project delivery (IPD) agreement describes new ways of working together, being characterized by the simultaneous work of all project stakeholders under the same virtual platform throughout the entire lifecycle of a building (AIA, 2007). The collaborative BIM implementation process tends to encourage this type of project delivery agreement, where full integration is verified among the main stakeholders of the project (see figure 2.22 c)).

In IPD the collaboration between the clients, key engineers, architects and builders commence in the early phases of the conceptual design and sustained until the delivery of the final project. During this process the design team can be enlarged, thus the initial core of engineers and architects are aware of all the activities that occur during the project´s development (Thomassen, 2011). So the IPD is defined by the early contributions of knowledge and expertise by the main actors, through the use of specialized technologies, with the idea that they are the main parties interested in the outcomes of the construction project, making them more responsible, creative and productive (Bongiorni, 2011). The actors who form the core project team must comply with the operating principles of the IPD, that is based on transparency, trust, leadership, open communication, profit, loss and risk sharing between the members of the project team and owner (Bongiorni, 2011).

The advantages are immense when adopting this delivery agreement, namely, resulting in the better quality of the project and productivity of the team, being able to overlap the phases of the project (Thomassen, 2011). However, there are various barriers that prevent the adoption of this collaborative method, particularly the necessary trust that is needed between the actors of different disciplines, the need for technological solutions that are capable to protect the intellectual property of the stakeholders and also the necessary technology able to produce the entire virtual construction based on a centralized information model server.

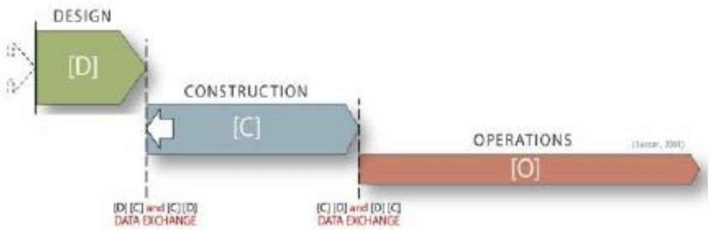
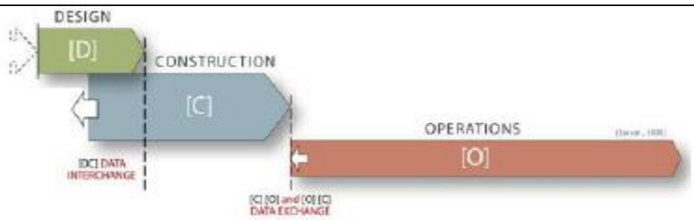
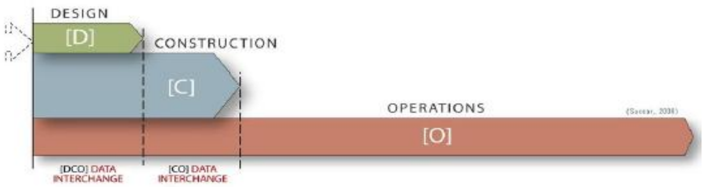
2.2.3. Data management in a collaborative BIM working project

2.2.3.1. Lifecycle of a project and its deliverables

A building´s lifecycle passes through multiple phases from conception to demolition. These phases are typically designated as the Project Lifecycle Phases (PLPs), which include pre-construction, construction and post-construction activities (Succar, 2008). According to Bilal Succar, it is possible to group all the phases related to the building´s lifecycle in three main lifecycle phases: Design (D), Construction (C) and Operation (O).

These main phases mentioned above exhibit temporal relations to one another, which is associated with the maturity of the collaborative BIM process implementation and/or with the adopted contractual delivery agreement. It should be noted, that the selection of the delivery agreement is independently associated with the maturity of the collaborative BIM process, however a high maturity level does encourage the stakeholders to adopt a more integrated contractual delivery agreement, for instance the IPD or DB. Nevertheless, the implementation of BIM in traditional delivery agreements is considered positive, but the management and interchange of data between stakeholders is considered inefficient and unproductive when compared to more integrated delivery-agreements (see table 2.1).

Table 2.1 – Temporal relations among the main phases of the building´s lifecycle, with relation to the BIM maturity stages and the contractual agreements, adapted from (Succar, 2009a).

BIM Maturity Stage	*Temporal Relations Amid the Main Phases of the building´s lifecycle*	*Delivery-Agreement*
Stage 1: Object-based model		Example: Design-Bid-Build (DBB)
Stage 2: Model-based Collaboration		Example: Design-Build (DB)
Stage 3: Network-based Integration		Example: Integrated Project Delivery (IPD)

The main phases that represent the lifecycle of a building are each constituted by sub-phases, which are further subdivided into activities, sub-activities and tasks. Given that the scope of this dissertation is to study the collaborative process that is developed between the structural engineer and the architect it will be only specified the sub-phases of the design phase. Although the construction phase could also embrace some collaborative work among these two actors, it is considered irrelevant because the work developed is more of technical assistance and supervision (Martins, 2009).

Accordingly to the Portuguese regulation (Portaria nº701-H/2008) the phase of design can be structured with the following sub-phases: Planning; schematic design; design development and detailed design. Once again, the division of the design phases are very similar of those adopted internationally (Eastman et al., 2011).

- **Planning**

This sub-phase of planning consist on the development of the following activities:
-Preliminary Program: The preliminary program consists on a document that is elaborated and shared by the owner/client with the design team. This document shares the definitions of the objectives, organic and functional characteristics of the construction, financial constraints and desired deadlines. Furthermore, this document can contemplate topographical elements, geotechnical reports, studies of the environmental impact, among other necessary support elements;
-Base Program: The base program is presented to provide the owner/client a clear understanding of the solutions proposed by the design team (e.g. architect or contractor), based on the information expressed in the preliminary program. In short, this document indicates the viability of the work and the generic alternative solutions of the design. When approved by the employer, the generic design(s) selected will be the basis of the subsequent phases of the project. This document can present the following elements: architectonic layout; possible generic dimensioning (when structural engineer is included in this activity); main constraints of the terrain occupation; generic estimation of the design solution(s) and construction costs and finally possible requirements needed by the design team that are not specified the preliminary program (geotechnical surveys; hydrological reports; among others).

- **Schematic Design**

The schematic design consists on the production of a document that is prepared by the design team, after the approval of the base program by the owner, which aims to select the solution that best accomplishes the client´s and technical requirements. In this sub-phase the design team, now constituted by more discipline expertise, develops the alternative solutions approved in the program base delivering the necessary informative elements that assist the employer to select the most adequate solution. These informative elements can contemplate 2D and 3D drawings, worksheets that specify generally the materials and quantities, giving the client a better idea of the type of construction works to be developed, site analyses, cost estimative, structural pre-dimensioning analyses, generic thermal/acoustic analyses, among other elements.

- **Design Development and detailed design**

The design development and detailed sub-phases, consists on the development of the schematic design solution approved by the design team and employer. The documents that materializes these sub-phases must incorporate a set of written and graphical coordinated information that allow an easy and unambiguous interpretation by the entities involved in the construction works. The information that is produced must obey the respective national laws, regulations and requirements. In brief, the resulting document must present the following elements:

- A report that justifies the decisions and considerations followed by the design team;
- Worksheets that specifies the material and construction works to be developed;
- Rigorous calculations of dimensioning of various components that constitute the building (structural, MEP analysis);
- Comprehensive QTO and cost estimations;
- Complete 2D drawings of the various specialities projects involved;
- Detailed drawing of construction details;
- Explanation of special conditions that need individual more rigours attention.

It should be noted, that during the design development and detailed design sub-phases the various actors of each discipline that constitute the design team must collaborate in order to produce projects that are coordinated with one another. At the end of the design phase the resulting project is to be validated by the contractor and employer, this last can contract third parties to verify the project.

Altogether, the lifecycle of a building contemplates the elaboration of various activities that are structured in phases. As already mentioned, there are many different tasks which can benefit with the incorporation of BIM. A study developed by the Computed Integrated Construction (CIC) Research Program, identified twenty-five possible BIM uses that can be practised throughout the main phases of the lifecycle (CIC, 2008) (see table 2.2). These BIM uses were developed through numerous interviews with AEC industry experts, case studies and broad literature review.

Table 2.2 – Chronological placement of the BIM uses (CIC, 2008).

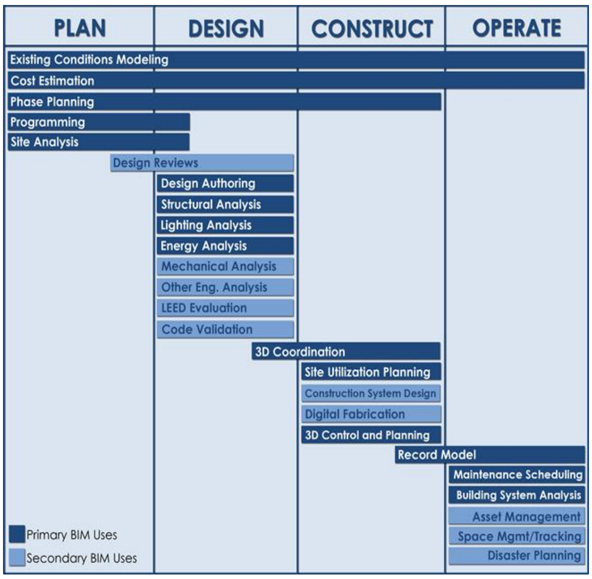


Table 2.3 – BIM use frequency and benefits with ranks (Kreider et al., 2008).

BIM USE	Frequency	Rank	Benefit	Rank
	%	1 to 25	-2 to +2	1 to 25
3D Coordination	60%	1	1.60	1
Design Reviews	54%	2	1.37	2
Design Authoring	42%	3	1.03	7
Construction System Design	37%	4	1.09	6
Existing Conditions Modeling	35%	5	1.16	3
3D Control and Planning	34%	6	1.10	5
Programming	31%	7	0.97	9
Phase Planning (4D Modeling)	30%	8	1.15	4
Record Modeling	28%	9	0.89	14
Site Utilization Planning	28%	10	0.99	8
Site Analysis	28%	11	0.85	17
Structural Analysis	27%	12	0.92	13
Energy Analysis	25%	13	0.92	11
Cost Estimation	25%	14	0.92	12
Sustainability LEED Evaluation	23%	15	0.93	10
Building System Analysis	22%	16	0.86	16
Space Management / Tracking	21%	17	0.78	18
Mechanical Analysis	21%	18	0.67	21
Code Validation	19%	19	0.77	19
Lighting Analysis	17%	20	0.73	20
Other Eng. Analysis	15%	21	0.59	22
Digital Fabrication	14%	22	0.89	15
Asset Management	10%	23	0.47	23
Building Maintenance Scheduling	5%	24	0.42	24
Disaster Planning	4%	25	0.26	25

Moreover, with the study mentioned above it was also intended to analyse the frequency and quantify the benefits of each BIM use that are practised in a specific phase of the project. Table 2.3, summarizes the results obtained, stating the percentage of the application frequency of the BIM use and the classification (-2 to 2, unprofitable to profitable, respectively) of the benefits of each BIM use. The results indicate that the most frequently and more productive BIM uses are of 3D coordination and design review. Another important indication is that the results of the survey indicate that all twenty-five BIM uses have had practical implementation and considered beneficial (Kreider et al., 2008).

2.2.3.2. Scope of the data workflow

The management of information and its accessibility will dictate the efficiency and productivity of a design team throughout the lifecycle of a building. This key variable of the collaborative process is dependent on the methodology that is adopted by the design team (traditional methodology or the BIM methodology and its respective level of maturity) and the contractual agreements approved among stakeholders.

BIM is a new design management system approach that intends to optimize the data workflow that unfolds during the phases of the project. The BIM methodology in terms of the data workflow among the actors, aims to transform the sequential "waterfall model" into an "iterative and integrated information management model" (Thomassen, 2011) (see figures 2.24 and 2.25), where the usage of the best technological equipment, techniques and knowledge expertise are used at the right time.

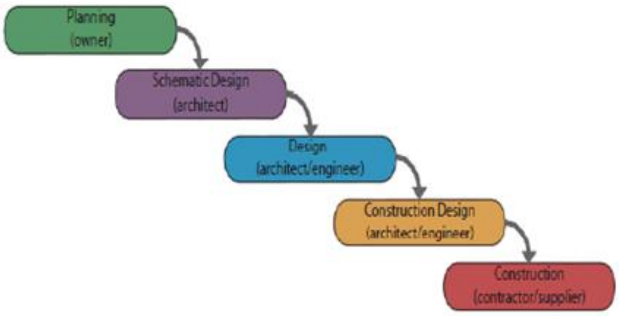


Figure 2.24 – Data workflow waterfall model, adapted (Thomassen, 2011).

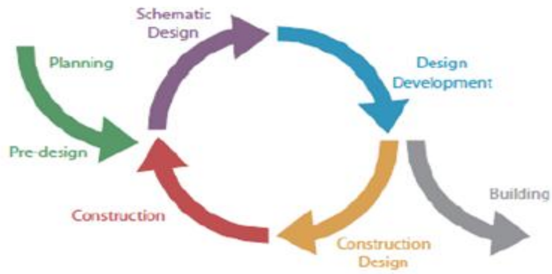


Figure 2.25 – Data workflow integrated and iterative model (Thomassen, 2011).

In the "waterfall model" (see figure 2.24), the data workflow proceeds from one phase to the next in a purely sequenced manner (Hung, 2011), following a linear behaviour over the execution of a project. In this data management model if an error is discovered in the final stages of a project, this implies possible modifications to all upstream phases, which can cause significative delays and increased costs. In the "iterative and integrated management model" (see figure 2.25) the data workflow is more cyclic (Hung, 2011), where the stakeholders have accessibility to all the relevant information of the project. Hence, all the aspects of the virtual construction can be discussed rapidly during the collaborative process, consequently optimizing the collaborative work.

This paradigm shift of the methodology used in the collaborative project, namely on the how the data management is processed among stakeholders, delivers advantages that are posteriorly visible on costs and on productivity. The application of the BIM methodology encourages in the initial phases of design bigger efforts from the design team, enabling the detection and resolution of errors and inconsistencies of the project where costs of change still are relatively low (Wang et al., 2002). This argument is defended by Patrick Macleamy, that stats the need for redistribution of the stakeholders efforts to improve the outcomes of a design, by graphically demonstrating that early phases of design possess critical features that impact the product lifecycle performance (Cavieres et al., 2011) (see figure 2.26).

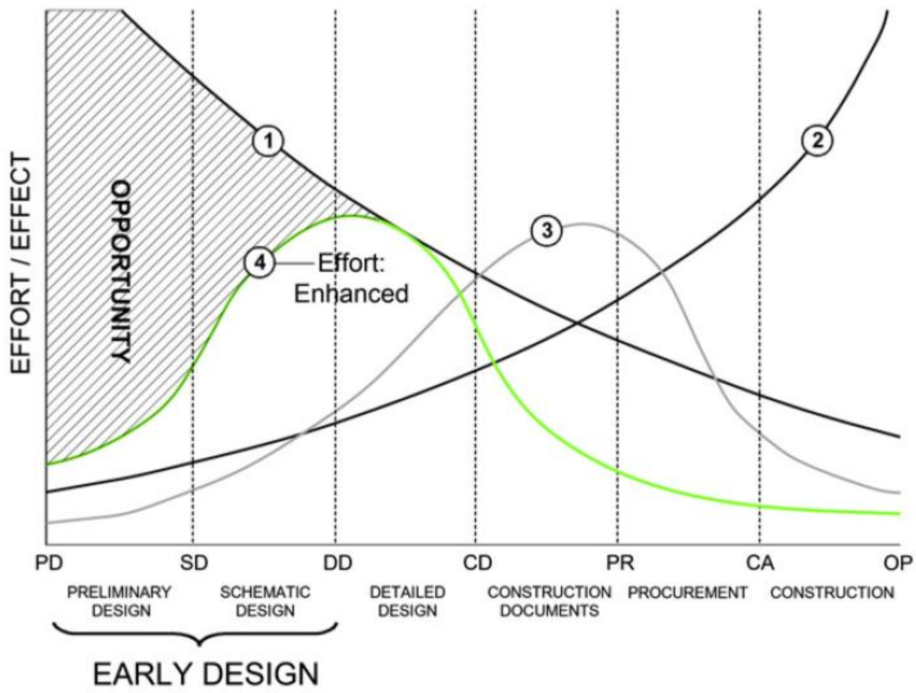


Figure 2.26 – Macleamy curve, advantages in anticipating design decisions (Cavieres et al., 2011).

Dismantling the Macleamy curve presented above, curve 1 indicates the influence of decision changes that effects on costs and performance, which its ability generally decreases during time. Curve 2 refers to the cost of design changes (redesigning), which normally increases during the phases of the project. Finally by comparing curve 3 and curve 4, which represent, respectively, the traditional design effort distribution and the redistribution of efforts by an enhanced approaches (like BIM), it is visibly possible to comprehend the benefits of concentration and developing more collaborative work in the early phases of design. Therefore, this paradigm shift regarding the collaborative working procedures should be seen as an opportunity to obtain viable projects, right from the early stages of design.

2.2.3.3. Storage and sharing of the information between stakeholders

For the BIM methodology to be implemented it is necessary the creation of a virtual platform which enables the utilization of BIM models in a parallel co-operation between the diverse stakeholders involved in the project (Thomassen, 2011). These various BIM models are generally sub-divided according to the disciplines that constitute a project, which has the purpose to enhance operational efficiency on large projects, multi-user access and inter-disciplinary collaboration (AEC-UK, 2012a). Thus, each disciplinary BIM model is linked with the remaining models within a common virtual platform (see figure 2.27). Furthermore, each discipline model is considered to be a central model where secondary BIM models (local models) are interconnected, enabling to separate work tasks within a specific discipline (see figure 2.28).

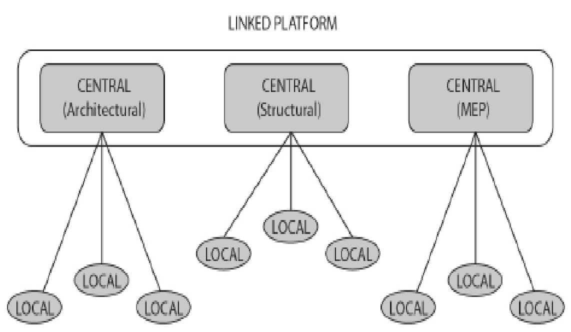


Figure 2.27 – Linked discipline models (Krygiel et al., 2010).

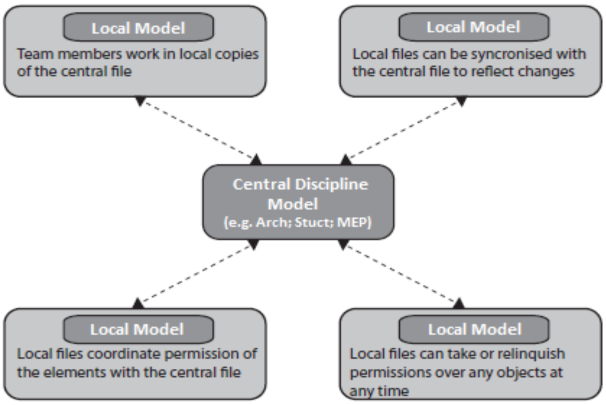


Figure 2.28 – Characteristics of local models, that constitute central disciple model (Krygiel et al., 2010).

The information that is to be shared among stakeholders is contained in the objects of each model, which represent physical elements like doors and columns, and encapsulate meta-data ("intelligence") (see figure 2.29).

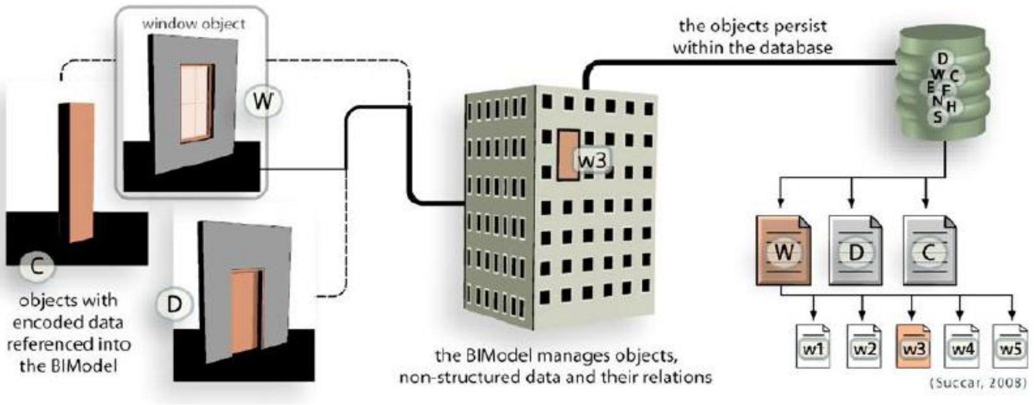


Figure 2.29 – BIM models and their objects – flow diagram (Succar, 2009a).

The following points classify the diverse types of BIM information flows that can occur in the collaborative process (Succar, 2009a):

-Structured/Computable: For instance, the sharing of BIM models (which are databases) that contains geometrical and semantic information, where this type of information can be digitally processed;

-Semi-Structured: For example, the sharing of worksheets where normally this type of information consists on results of executed processes;

-Non-Structured/Non Computable: A possible example can be the sharing of 2D or 3D drawings. This type of information can only be humanly processed.

According to the literature review, the methods of transfer of data when embracing the BIM methodology can be classified either as BIM data exchanges or BIM data interchanges (Succar, 2009a). The BIM data exchanges are when an actor exports or imports data that is not structured or computable (e.g. export of 2D drawings from a BIM model or export QTO results). On the contrary, BIM data interchanges is when an actor exports and imports data that are structured and computable by applications (e.g. importation of the analytical model for structural analysis from the structural BIM model). Interoperability between systems plays an important role in the succession of this last method of transfer.

2.2.3.4. Common Data Environment (CDE)

The definitions of methods that enable efficient data sharing in collaborative BIM working procedures are fundamental to achieve the potentials of BIM. According to the literature review, the Common Data Environment (CDE) approach is generally practised in collaborative projects where the BIM methodology is implemented. The CDE is a methodology of data sharing which allows information to be shared between all members of a project team, with the aim to reduce the checking, revision and reissue cycle of data (AEC-UK, 2012a). There are four areas relevant to a CDE as illustrated bellow (see figure 2.30).

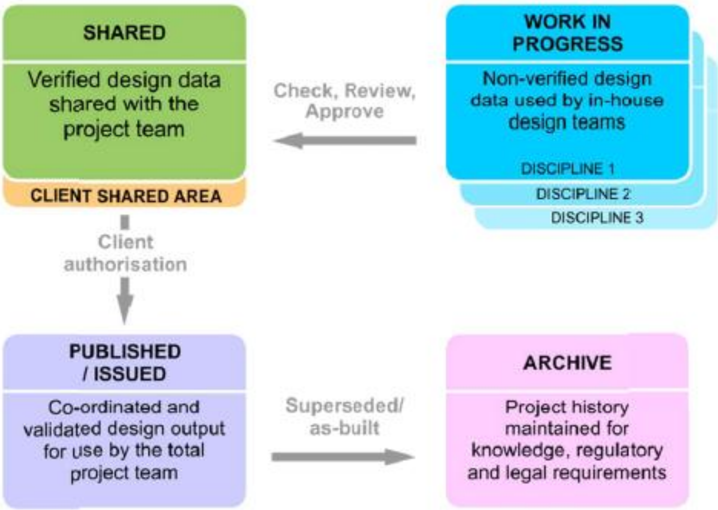


Figure 2.30 – Four stages of the Common Data Environment (CDE) (AEC-UK, 2012a).

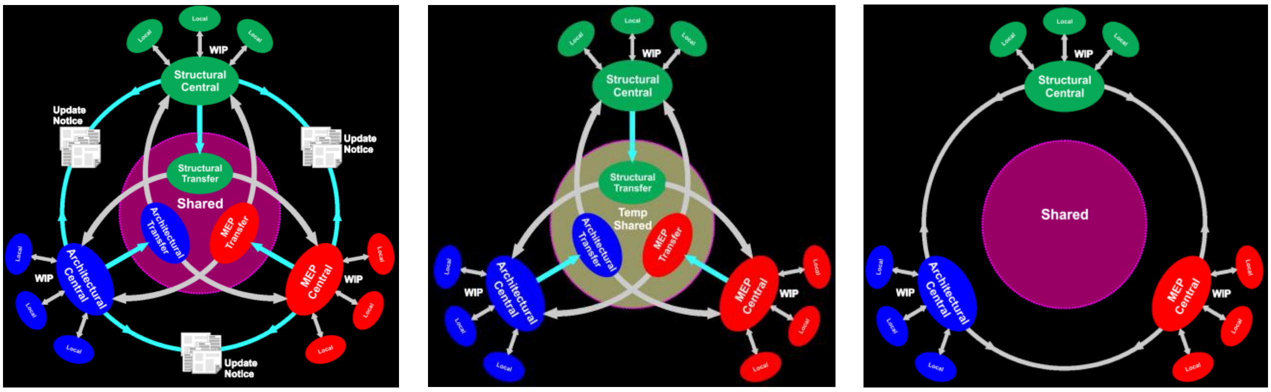
The first area consists on the information that is generated in each discipline, which is allocated in their respective Work in Progress (WIP) area. This is typically located on the data servers within each firm`s own unique local area network, where only the authorized members of that firm have access (AEC-UK, 2009).

Once checked and approved the data generated in each discipline BIM model, it is formally released to the Shared area, in order to facilitate co-ordinated and efficient collaboration among the stakeholders (AEC-UK, 2012a). This operation shall be carried out on a regular basis in order that other disciplines are working with the latest validated information. When the data is released in the shared area or when modified, an update notice should be communicated to the remaining members of the project team.

All published documents and additional data must be only obtained from the BIM models in the Shared area, being previously approved by the client. These documents consists on drawings, schedules, quantities and additional file formats and when obtained and approved are allocated to the Publication ad Document Issue area. All validated and applied output data from the BIM models shall be stored in the Archive area of the project folder (AEC-UK, 2012a).

2.2.3.5. Review of the collaborative BIM working procedures

One of the major challenges of a BIM collaborative project is to determine how to connect the various BIM models when using a shared virtual platform and how the actors should organize their BIM models in order to facilitate the data management in the collaborative process. Figure 2.31 illustrates a set of collaborative BIM working procedures that can be adopted in a multidisciplinary project.



a) b) c)

Figure 2.31 a), b) and c) – Multi-discipline collaborative BIM working methods (Woddy, 2012).

The AEC (UK) BIM Protocol 2012 v2.0 and the Singapore BIM Guide 2013 v2.0, both national standards, recommend the collaborative BIM working method presented in figure 2.31.a). This multi-discipline collaboration method is in concordance with the principals of the CDE, mentioned above. Here all disciplines have their central model that is developed in their private servers, which are constituted by local BIM models. During the development of each central discipline model there is collaboration with other actors and informal sharing of information. When concluded a certain task, these actors formally import the resulting developed data (deliverable) to the shared virtual platform (Shared area) and give notice to the remaining elements of the project team.

The collaborative methods represented in figures 2.31 b) and 2.31 c), diverge from the indications of the CDE. In figure 2.31 b), the main differences consist on the fact that there are no communication procedures among the stakeholders, were all collaboration occurs solely through the shared virtual platform. On the contrary, the collaboration method demonstrated in figure 2.31 c), there is no shared virtual platform. Here, all exchanges of information are realized directly between stakeholders, where the accessibility to information can be constraint.

2.2.3.6. Level of development (LOD)

Jim Bedrick comments, that the core of architectural design is the process of moving from approximations to progressively more precise details (Bedrick, 2008). The process of modelling building objects in BIM models follows a parallel procedure as mentioned in architectural design, in which there is a process of maturation in the modelling procedures during the development of a project. This process of maturation is materialized by the increment of the information level (geometric and/or semantic) that is contained in the various elements that composes a BIM model. In order to determine the level of maturation, it will be necessary to adopt a system which is able to classify the information that is contained in each model element.

During the collaborative process it is fundamental that the stakeholders are able to acknowledge the performance of the BIM models in terms of its information level and readiness for sharing and usability. Several BIM national standards (AEC (UK) BIM Protocol 2012 V2, Singapore BIM Guide 2013 v2.0, COBIM 2012 and AIA E203/G202) have adopted modelling methodologies and classification systems of BIM data, in order for the stakeholders to follow and implement during the collaborative process, allowing to share information and deliver BIM uses efficiently throughout the lifecycle of a building.

One of the most recognized BIM classification systems applied in the collaborative BIM process is designated as level of development (LOD) (Manzione, 2013). The LOD quantifies the dimensional, spatial, quantitative, qualitative, and other BIM data that are included in a model element that are able to describe the maturity and usability of the resultant BIM model for a specific BIM use regarding a certain phase of the project (AIA, 2013). The LOD definitions entitles the minimum requirements in terms of modelling and information (geometrical and meta-data) for it to be part of a certain category. The descriptions of the LOD definitions, according to the LOD Specification 2013 are indicated in appendix 1, where it is defined six categories – LOD 100; LOD 200; LOD 300; LOD 350; LOD 400; LOD 500.

In practical terms, the LOD framework is ready to become the future language of BIM modelling procedures, enabling an accurate and effective planning of many aspects of the project´s BIM collaborative delivery process (Bedrick, 2013). Here are some practical applications of the LOD framework (Bedrick, 2013):

-<u>Mapping firm standards</u>: Consists on determining the firm´s BIM modelling standards in the LOD format, thus the employees of the firm are aware of the minimum requirements to be achieved throughout the modelling procedures when delivering a project;

-<u>Definition of modelling efforts</u>: Consists on providing a clear basis for determining the efforts of modelling needed to develop model elements to a necessary detail that is required, without exceeding the adequate modelling efforts. Thus, the LOD enables an accurate and transparent determination of the cost and time needed to develop a project;

-<u>Defining Use-Case milestones:</u> Consists on defining the expectancies to retrieve from BIM uses, by defining the precision needed in the model elements (LOD) to generate the necessary information requirements in order to obtain the milestones outlined for that specific use;

-Model sharing throughout the design phase: On projects where there are diverse entities involved in the design phase, by defining the model exchanges through the LOD format can eliminate unnecessary uncertainties, simplifying the information sharing process;

-Passing a model from design to construction: It is still common practice for contractor to re-create a model from scratch, even when design teams have created a detailed model. This occurs because the design teams produce models that don´t match the requirements or standards of the contractors firms which are needed to process construction tasks such as cost estimating, coordination, among other activities. By implementing the LOD framework allows to specify the minimum requirements needed when conveying from the design phase to the construction phase.

In short, the implementation of LOD in a collaborative BIM project enables more organization of the data management that is held between stakeholders when sharing and developing their BIM models.

2.2.3.7. Collaborative BIM information technologies

BIM is a methodology that aims to optimize the data management among stakeholders (Bryde et al., 2012). However, it is dependent on other ICTs to support the sharing and communication between the actors of the project. These other ICTs can be grouped as electronic virtual communication technologies or as virtual interactive platforms.

The electronic virtual communication technologies consist on allowing virtual dialogs between members of the project team. Some examples of these ICTs are electronic mail, social networks, videoconferencing, among others. These collaborative technologies have been profusely implemented in traditional methodologies, supporting the main information exchanges and collaborative discussions of the project. In the BIM methodology, these technologies have been adapted and implemented, however these ICTs only support basic textual communications, such as notices and dialogs (Woddy, 2012).

When BIM is implemented, the main collaborative work takes place in the virtual interactive platforms shared and central to all stakeholders. It should be noted, that each actor can possess a local virtual interactive platform that is used to facilitate inner discipline collaboration. These virtual platforms are designated as "host-based" servers, which rely on web-based collaborative platforms, established on cloud computing technology to enable constant accessibility to the most updated information, independently of the stakeholders location (Chuang et al., 2011). In short, by employing these web-based collaborative platforms enables the project team to not only visualize and manipulate BIM models through the web, without time and distance limitations, it also can provide easy to use web services for the various actors to access and view project information effectively and efficiently via the web (Chuang et al., 2011). Some examples of this type of web-based collaborative platforms used in the AEC industry are: Autodesk Collaborative Project Management; Bentley ProjectWise Integration Server; BIM Server; Drofus; EuroSTEP Share-A-Space Model Server; Graphisoft ArchiCad BIM Server; BIM 360 Glue; Jotne EDM Model Server; Oracle Primavera and AutoView (Eastman et al., 2011).

2.2.4. Interoperability

2.2.4.1. General Aspects

Interoperability can be defined as the ability of systems and organizations to operate in sync (Venugopal et al., 2012). One of the main benefits of the use of information technologies is the ability to re-use information that has been processed with a given initial objective in a different context. This requires that the information systems involved are interoperable, allowing reprocessing of such information (Eastman et al., 2011). The BIM methodology rests on a paradigm of collaborative work between the various players of the AEC industry, based on the sharing of models of digital information. To this end, it is essential to ensure interoperability between the different BIM platforms and BIM tools used throughout the lifecycle of a building (Eastman et al., 2010).

The BIM applications serving the AEC/FM industry cover various domains and have different internal data model structures (Venugopal et al., 2012). Due to this incompatibility that can be verified between these data model structures of the various BIM applications used in a collaborative project, the interoperability when exchanging information will be compromised and consequently causing an inefficient data management. In order to exceed this limitation, interoperability is obtained by mapping parts of each native application´s internal data model structure to a universal data model structure and vice-versa (Grilo and Jardim-Goncalves, 2010). This universal data model structure is open, therefore any native application can contribute in the mapping process and in this way becoming interoperable with any other BIM software applications that are included in this operation (Grilo and Jardim-Goncalves, 2010). Many initiatives have been undertaken to develop an data exchange standard that consists on creating an open universal data model, where the *Industry Foundation Classes* (IFC) and the *CIMsteel Integration Version 2* (CIS/2) are considered the most applied data exchange standards in the current practices of the BIM methodology (Eastman et al., 2011).

2.2.4.2. IFC (Industry Foundation Classes) data exchange standard

With the aim to establish a universal protocol for data transmission of semantically rich 3D objects, related with building elements, the International Alliance for Interoperability (IAI) (which has been re-entitled as the BuildingSMART International) elaborated an data exchange standard designated as the IFC data model (buildingSMART, 2013). This universal model is an open, neutral and standardized specification for BIM. Thus, for the IFC model to obtain an accurate flow of information between the various data model structures of the BIM applications and throughout the lifecycle of the building, it is required to meet three essential factors (Nielson and Madsen, 2010) (see figure 2.32):

1. How to share and store the information?

This is obtained by applying the IFC data model.

2. What is the information being exchanged?

This is specified through the International Framework of Dictionaries (IFD).

3. Which information to exchange and when to exchange the information?

This is defined via the Information Delivery Manuals (IDMs) and Model View Definitions (MVDs).

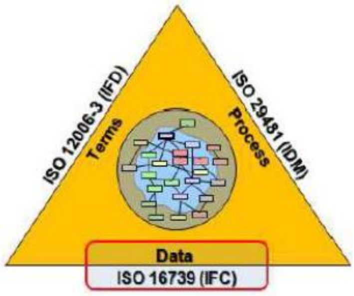


Figure 2.32 – IFC platform (buildingSMART, 2013).

- **IFC (Industry Foundation Classes) Data Model**

The first feature is the IFC data model. This universal data model possess a schema developed to define an extensible set of consistent data representations of building information for exchange between AEC software applications (Eastman et al., 2011) (see figure 2.33). Therefore, it enables the creation of a neutral environment for interoperability by providing a comprehensive specification of information throughout the AEC/FM project lifecycle, across all disciplines and software applications (Venugopal et al., 2012).

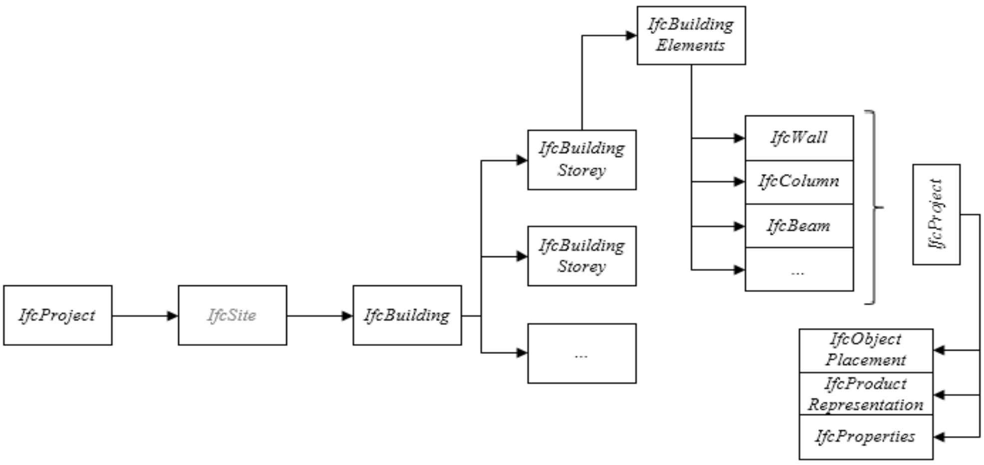


Figure 2.33 - Spatial structure of the data model.

The schema of the IFC follows a hierarchical organization where all the identities have the prefix "I*fc*". This schema is developed by considering the relations between various classes that contain the buildings information (see figure 2.33). The *IfcProject* corresponds to the root entity of the construction project, defining the general information for all the other building elements that constitute the project (e.g. unit systems). Then follows the *IfcSite*, *IfcBuilding* and *IfcBuildingStorey* (Liu et al., 2010). The *IfcSite* serves to represent the location where the construction will take place, however this entity is not noted as mandatory. The *IfcBuilding* and *IfcBuildingStorey* are obligatory and contain the information concerning the building elements, where the *IfcBuilding* represents the buildings and the *IfcBuildingStorey* embodies the stories that constitute a specific building. Contained in the

IfcBuildingStorey is the *IfcBuildingElements* that corresponds to the diverse elements that make up a floor in a building, such as *IfcWall, IfcColumns, IfcBeam*, among others. Finally, all these elements are characterized by *IfcProduct* that define the geometrical positioning of the object in a 3D environment (*IfcObjectPlacement*), the visual representation of it (*IfcProductRepresentation*) and the properties that characterize each element (*IfcProperties)*.

The IFC data model can be applied in two ways. The first method and more traditional consists on a simple transformation of a native file to an IFC format file, by implementing an application of import and export (applications X and Y – see figure 2.34 a)) being adapted the native data model structure (Nielson and Madsen, 2010). These types of applications are normally designated as “translators”. The second method consists on using the IFC as a central BIM model by congregating all the discipline BIM models of the involved stakeholders of the collaborative process (see figure 2.34 b)). By following this last method, the usage IFC model foments more integration in the project delivery process.

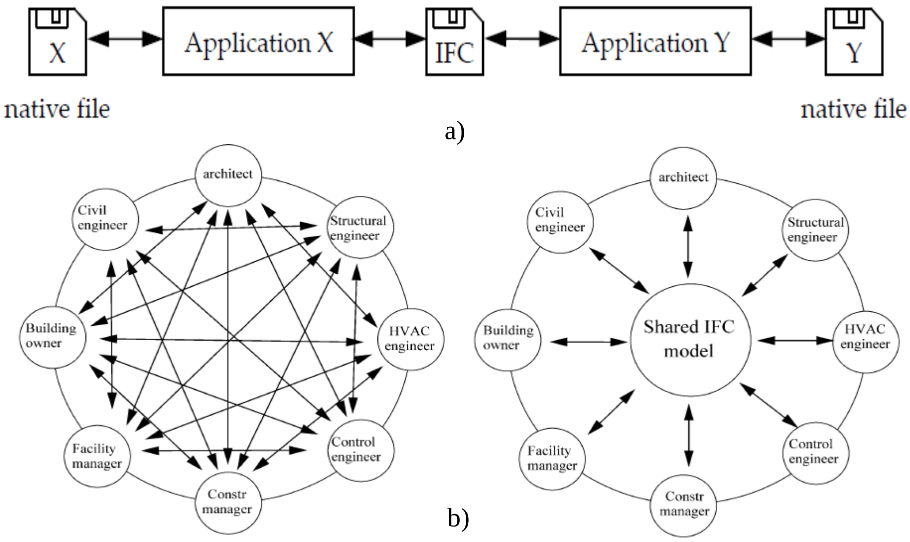


Figure 2.34 - Usage of the IFC data model: Format of exchange files (a) *vs* central IFC BIM model (b), adapted from (Nielson and Madsen, 2010, Chen et al., 2005).

Although the IFC data model presents an extensible framework which is able to store and capture the buildings information from the native models, the recent tests of interoperability indicate that much work is still needed to achieve fully effective interoperability (Joeng et al., 2009). Some of the main reasons that contribute to the difficulties arise when using complex geometric shapes, non-recognition of specific parameters that define the buildings elements (still no considered in the *IfcProperties*) and unique building components.

The IFC is the main data model standard of the BuildingSMART, where this format is registered by International Organization for Standardization (ISO) as ISO/PAS 16739 and, currently, in the process of becoming an official International Standard ISO/IS 16739. Since 1994 there has been released several versions of the IFC data model, where the most recent version is the IFC4.

- **IFD (International Framework for Dictionaries)**

Another essential feature of the IFC exchange standard is the International Framework of Dictionaries (IFD). In short, the IFD is a dictionary for exchanges that are able to reference a specific entity by depending solely on a universal and single catalogue for building elements and properties. Therefore, when exchanges occur between BIM applications the identification of the elements is exact, flawless of errors and misinterpretations. This dictionary of terminologies is derived from a concept by accepted open standards that have been already developed by ISO, mainly ISO 12006-3:2007.

The GUID (*Globally unique identifier*) provides a way of uniquely identifying an object (buildingSMART, 2013). By attributing a code to each element of the building enables to trace the alterations that proceed to each unique building component during the collaborative process.

- **IDM (Information Delivery Manual)**

The final feature that completes the IFC exchange standard is the Information Delivery Manual (IDM). In order for the data of the building elements verified throughout the AEC/FM lifecycle to be independent of a specific system (interoperable), it is not only necessary a neutral database for sharing (IFC) with a specific terminology (IFD), but is also fundamental to acknowledge the business processes and the information these processes operate on (IDM) (Zhang et al., 2012) (see figure 2.35).

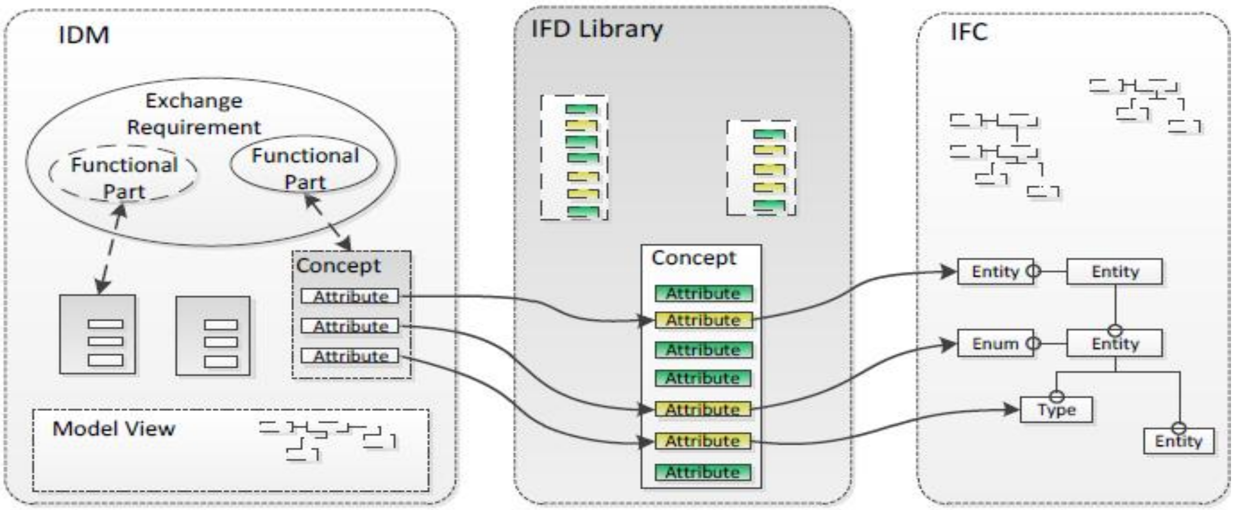


Figure 2.35 – Functionality of the IFC platform (Zhang et al., 2012).

The IDM presents a methodology (ISO 29481-1:2010) that is used in the AEC/FM industry to document the various business processes and describe the diverse information exchanges that occur among the stakeholders (buildingSMART, 2013). The objective of the IDM is to specify when certain types of information are required during the AEC/FM phases. It is also intended that the IDM provides detailed specification of the information that a particular party needs to provide at a specific phase and with whom that information is exchanged with (buildingSMART, 2013). The output results can serve as general guideline for the stakeholders who participate in the analysed business processes to follow and as well as for preparation of software specifications (Berard and Karlshoej, 2012).

The IDM is constituted by three parts (see figure 2.36), that are described in the flowing paragraphs (Wix and Karlshøj, 2010):

-Process Map (PM): Describes the flow of activities required to obtain a specific usage. The objective of the process maps (PMs) is to obtain an understanding of the characteristics of activities that constitute the desired deliverable, for instance the actors involved, the information required and produced. The PMs that are produced employ the Business Process Modeling Notation (BPMN) to illustrate graphically the business procedures (Eastman et al., 2010) (see section 2.3.2);

-Exchange requirements (ERs): Indicates the set of information that needs to be exchanged in order to support a particular business requirement at a particular phase of a project. An exchange requirement is intended to provide a description of the information needed to be used, in non-technical terms (buildingSMART, 2013);

-Functional parts (FPs): Consists on the unit of information (technical content) that is required by providers to support an ER. The FPs indicates the information in terms of the required capabilities of the IFC data model that is necessary to sustain ER.

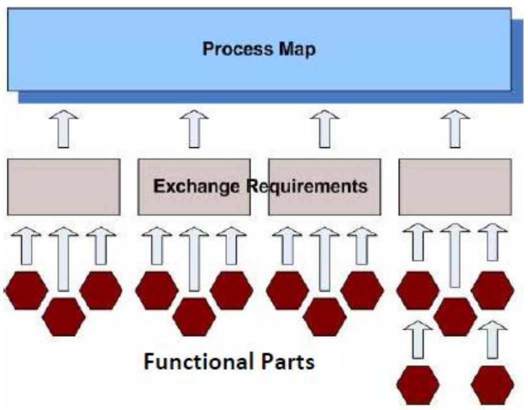


Figure 2.36 – IDM basic framework (Wix and Karlshøj, 2010).

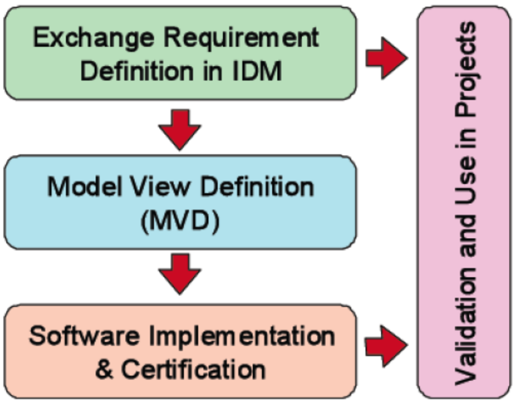


Figure 2.37 – Procedure of accreditation of software in IFC (buildingSMART, 2013).

When determined the IDMs for specific uses of a certain domain, information experts prepare the Model View Definitions (MVDs) to provide the information specifications requirements to enable software developers to write suitable export and import translators (Eastman et al., 2010) (see figure 2.37). MVD defines a subset of the IFC data model schema that is needed to satisfy one or many exchange requirements. It also provides implementation guidance (implementation agreements) for all IFC concepts (classes, attributes, relationships, among others) used within that subset. It thereby represents the software requirements specification for the implementation of an IFC interface to satisfy the delineated ERs to attain a specific usage of BIM (buildingSMART, 2013).

2.2.4.3. BCF (BIM collaboration format)

The Building Collaboration Format (BCF) consists on an open standard to enable workflow communication between different BIM software tools, by encoding messages that inform a specific BIM application of issues detected in the BIM model by another BIM application (buildingSMART, 2013).

In practical terms, this standard has the objective to support a more efficient collaboration of BIM projects, by enabling designers and other stakeholders to trade messages, action items, viewpoints and snapshots regarding specific components in a model (Solibri, 2013). With the employment of the BCF format, the implication is that only the issues and not the entire BIM model need to be shared between BIM applications.

Tekla Corporation and Solibri announced this idea to the BuildingSMART alliance, and now it is on a pre-release and being developed to become an official BuildingSMART specification. Other software houses have supported the implementation of the BCF, namely Autodesk, DDS, Eurostep, Gehry Technologies, among others (Eastman et al., 2011).

2.2.5. BIM national standards applied in collaborative projects

Over the last few years, government organizations all around the word have begun to realize the potential of BIM and the benefits that can be reflected in their construction sector when embracing this methodology (Khemlani, 2012). Already several countries have assumed BIM in their legislative frameworks, and have defined expectancies dates for full implementation for collaborative BIM projects. The AIA has organized a table that indicates the main initiatives undertaken around the world of developing standards to assist in the effective implementation of BIM in the AEC industry (see appendix 2). The following paragraphs address, briefly, the BIM national standards that were studied and applied in this dissertation.

- **AEC (UK) BIM Protocol 2012 V 2.0**

The AEC (UK) BIM Protocol V2.0 is derived from the AEC (UK) initiative. This initiative was commenced in 2000, with the objective to improve the production processes, management and sharing of design information. In the initial phases this initiative addressed CAD conventions, but with the design needs and the technology developments, namely BIM, this initiatives had to be expanded covering other aspects of design, such as design data production and information exchanges (AEC-UK, 2012a).

The AEC (UK) BIM Protocol V2.0 builds on the guidelines and frameworks defined by the British Standards documents (BS 1192:2007, PAS1192-2 and BS8541-1) (AEC-UK, 2012a), with the objective to provide a standard and best-practice methods for the development, organization and management of the construction industry information when implementing BIM in a collaborative project.

- **Common BIM Requirements (COBIM) 2012**

The COBIM 2012 covers the requirements that are needed for new constructions and renovations, as well as facility management of buildings. This standard indicates the minimum requirements for modelling and information contents for models that are developed during the phases of the project (COBIM, 2012c). The COBIM standard has the objective to produce a series of documents that can be used as appendices to procurement and contractual documents, only regarding the technical qualities of the model and not the issues such as ownership and fees (Silva, 2013). This standard has the approval of national/international organizations and companies (software houses and AEC firms).

- **AIA Documents E203/ G201/ G202 and LOD Specification 2013**

The AIA Document E203 is an standard that provides for the establishment of protocols for the development, use, transmission, and exchange of digital data for the project and if BIM is used it provides for the establishment of the protocols to implement BIM on projects (AIA, 2013). The AIA Document E203 is supported by two forms: AIA Document G201 – Project Digital Data Protocol Form and G202 – Project Building Information Modeling Form, which are forms used to document, respectively, the digital data and building information modelling protocols once the project participants have agreed on them.

The AIA Document G202 is the more important form when implementing BIM in a collaborative project. This document establishes the requirements for model content at specific levels of development (LOD), and indicates the authorized uses of the model content regarding each LOD category (AIA, 2013). Later on, the BIMForum with the support of AIA, have developed a specification entitled the LOD Specification 2013 that defines and illustrates characteristics of model elements of different building systems at different LOD (BIMForum, 2013). With this specification and relating it with the indications of the AIA Document G202, allows model authors to define the performance and reliability of their models, and allows downstream users to clearly comprehend the usability and the limitations of models when they are received (BIMForum, 2013).

- **Singapore BIM Guide 2013 Version 2**

The Singapore BIM Guide 2013, developed by the Building and Construction Authority (BCA), aims to outline the various usages, procedures and personnel/professionals that are involved when BIM is being applied in construction project (BCA, 2013f). This guide addresses several subjects, such as the roles and responsibilities when using BIM, collaborative procedure methods to follow during the project delivery process and modelling guidelines to obtain the deliverables initially outlined (BCA, 2013f). The Singapore BIM Guide 2013 is assisted with the BIM Essential Guides which aim to better assist individually each stakeholder during the execution of a BIM project.

- **Statsbygg BIM Manual 1.2**

The Statsbygg BIM Manual 1.2, was formulated by the Statsbygg which is the Norwegian government´s key advisor in construction and property affairs, building commissioner, property manager and property developer. The purpose of this standard is to describe Stastbygg´s requirements regarding the management of BIM models in the open IFC format, stating both generic and discipline specific requirements (Satsbygg, 2010).

- **National BIM Standard (NBIMS) Version 2 2013**

The NBIMS Version 2 results from an on-going project of the buildingSMART alliance (bSa), the Northern American Chapter of BuildingSMART International. This standard intends to provide the necessary structure and framework basis to support the collaborative BIM process, by attending to two parties: software developers and the project members of the AEC industry (NBIMS, 2013).

2.2.6. Construction classification systems

Up to now, the IFC data exchange standard and BIM national standards are two key features that support efficient collaboration in BIM. Allied with these standards are the construction classifications systems, which are methods of organizing information specifically designed for the construction industry (Eastman et al., 2011).

OmniClass is currently the most implemented classification system being applied by many BIM applications, with the intent to organize library materials and project information, to provide a classification structure for electronic databases (OmniClasss, 2013).

There are other recognized construction classification systems, namely, the CSI Uniformats II and Building 2000 project classification (Talo 2000 classification). The Talo 2000 classification is a construction classification system developed in Finland and referenced in the COBIM nation standard.

In Portugal, there is an initiative named PRONIC which is still under initial developments to be implemented in BIM applications as a national construction classification system.

2.3. BIM execution plans

2.3.1. Importance and definition of BIM Execution Plans

Over several years the BIM national standards, IFC exchange standard and the construction classification systems have revealed extraordinary developments. Thus, few project teams have been able to exploit the benefits of BIM to their fullest potentialities, being the lack of knowledge in implementing BIM in specific organizations and projects considered the main reason for the unachieved expectancies (Saluja, 2009). These documents that support the collaborative processes and the respective information exchanges, technical and contractual requirements are considered to comprehensive to be adopted in specific cases of implementation (Ahmad et al., 2012). According to (AGC, 2006), refers that "*each project is unique, and the implementation of BIM should be tailored to the needs of the project*", hence the implementation of BIM must suit each firms working styles and cultures, and when engaged in projects must be sensitive and adaptive to the individual characteristics of each project (Ahmad et al., 2012).

To successfully implement BIM in a project, it is fundamental for a project team to discuss and perform a detailed plan to follow throughout the project, which takes in consideration the BIM standards that are already developed. A potential solution consists on providing a project team a document designated as the BIM Execution Plan (BEP) that indicates the key factors to consider for implementing BIM throughout the various stages of the project´s lifecycle (Saluja, 2009). BEP provides a practical methodology for project teams to programme a structured procedure for implementing a BIM collaborative workflow throughout the stages of a building project, acknowledging the project´s unique aspects, the owner's requirements, the agreements between the stakeholders and the technical aspects to consider when elaborating a collaborative project in BIM.

There have been some developments verified around the world on the development of BIM Execution Plans. Accordingly to the literature review, the organizations that have created these types of documents are the same that are responsible for the developments of national BIM standards. Table 2.4 summarizes the main BEPs developed and practised worldwide.

Table 2.4 – Main BIM Execution Plans initiatives.

Country	Organization	Name of the BEP	Date of publication
United Sates of America	NBIMS	BIM Execution Planning Guide – Version 2	July 2010
	MIT	MIT BIM Execution Plan v3.2	May 2010
United Kingdom	AEC (UK)	AEC (UK) BIM Protocol Project Execution Plan	September 2012
Singapore	BCA	BIM Essential Guide – For BIM Execution Plan	August 2013

The typical content of a BEP includes the following aspects according to, (CIC, 2010, AEC-UK, 2012b, BCA, 2013b):

-Project Information: Consists on the basic information about the project, namely: identification of the employer; name of the project; location and address; project delivery agreements; description of the project; unit systems; deadlines; among other information.

-Project Members: Identification about each member of the project team, with indication of each stakeholder´s contact information;

-Project Objectives: Description of the goals to achieve, that are required from the owner;

-BIM Uses cases distributed throughout the lifecycle: Selection, identification and positioning of the BIM uses that are necessary to develop throughout the project delivery in order to achieve the client´s requirements;

-Organization Roles: Indication of the responsibilities and roles that each stakeholder must fulfil, accordingly with the defined BIM uses that were distributed throughout the phases of the project;

-BIM Process Design: Consists on mapping the development of the project, interlinking the BIM uses that are chronologically distributed. The objective is to create an overall map that determines the dependencies in terms of information requirements between the BIM uses. The process maps that are generated are considered to be the foundation of the BEP, because it graphically indicates the flow of information throughout the phases of the project. See section 2.3.2 for more information;

-BIM Information Exchanges: Consists on specifically indicating the information that is needed to be required in each building element to deliver each BIM use. Accordingly to the overall process maps that are created and the information requirements of each BIM use, a document is generated that specifies the information that is needed to be exchanged and/or introduced, in order to accomplish each BIM use throughout the collaborative project;

-Collaboration Procedures: The stakeholders must agree on the collaborative working procedures that are to be followed during the project, in order to fulfil efficiently the information exchanges determined in the process maps;

-Quality Assurance Checks: Consist of defining and documenting and overall strategy for quality control of the BIM models involved in the collaborative process. The quality control checks common to be applied are visual and interference checks;

-Technological Infrastructure Needs: The stakeholders must determine the requirements for hardware, software licenses, software platforms and technical issues;

-Model Structure: Consists on specifying how to manage the information during the collaborative process between the members of the project team. This includes the organization of the virtual platform that is shared, data segregation of BIM models, among other aspects.

To successfully amplify the advantages on performing a BIM Execution Plan, a planning team should be established in the early stages of the project. This team should embrace all stakeholders with significant relevance in the project, such as the owner, designers, main contractor, and facility manager (CIC, 2010). To enhance the coordination and compilation of a BEP it is recommended the selection of a leading party, which should be based on the stakeholder´s BIM competencies and/or experience on collaborative BIM project delivery. In usual cases, the assumed leading party can either be assembled by the owner, architect, contractor or by a third party (BIM consultant) contracted by the owner. However, throughout the building lifecycle, the leading party may be substituted being dependent on the delivery contractual agreement assumed for the project.

For an efficient implementation of a BEP it is imperative that the organizations involved foster an open environment of sharing and collaboration throughout the execution of the multi-disciplinary project. It is important that in the planning phase the organizations are open to share their standard processes, specifically the information exchange requirements needed to develop certain BIM uses (CIC, 2010). Equally important, is the flexibility needed by the stakeholders to negotiate a strategy that comprehends the BIM capabilities of the involved project teams, the project goals and it´s characteristics. In addition, it is also suggested that the assembled implementation strategy should be revised and updated, during the project delivery, in a periodic basis in order to facilitate the incorporation of new project team members and evaluate the actual implementation procedure.

BIM, like any new methodology, can carry some additional process risks when implemented by teams unfamiliar with its implementation process. Ultimately, all stakeholders will gain value when increasing the level of planning, consequently reducing the unknown variables in the implementation process thereby abating the overall risk of all project teams involved.

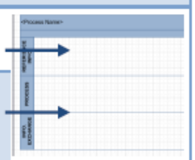
2.3.2. BIM process mapping

The BIM process mapping procedure is one of the essential elements to incorporate when planning the implementation of BIM in a collaborative project. This procedure can be considered as the development of a framework that presents which actors of the project team are supposed to develop a certain BIM use, when they must develop it and how to develop that BIM use, with indication of the necessary information exchanges that are involved.

Several BEPs present different methodologies to formulate the BIM process maps, where some consider one overall process map (PM) that incorporates all the specificities of the collaborative processes. Other BEPs, consider two levels, where an overall PM solely indicates the relationships between BIM uses with indication of the information exchanges involved. Additionally, more detailed PM particularize and define the sequence of the various activities needed to be developed.

The PM which are developed in BEP, resort to the Business Process Modeling Notation (BPMN) to represent their processes. This aspect is also shared with the IDM, which enables possible integration with this specification (Saluja, 2009). Table 2.5 describes the symbols and modelling notations of the BPMN modelling representation, which is applied for illustrating the BIM process maps presented in this work.

Table 2.5 - Business Process Modeling Notation for BIM Process Maps (CIC, 2010).

Element	Description	Notation
Event	An Event is an occurrence in the course of a business process. Three types of Events exist, based on when they affect the flow: Start, Intermediate, and End.	
Process	A Process is represented by a rectangle and is a generic term for work or activity that entity performs.	
Gateway	A Gateway is used to control the divergence and convergence of Sequence Flow. A Gateway can also be seen as equivalent to a decision in conventional flowcharting.	
Sequence Flow	A Sequence Flow is used to show the order (predecessors and successors) that activities will be performed in a Process.	
Association	An Association is used to tie information and processes with Data Objects. An arrowhead on the Association indicates a direction of flow, when appropriate.	
Pool	A Pool acts as a graphical container for partitioning a set of activities from other Pools.	
Lane	A Lane is a sub-partition within a Pool and will extend the entire length of the Pool - either vertically or horizontally. Lanes are used to organize and categorize activities.	
Data Object	A Data Object is a mechanism to show how data is required or produced by activities. They are connected to the activities through Associations.	
Group	A group represents a category of information. This type of grouping does not affect the Sequence Flow of the activities within the group. The category name appears on the diagram as the group label. Groups can be used for documentation or analysis purposes.	

CHAPTER 3

3. THE IMPORTANCE OF EDUCATION AS AN ACTIVE AGENT ON THE IMPLEMENTATION OF BIM

3.1. Introduction

As mentioned in chapter 2 (the main issues of implementation), the lack of BIM knowledge and skills of the stakeholders of the AEC industry, induces an unbalanced usage of this methodology. Thereupon, only a fraction of the actors of a design team have the minimum requirements to embrace a collaborative project supported by this methodology, consequently minimizing the capabilities and potentialities of BIM. Unless BIM is introduced into civil engineering and architecture curriculum, the 21st century engineers and architects will have difficulties to correspond to the requirements that the AEC industry are already demanding (Becerik-Gerber et al., 2010, Sacks and Barak, 2010, Kim, 2011).

In the following paragraphs three possible approaches to enhance the BIM maturity of the Portuguese AEC firms are analysed. The first two strategies depart from the firms themselves, by adopting top-down strategies such as admitting an expert/consultant on BIM implementation and/or by training their staff in BIM skills. The third approach is done in a national context, by performing educational initiatives in the formation of BIM which is accessible to all interested individuals of the AEC sector and establishing research programmes to develop and enhance the current application of this concept. This last approach is considered a bottom-up strategy, where individuals perceive the importance of BIM and require, autonomously, competencies and/or engage in its research. Figure 3.1 predicts the evolution of the BIM maturity behaviour of each of the approaches referred above. It should be noted that these maturity curves are based on an analysis performed by the advisors of this dissertation (Azenha et al., 2013b).

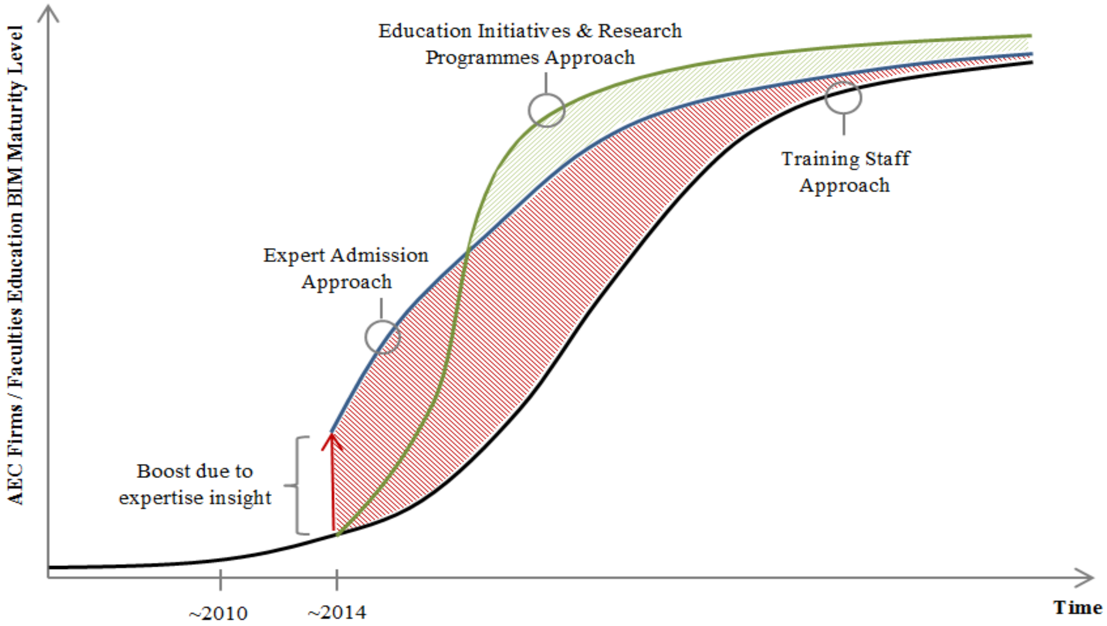


Figure 3.1 - BIM maturity curves – Training Staff Approach, Expert Admission Approach and Education Initiatives & Research Programme Approach, adapted from (Azenha et al., 2013b).

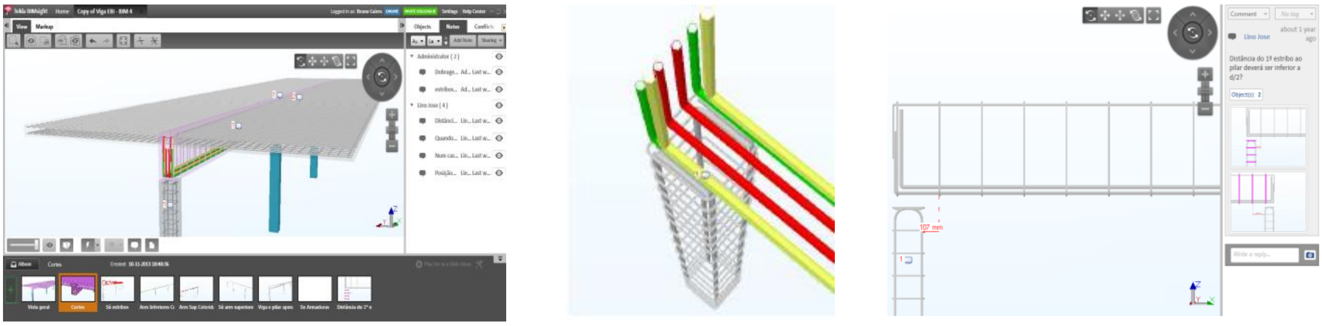
As can be seen in figure 3.1, the next few years it is predicted in a national context vast developments regarding the implementation of BIM. The Portuguese AEC firms are expected to employ the approaches of training their staff in BIM and/or hiring consultants, were both approaches endorse elevated financial costs. The approach of training the staff in BIM competencies is considered a lethargic process, but necessary in order to develop BIM internal processes and standards. The approach of contracting a consultant of BIM is expected to accelerate the process of implementation (see figure 3.1 – red zone), but on the other hand the endorsement of training the staff and additionally contracting a consultant can be excessive.

The education initiatives and the research programmes play an important role as an implementation agent of BIM, by developing an equal framework of BIM competencies which are transversal to all current and future professionals of the AEC industry. Therefore, it shall be unnecessary for the AEC firms on acquiring individual staff formation in BIM regarding the generic features of that concept, being this activity assured by the education curriculums established at faculties. In terms of the BIM collaborative process, these education initiatives enable the acquisition of a standard BIM knowledge across all the parties of a project team contributing to a more effective collaborative delivery process. The research that is developed under a scientific scope will enable the increment of the academic BIM maturity level and consequently deliver more effective educational curriculums. It is predicted that the scientific work developed at faculties is to exceed, in terms of BIM maturity the levels verified at professional firms (see figure 3.1 – green zone).

In this chapter it will be discussed the strategy assumed by the University of Minho, which was careful to take diligences in creating conditions to promote the BIM methodology among their students. During this MSc dissertation period, the author was included in a BIM research group at the University of Minho, with others, namely the advisors of this dissertation. The following sections describe and analyse the work developed regarding the promotional and education initiatives of BIM, with indication of the strategy assumed and the contributions of the author.

3.2. Strategy outline of the main promotional and education initiatives

In 2010, the first implementation of BIM in academic teaching at the University of Minho was initiated. In that year, a pilot experiment was developed regarding the enhancement in the knowledge transmission of subjects related to structural concrete with the support of BIM. BIM models of specific parts of concrete structures were presented to the 4th year students of the curricular unit of Structural Concrete II, and subsequently provided those models to the students in IFC format for posterior visualization (Fontes et al., 2010). Later on, the concept of BIM as a knowledge transmission tool was extended to the curricular unit of Structural Concrete I. Here, a BIM model was developed that represented a worked example included in the lecture notes of that curricular unit, concerning the complete design and rebar detailing of a continuous reinforced concrete beam with three spans (see figure 3.2 a) and b)). Comments were also included in the BIM model, justifying all detailing decisions (see figure 3.2 c)). Furthermore, the BIM model was lectured to the students during a theoretical class and posteriorly provided in the IFC format for visualization outside school hours being suggested the usage of, costless, BIM visualization tools, specifically Tekla BIMsight, due to its easy learning and enhanced capabilities of visualization.



a) b) c)

Figure 3.2 – Developed BIM model as a knowledge transmission tool for the curricular unit of Structural Concrete I (Lino et al., 2012): a) Dynamic view of the BIM model; b) View of the BIM model with coloured rebar; c) Commented notes highlighted in the BIM environment.

In addition, a survey was distributed among the students, with the objective to quantify their opinions about the capabilities of BIM as a knowledge transmission tool for the subjects related to structural concrete, its relevance and applicability as a project instrument and finally the overall recognition of the thematic BIM (Lino et al., 2012).

The results were based on the response of 65 students, being highlighted three main conclusions. The first two conclusions are positive, in which the students consider BIM to be an effective instrument to assist the lecturing of structural concrete subjects and a relevant methodology to bring more efficiency to professional practices. However, only 12% of the 4th year students had already heard about the BIM concept, reflecting a noteworthy concern on the lack of awareness on behalf of the students regarding this methodology.

Allied to the results obtained by the survey and considering the developments that are occurring in an international context, the following strategy was outlined at the University of Minho:

- Increase awareness of undergraduate and graduate students through promotional events (seminars, conference hearings and workshops) about BIM related subjects;
- Establishment of a national-wide virtual community for informal discussion and promotion of initiatives related to the implementation and dissemination of BIM, particularly directed for students and teachers but also open to the professional community;
- Develop a curricular unit that addresses, comprehensively, the main concepts of BIM, with the objective to prepare the students with capacities to implement, develop and manage collaborative projects in real practises of the AEC industry.

The following figure presents a timeline that summarizes the various events that were organized and/or participated in by this BIM research group during the period of dissertation (see figure 3.3), where the key initiatives performed at the University of Minho are described in detail throughout the following sections.

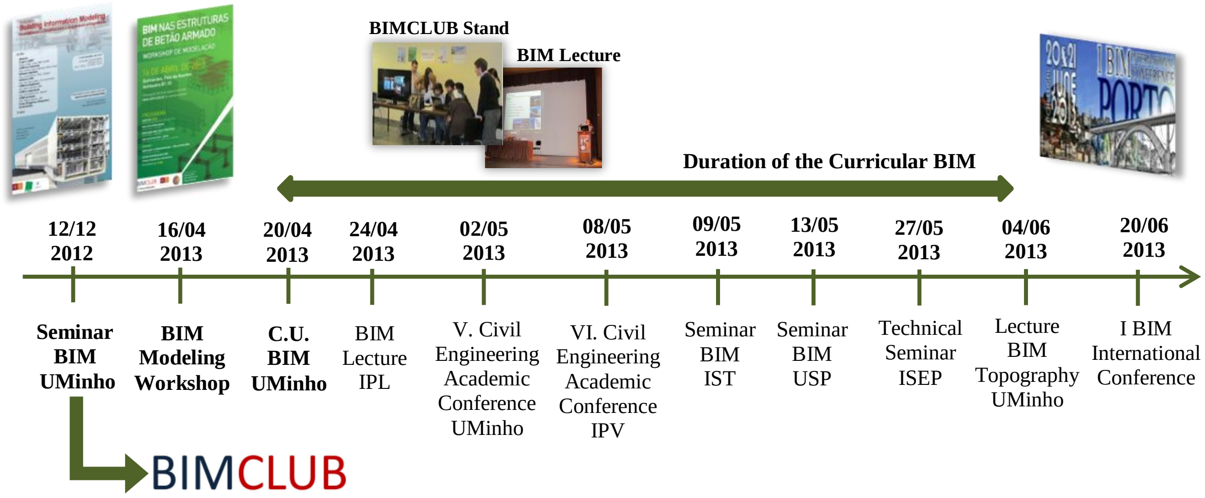


Figure 3.3 – Timeline of the events organized and/or participated by the BIM group of investigation at University of Minho.

3.2.1. Seminar: "Building Information Modeling: Possibilities and challenges for the architecture and engineering sectors"

The seminar: "Building Information Modeling: Possibilities and challenges for the architecture and engineering sectors" was held on the 12/12/2012, at the engineering school of the University of Minho. This first seminar of BIM was embraced by the Civil Engineering Department and directed to the academic community of the schools of engineering and architecture. The poster of the event is presented in appendix 3, in which illustrates the themes and speakers of each performed lecture.

This seminar had the objective to raise awareness to all students of both schools about the possibilities and challenges of the AEC industry, where the BIM concept was firstly introduced and then demonstrated some practical applications. The organizing committee of this seminar gathered representatives of recognized software houses to illustrate the potentialities of their BIM applications, as well as a number of invited speakers that represent the various AEC professionals of the construction sector, to come and share their experiences and their visions of BIM. Another important objective was to illustrate, through an academic and professional scope, the importance of adopting BIM in the academic formation of the students, with the aim to encourage other academic professors of the civil engineering and architecture courses to embrace BIM in their curricular units. Equally important, this seminar was used to kick-start a national initiative that intends to generate informal collaboration and sharing of BIM knowledge through an open platform, aiming to establish a virtual community. This initiative is designated as BIMClub (see section 3.2.2).

Regarding the seminar, the author was incorporated in the organization committee of the event and gave an initial lecture about the concept of BIM, addressing the basic topics which characterize the

BIM methodology serving as an introduction to the following speeches. At the conclusion of the seminar, the author was given the opportunity to represent the BIMClub initiative, being discussed its objectives and principals.

The seminar received more than 230 participants, being composed by undergraduate students, graduate students, professors and professionals. This over excepted number of participants demonstrates the interest and curiosity of the academic community at the University of Minho in learning the BIM methodology. The following statistical analysis aims to study the population that attended this event (see figure 3.4).

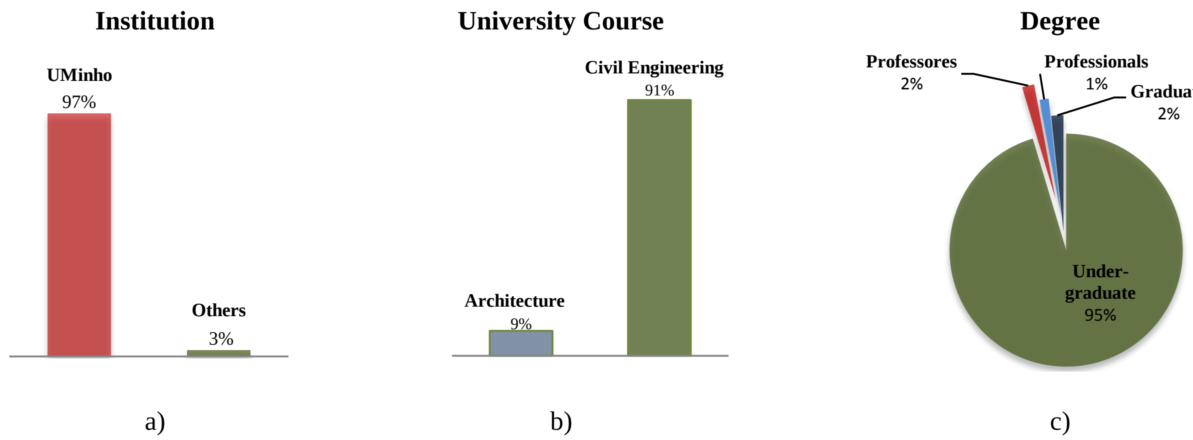


Figure 3.4 a), b) and c) – Partial results of a statistical analysis about the subscribed participants of the BIM seminar 12/12/2012 held at the University of Minho.

Based on the response of the 238 participants who registered to attend this seminar, the following statements aim to briefly attend the main conclusions of this statistical analysis. Firstly, the majority of the subscribers were undergraduate students, where the number of professors, professionals and graduate students were less than 5% of the population (see figure 3.4 c)). As anticipated, 97% of the registers were made by members associated to the University of Minho, due to the fact that this seminar was only publicized at that faculty (see figure 3.4 a)). An unachieved result was the low number of participants related to architecture course (9%) in relation to the participants associated to civil engineering (91%) (see figure 3.4 b)). This result can be justified by the fact that the date of the seminar coincided with a phase of greater demand in the academic calendar of the students attending the school of architecture.

3.2.2. The BIMClub initiative

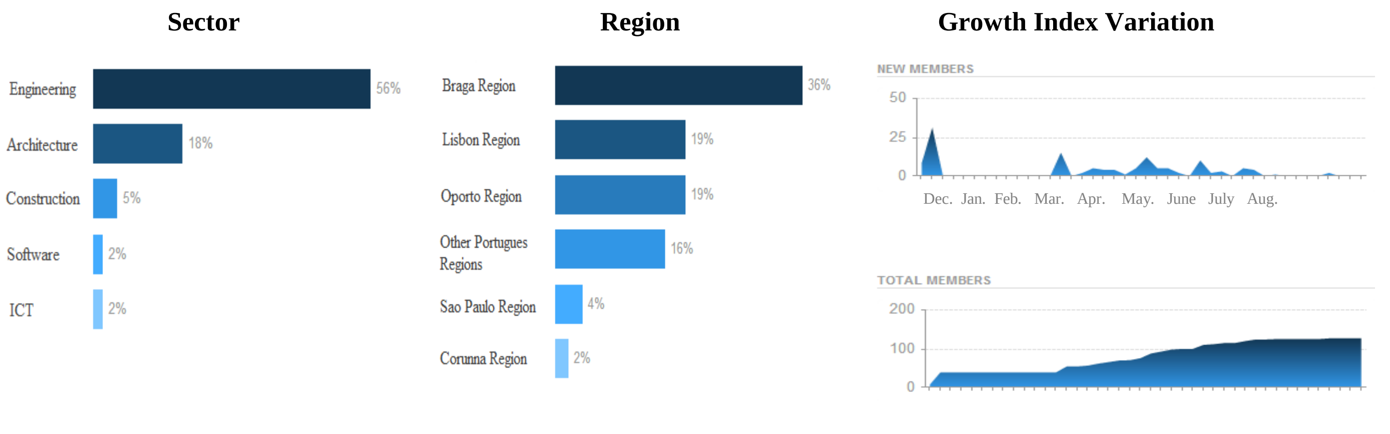
Together with the other founders, the author participated in the genesis of BIMClub at the University of Minho, which later extended to a national-wide initiative. This initiative aims to establish a virtual platform that fosters informal discussion and promotion of initiatives related to the implementation and dissemination of BIM, aimed particularly for students, researchers and teachers but also open to the professional sector, with the objective to form a virtual community. In other words, the BIMClub initiative consists *"on a group of people involved in the dissemination of BIM and interested in* *learning, through promotion of knowledge sharing and collaborative practices*" (BIMClub, 2013). This initiative was approved as a complementary initiative of the BIMFORUM Portugal, and consequently considered as a national initiative of BIM.

The creation of BIMClub is related with the important role that the educational institutions should consider when lecturing their students, in providing sufficient skills, such as BIM competencies, to correspond to the future requirements and demands of the construction sector.

Almost coincidently with its creation, the BIMClub initiative has been embraced by other faculties and organizations, being at the present time a joint national initiative supported by the staff at: UMinho, FEUP, IST, UC, FAUP, UL, FAUTL and LNEC, being extensible to other interested parties. Each faculty constitutes an institutional pole formed by two representatives, a staff member and a student. The generic strategy recommended to follow at each pole is to internally perform promotional initiatives developed by students to students, whereas the staff member assures continuity of the pole. This bottom-up strategy, where the students assume an active role, properly oriented by their supervisor staff member, has the aim to foster more motivation among the students when learning BIM. BIMClub is characterized as a strategic collaborative effort of enhancing one´s capabilities in BIM, hence the cooperation among the various poles is fundamental, where meetings should be held every six months and establish collaborative organization of events among institutional poles. It is intended that a national conference should be held every two years, with the objective to share the scientific work developed. To conclude, BIMClub is a non-profitable organization without membership fees, where all necessary funds are obtained from research programs, private money or sponsorship.

The creation of this initiative involved the establishment of a forum and website which served as virtual platforms. The forum was created on two social networks (LinkedIn and Facebook) were the main interactions among coordinators and members of the group were assured. The website has a more static role, by containing: the definition, background and principles of the initiative; news and promotion of future events; repository of national scientific documents with relation to BIM, being accessible developed thesis and indicated the current thesis underdevelopment; contacts of the coordinators responsible for this initiative. During the duration of the thesis the author besides being one of the founders of this initiative, contributed in the creation and maintenance of these forums and website.

BIMClub initiative has been promoted by its members and particularly by the University of Minho research team in various events (see figure 3.3). Due to all these promotional events, the BIMClub virtual community has grown extensively across Portugal during these few months. The following statistical study aims to analyse the members that are integrated in this virtual community, in terms of their sector of work and locality. Moreover, it will be analysed the variation of the index growth verified since its genesis 12/12/2012 (see figure 3.5).



a) b) c)

Figure 3.5 a), b) and c) – Partial results of a statistical analysis about the members that are integrated in the BIMClub virtual community, elaborated on the 25/09/2013.

When the statistical analysis (see figure 3.5) was performed, the BIMClub virtual community was constituted by 126 members, who were subscribed to the LinkedIn group of BIMClub. Firstly, in relation of the member's sector of work, the majority of members that constitute this group are associated with the engineering sector (56%), which can be justified by fact that the preponderance of the events conducted agglomerated mostly individuals related to that respective sector (see figure 3.4 a)). However, as alarming signs, were the low percentages of members associated to the architecture (18%). Future promotional events of the BIMClub initiative should attend to this matter, in order to nature more multi-discipline views within the BIMClub virtual community. Regarding the location distribution, it is noticeable that the regions of Braga (36%), Lisbon (19%) and Oporto (19%) lead the ranking (see figure 3.4 b)), due to the fact that the main promotion initiatives of this group were delivered in those areas. Out of curiosity, are the percentages of members from international regions that are interested in being connected to this national initiative, namely the cases of the individuals situated in Brazil, Sao Paulo (4%) and Spain, Corunna (2%). As a final analysis, the index of growth of the membership has been inconsistent over the various months, where the peaks of growth are coincident with the posterior days of the events where the BIMClub was promoted (see figure 3.4 c)). The highest peak of subscription occurred in the following days after the BIM seminar held at the University of Minho, where this initiative was firstly presented to the public. Furthermore, in the months of May and June the behaviour of the growth index was more regular, due to the fact that in these months 6 events were performed, where the BIMClub initiative was divulgated.

The BIMClub initiative has brought the attention of international individuals who attend to learn and commence a similar strategy of implementation in their respective countries. These contacts were developed in the BIM seminar held at the University of Sao Paulo and in the I BIM International Conference occurred in Oporto.

3.2.3. BIM Modelling Workshop in Reinforced Concrete Structures

Under the guidance of the supervisors of this thesis, the author was the main organizer of the Workshop: "BIM Modelling in Reinforced Concrete Structures", held on the 16/04/2013 at the University of Minho. This workshop was developed under the aegis of the Civil Engineering Department and the curricular unit of Structural Concrete II, specifically directed to the 4th year students of that curricular unit but open to all the academic community of civil engineering. The poster of this event is presented in appendix 4, being illustrated the themes and speakers of each performed lecture.

This event aimed to address the necessary topics that were needed to be lectured to the students of the referred curricular unit in order to confer sufficient competencies to implement the BIM methodology in their practical work. This need was acknowledged by the author, when as a student of that curricular unit intended to implement this methodology in his practical work, being verified some barriers due to lack of knowledge regarding the more detailed technical aspects of the BIM applications when applied to reinforced concrete structures. Furthermore, as additional objectives the generic functionalities of BIM relative to structural engineering and the BIMClub initiative were promoted during this event.

For the development of this workshop other students (Luís Carlos Silva, Julien Domingues and Hugo Sousa) were invited to join this initiative, where, together with the author, were speakers at this event. Cooperatively, these students and the author discussed the outline of the contents to address and the pedagogical strategies to bring into play during the presentation of this event. The selection of the BIM software applications embraced during the workshop were based on the academic accessibility to students and their common use in real practices, being chosen Revit Structure, Robot Structural Analysis, Tekla Structures and Tekla BIMsight.

The practical work consisted on performing a complete structural design based on an architectural layout. Therefore, to correspond to the needs of the students, this workshop embraced a practical character by illustrating an application of the BIM capabilities regarding a similar example (see figure 3.6), with explicit coverage of the following topics within its programme:

-Basic BIM concepts related to structural design workflow: This topic had the aim to generically explain the application of the BIM methodology under a structural engineer perspective, in order to situate the attendees regarding the field of BIM under analysis;

-BIM structural modelling procedures: This topic was considered the most relevant of the workshop, which had the intent to present a workflow on developing a structural BIM model. Firstly, to accustom the attendees to the structural BIM platform used (Revit Structure) the user interface of the application was explained. Thereafter, the modelling characteristics that should be attended before initiating the actual modelling process were demonstrated namely, defining the characteristics of the project information, delineation of the mechanical properties of the materials and identification/creation of the required BIM structural building components. Furthermore, the geometric modelling of the building was performed, being initially inserted the necessary reference lines and then introduced the diverse building elements that were prepared in the antecedent phase. In addition, the possible applications to retrieve form the structural BIM model, within a BIM platform, were demonstrated, such as the automatic production of views/ documentation and automatic quantity-take-off analysis. To conclude, the preparation of the structural BIM model for structural analysis was explained, by illustrating on how to define the support conditions, structural loading and loading combinations;

-Interoperability between a BIM platform and an application of structural analysis: This topic essentially had the aim to address the necessary characteristics when exporting the structural BIM model to an application for structural analysis (Robot Structural Analysis). Firstly the required consistency checks of the structural BIM model were interpreted, in order to assure that the analytical model of the structural analysis application was equitable to be analysed. To finalize, the properties of the BIM platform, regarding the exportation to the structural analysis tool were specified. Moreover, the main errors of interoperability were discussed with the intent to aware the attendees of the potential flaws that can occur;

-Structural analysis: This topic had the aim to demonstrate on how to prepare the imported analytical model from the structural BIM platform to enable the correct structural analysis. Furthermore, with the intent to further support the students of the 4th year, the functionally of the selected structural analysis software and tips regarding the interpretation of the structural analysis results were shared. To conclude, the bi-directionality between the structural analysis application and the BIM platform was illustrated, showing its potentiality regarding the automatic update of the structural BIM model when edited the structural design within the structural analysis application and vice-versa;

-BIM rebar detailing: The conclusive topic of this workshop was the explanation of how to perform the structural detailing regarding the reinforcement of the structural concrete building elements of the practical example. Before that description, the incongruities and tips was discussed regarding the interoperability between the original BIM platform of the structural model (Revit Structure) and the platform used for structural detailing (Tekla Structures), with the intent to avoid and aware the attendees of potential limitations.

The development of this workshop was based on a bottom-up strategy, as encouraged by the BIMClub initiative. In this case, the students that were invited by the author were unfamiliar with the BIM methodology and its application in structural design. Thus, due to the cooperation among the organizing team the enhancement of each individual’s competencies in BIM was achievable. Furthermore, the adoption of a bottom-up approach capacitated more dialog during the workshop, bridging the gap normally verified between speakers and attending members.

Figure 3.7 epitomizes the statistical study that is intended to analyse the academic annual distribution of the participants (above 50 attendees), being plausible to conclude that the preeminent interest to assist on this event falls within the 5th and 4th year of undergraduate students. The elevated value of the 4th year subscribed participants (51%) is justified by their interest of implementing BIM in their practical work of the curricular unit, thus the 5th year subscribed participants (33%) illustrates the preoccupation of the finalists students on acquiring knowledge about this promising concept of project delivery, recognizing its important value.

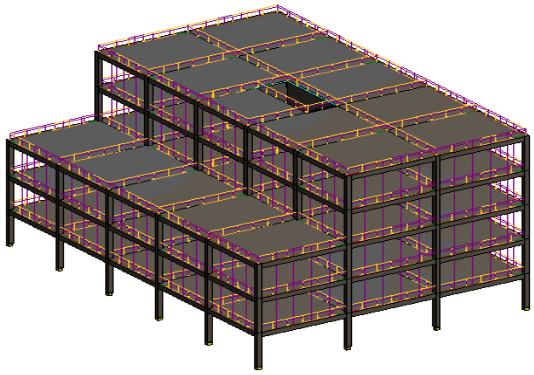


Figure 3.6 – Structural BIM model designed for the BIM modelling workshop in reinforced concrete structures.

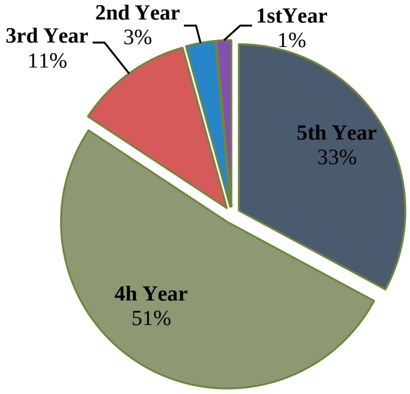


Figure 3.7 – Partial results of a statistical analysis regarding the participants of the BIM modelling workshop in reinforced concrete structures.

A concerning result was that no group of the curricular unit of Structural Concrete II employed the BIM methodology in their practical work. In an initial phase some students demonstrated intent, however the arduous learning curve of attaining BIM competencies combined with the limited availability of the students due to a demanding school calendar could justify the selection of the known traditional methodology. Another justification could be the absence of guidelines which could facilitate the students on familiarizing more rapidly with the required software applications, to perform the BIM structural engineering workflow. Given these points, it suggested that the preparation of students regarding the application of the BIM methodology should commence in earlier stages of the civil engineering curriculum, in order to establish a more sustainable process of maturation regarding the attainment of BIM knowledge by the students.

3.2.4. Curricular Unit: “Building Information Modeling: Conception, Design and Construction”

A curricular unit exclusively dedicated to the comprehension of the BIM methodology was held between 20/04/2013 and 17/06/2013, at the University of Minho, integrated in the master programme in Sustainable Construction and Rehabilitation. The coordinators of this curricular unit were Prof. Miguel Azenha, Prof. João Pedro Couto and Eng. José Carlos Lino. Furthermore, this curricular unit congregated a wide range of lecturers from the diverse fields of the AEC industry, namely Arch. Nuno Lacerda Lopes, Arch. Vanessa Tavares, Eng. Francisco Reis and Eng. António Ruivo Meireles. All invited lectures are associated with the BIM work group of the PTPC. The author participated as a monitor during the development of the curricular unit.

The students that attended this master’s curriculum and selected this curricular unit are professionals of the civil engineering and architectural sectors. However, this curricular unit was also embraced as an extra-curriculum activity by other students, namely by PhD students (PhD), professionals of the AEC industry (External) and undergraduate students in their final years (MIEC). As can been seen, the majority of the attendees of this curricular unit where qualified students, with some experience in AEC projects. Figure 3.8 illustrates the outline of the students that attended this course.

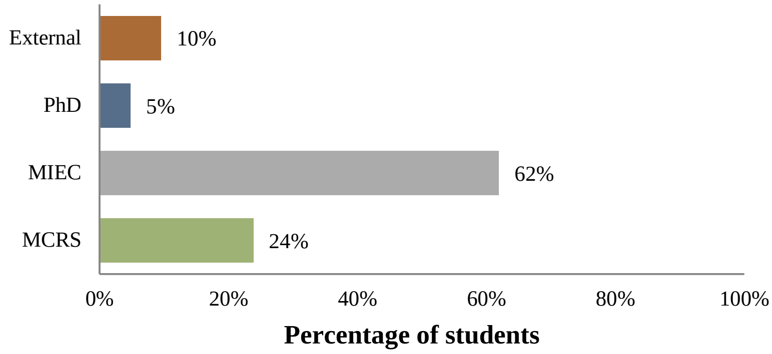


Figure 3.8 – Subscribed student outline of the curricular unit "Building Information Modeling: Conception, Design and Construction" of 2012/2013 held at the University of Minho.

The curricular unit was constituted by 21 students, in which only 24% were subscribed students in the Master in Sustainable Construction and Rehabilitation programme and the remaining were students that embraced this curricular unit as an extra-curricular activity (see figure 3.8). This is a clear indication that students already perceive the importance on acquiring BIM competencies as a differential feature that is considered by AEC industry.

The target of this course was to form potential BIM managers, by conveying the necessary intellectual competencies needed to implement the BIM methodology in firms and in collaborative projects. The teaching staff strategically decided that the specific training in the use of any software was not part of the curricular unit´s scope. Thereby, the students were responsible to embrace parallel efforts in the understanding of the BIM software usage.

The programmatic content of this curricular unit was divided in 7 chapters, being distributed among the lecturing team. The initial three chapters were introductory, being lectured in the first the definition of the BIM concept and its related topics and the following two embraced the lecturing of parametric modelling and interoperability, considering their relations to BIM. The remaining chapters were dedicated in addressing the issues associated to the implementation of BIM considering the vision and experiences of each stakeholder (architect, structural engineer, MEP engineer and contractor), being divided in a theoretical and practical modules.

Regarding the teaching methodologies, in the theoretical modules of this curricular unit a set of concepts and approaches were addressed through presentations and practical confirmations, frequently demonstrating real cases of implementation. In additional, pedagogical videos were developed. In many cases the lecturing team members assisted to each other´s lessons, being developed collaborative discussions which contributed to a more fulfilling and comprehensive environment of learning.

As to the practical modules of the course, the learning was done on a project basis ("i.e. project-based learning"), where the students are grouped in a set of three-four elements with internet and BIM software access with the intent to develop the practical project of the curricular unit. The practical project of the curricular unit constituted the main element under evaluation by the teaching staff. Each group was required to deliver a multidisciplinary project of a sanitary facility located in a campsite, performing and integrating through the BIM methodology the specialities of architecture, structural engineering, MEP engineering and concluding with the construction management. The generic requirements and specific requirements of each project discipline that are necessary to be achieved by the students when completed their projects were delineated (see appendix 5). The students were free to choose the BIM applications intended more suitable within the academic licenses available. Each group was open to decide upon the collaborative method, data management procedure, selection of the ICTs, methods of interconnection between BIM models and among other aspects, to implement during the collaborative process, where the indications lectured during the theoretical modules are sufficient to cover these matters. The final result of the practical work was to perform a report and presentation, describing the project´s main considerations and issues by addressing the BIM models that were developed by the respective groups.

The lecturing team, with the contribution of the author, accompanied the students by also developing the proposed practical project, where at each practical lesson it was discussed, in the presence of the students, its issues of development serving as a reference. It should be noted, that the project performed by the lecturing team and the author will develop into the case study discussed in chapter 4 of this thesis, where it is analysed the BIM collaborative process verified during the design delivery, specifically between the structural engineer and architect.

The author as a monitor assisted the teaching staff during the phases of preparation and lecturing of the curricular unit. In the preparation phase, the author contributed in the development of theoretical presentations. In addition, with the supervision of the teaching staff the author performed three pedagogical videos (see appendix 6), where two are related with parametric modelling and one related with interoperability. The first two intended to demonstrate the applicability and functionality of parametric modelling applied in the BIM context. The last video demonstrates the various types of interoperability that persist in a BIM environment. Still in the preparation phase, the author developed an initial project of a sanitary facility in BIM, similar to that of the practical work, which integrated the disciplines of architecture, structural engineering and MEP engineering serving as an initial reference for the students (see appendix 6). During the phase of lecturing, the author assisted on the monitoring of each group during the practical sessions, supporting the development of their practical work. To conclude, under the guidance of Professor Miguel Azenha and Engineer José Carlos Lino, the author was responsible for the development of the structural design in BIM of the practical project conducted by the lecturing team of this curricular unit (see chapter 4, case study).

For the development of the practical project, six groups were established among the students. Appendix 5 presents a table that summarizes the performance of each group, considering the main generic requirements and the specific requirements of each discipline outlined in the practical work. As can be seen, the majority of the groups were able to complete most of the requirements stipulated. It should be noted, that the groups had a short period of eight weeks to learn and apply the BIM methodology in a complete collaborative project, without the specific formation in BIM software usage. However, each group presented positive results considering the short period of development, confirming the usefulness of the multitude of information available online.

As mentioned above, the groups were free to select the BIM applications that were considered more suitable to develop their projects. The diversity of software that was academically available included BIM platforms and tools from the software producers of Autodesk, Graphisoft, Tekla, Bentley, Allplan, Vectorworks, Cype, Vico Office and Solibri. The following table presents the selection of the BIM applications that were employed by each group, including the lecturing team (case study), regarding the execution of the practical project (see table 3.1). For a more precise description of the BIM software used in this dissertation see appendix 7.

Table 3.1 - Software selection by the groups and lecturing of the curricular unit BIM.

BIM Software	**Group A**	**Group B**	**Group C**	**Group D**	**Group E**	**Group F**	**Case Study**	**Total selections**
BIM Platforms								
Autodesk – Revit MEP	✓	✓	✓	✓	✓	✓	✓	**7**
Tekla Structures		✓				✓	✓	**3**
Autodesk – Revit Structure	✓	✓	✓	✓	✓	✓	✓	**7**
Graphisoft ArchiCAD						✓	✓	**2**
Autodesk – Revit Architecture	✓	✓	✓	✓	✓		✓	**6**
BIM Tools								
Tekla BIMsight		✓		✓		✓	✓	**4**
Solibri Model View		✓					✓	**2**
Solibri Model Checker							✓	**1**
Autodesk – Navisworks				✓				**1**
Vico Office	✓	✓				✓	✓	**4**
CypeCAD				✓				**1**
Autodesk – Robot Structural Analysis	✓	✓			✓	✓	✓	**5**
Total BIM applications selected	**5**	**8**	**3**	**6**	**4**	**7**	**10**	

The following analysis aims to retrieve the main conclusions of the BIM software selection, visible in table 3.1. The lecturing team had the objective to embrace the more common used BIM applications of the AEC industry, where all communications among stakeholders were executed using the IFC format with the purpose to encounter possible interoperability issues and establish workaround strategies. As to the students, the BIM platforms of Autodesk were selected by the groups as the preferential applications to develop their discipline models, where Revit MEP was selected by all groups. In the case of the structural design all groups selected Revit Structure as the primordial native structural platform, where Tekla Structures was selected by two groups to develop the structural detailing. The efficient interoperability with structural analysis software is considered the main justification of the high selection of Revit Structure which is correlated with the high usage of the BIM tool Robot Structural Analysis. Regarding the architectural design, only one of the six groups selected ArchiCAD as the preferential architectural platform. Vico Office in relation to Navisworks was the desired BIM tool to develop the construction management of the project. Regarding the BIM viewers, Tekla BIMsight seems to be the more desirable viewer, although due to the low number of groups that operated with BIM viewers, it is not possible to conclude which application was the preferential. Summing up, the BIM applications of Autodesk were the preferential selection in all disciplines, which serves as an indication that the groups intended to avoid issues of interoperability by selecting BIM platforms and BIM tools under the same environment. The discipline of construction management is an exception, however Vico Office has a high interoperability succession rate with Autodesk BIM platforms, not being reported interoperability issues by the students during the development of their projects.

All groups embraced the Dropbox commercial web-based virtual platform as an information technological tool to support the data management that occurred during the delivery of the practical projects.

As a result of the positive outcomes and intriguing considerations outlined by the majority of the groups, chapter 4 will embrace these elements with the purpose to enhance the study of the BIM collaborative process of an AEC project. Figure 3.9 illustrates a summary of the BIM models that were produced by the students.

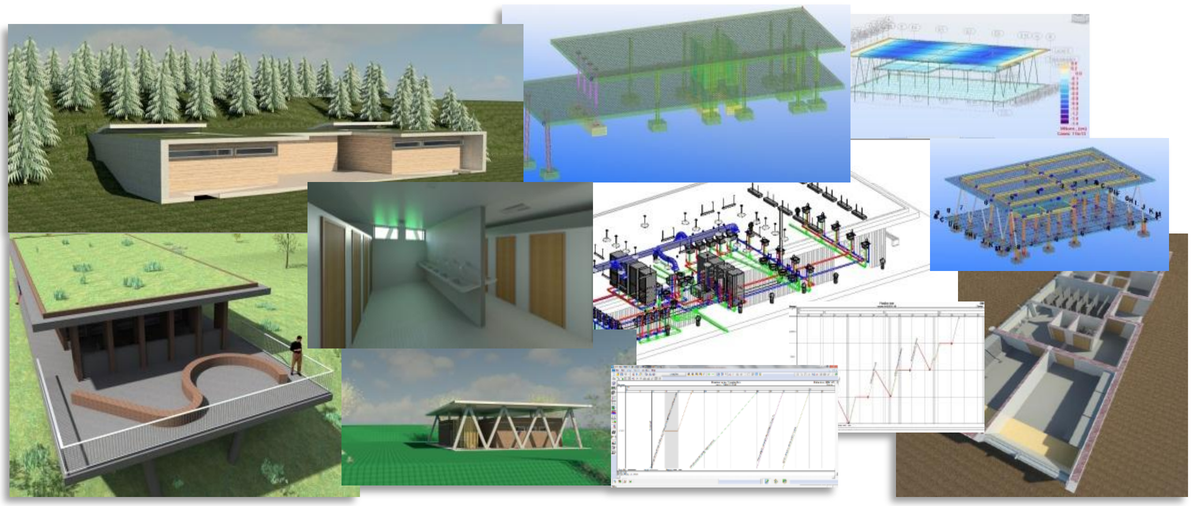


Figure 3.9 – Summary of the BIM models developed by the students of the curricular unit BIM held at University of Minho 2012/2013.

CHAPTER 4

4. BIM EXECUTION PLAN (BEP) FRAMEWORK FOR COLLABORATIVE PROJECT IMPLEMENTATION PLANNING

4.1. Introduction and research methodology

BIM is hastily disseminating, in a global context, wherever any public entities and private organizations are demanding the implementation of BIM collaborative working procedures (level 2 on BIM maturity scale) in their projects, which are presently many. However, in several practical cases, many owners and project team members are struggling with how to effectively implement BIM throughout the lifecycle of a building project, due to the ineffective planning procedures for the execution of BIM within a project team. The definition of a BIM strategy that dictates implementation methodologies to effectively integrate BIM into a project delivery process is of paramount importance to achieve the expected BIM deliverables outlined.

In this chapter it is established a BIM Execution Plan framework configured to assist the Portuguese AEC firms on developing collaborative BIM projects in a national/international scale. In the development of this BEP framework, it was analysed with peculiar detail the collaborative processes that ensue between the structural engineer and the architect, nevertheless the framework of implementation presented can be transversal to all stakeholders involved. The collaborative relations between these two actors are of great importance, constituting in many practical cases the initial collaborations verified in a project, where the most critical features that impact the project performance, are normally decided.

The various contents that are embraced in this BEP framework are consistent with the results accomplished from a multi-level research method. Firstly, it was developed a process of benchmarking regarding the current bibliographical references available, with the intent to retrieve the first-rated issues from the most reputable BIM standards (AEC (UK) BIM Protocol; COBIM; Singapore BIM Guide; AIA E203/G201/G202) and from alternative BEP employed in other countries (BIM Execution Planning Guide; AEC (UK) BIM Protocol Project BIM Execution Plan; MIT BIM Execution Plan; Singapore BIM Essential Guide for BIM Execution Plan). Alongside this international widespread literature review, it was considered the results assembled with the interviews performed to AEC professionals who are well recognized by their national and international experiences in the construction industry, namely in the architectural, structural engineering and project management fields. The interviews were conducted simultaneously with Arch. Vanessa Tavares (CNLL), Arch. Nuno Lacerda (CNLL) and Eng. José Carlos Lino (NEWTON-C), all members associated to the BIM workgroup of the PTPC, with the scope to attend under a collaborative environment the issues related with the collaborative process, information workflow and the Portuguese cultural relations verified among architects and structural engineers and also in the general construction sector. Finally, with the results retrieved from the bibliographical review and the interviews performed, were analysed, optimized and established their practical implementation on a case study. As already mentioned in chapter 3 (see section 3.2.4), this case study resembles the practical work of the curricular unit “BIM: Conception, Design and Construction”, developed by the lecturing team, where the obtained requirements and implemented software are visible in appendix 5 and table 3.1, respectively. In this case study, the lecturing team had as an objective the development of a project with specific complexities of architectural design, such as the employment of unique BIM objects and curved building elements that are known to hamper the information exchanging through the IFC format, which was embraced as the only format of information exchange among the members of the project team. In specific contents of this BEP framework it was used the practical work of the students of that same curricular unit in order to perform statistical analysis, conferring more data to the study of a particular facet of this BIM implementation framework.

The BEP framework that was designed in this MSc dissertation enables the project team to develop a BIM implementation strategy by addressing the necessary BIM uses to deliver throughout the project. Therefore, this BEP planning guide has the particularity of representing strategies that grant the implementation of BIM as general or partial project methodology. The general project methodology occurs when all stakeholders develop a complete project workflow in BIM, yet the partial project methodology arises when only part of the stakeholders and/or part of the project workflow is developed under this methodology.

The BIM execution plan described throughout this chapter presents an implementation framework comprised of 6 stages (see figure 4.1):

- **Stage 1** (see section 4.2) aims to compile the project basic information, such as generic information, basic technical information and information relative to the stakeholders involved. More important, this stage presents a procedure that analyses the characteristics of the project and the client’s requirements being defined and prioritized the main project goals and tasks to be attained. Posteriorly, potential BIM uses are discussed and assigned in order to achieve the goals and tasks delineated;
- **Stage 2** (see section 4.3) commences by establishing a method for the selection of the potential BIM uses, delineated in stage 1, that are to be implemented throughout the lifecycle of the building. Then it is illustrated a protocol for defining the roles of each stakeholder towards each particular BIM use appointed. Once selected the BIM uses to be undertaken, a procedure of developing process maps is demonstrated with the purpose to represent the workflow and interactions, in terms of information exchanges, between the BIM uses of the project, stipulating in this way the future relations among stakeholders throughout the project delivery. More detailed process maps are established which describe the sequencing of activities needed to deliver a specific BIM use;
- **Stage 3** (see section 4.4) presents a methodology for determining specifically each information exchange that occurs throughout the project, being determined the minimum information requirements needed to perform, considered the specific BIM uses;
- **Stage 4 and stage 5** (see section 4.5 and 4.6, respectively) study the management required in terms of the BIM models and their data during the project delivery process;

- **Stage 6** (see section 4.7) indicates the various quality assurances checks that can be practiced on the developed BIM models which should be followed to guarantee a competent BIM collaborative project.

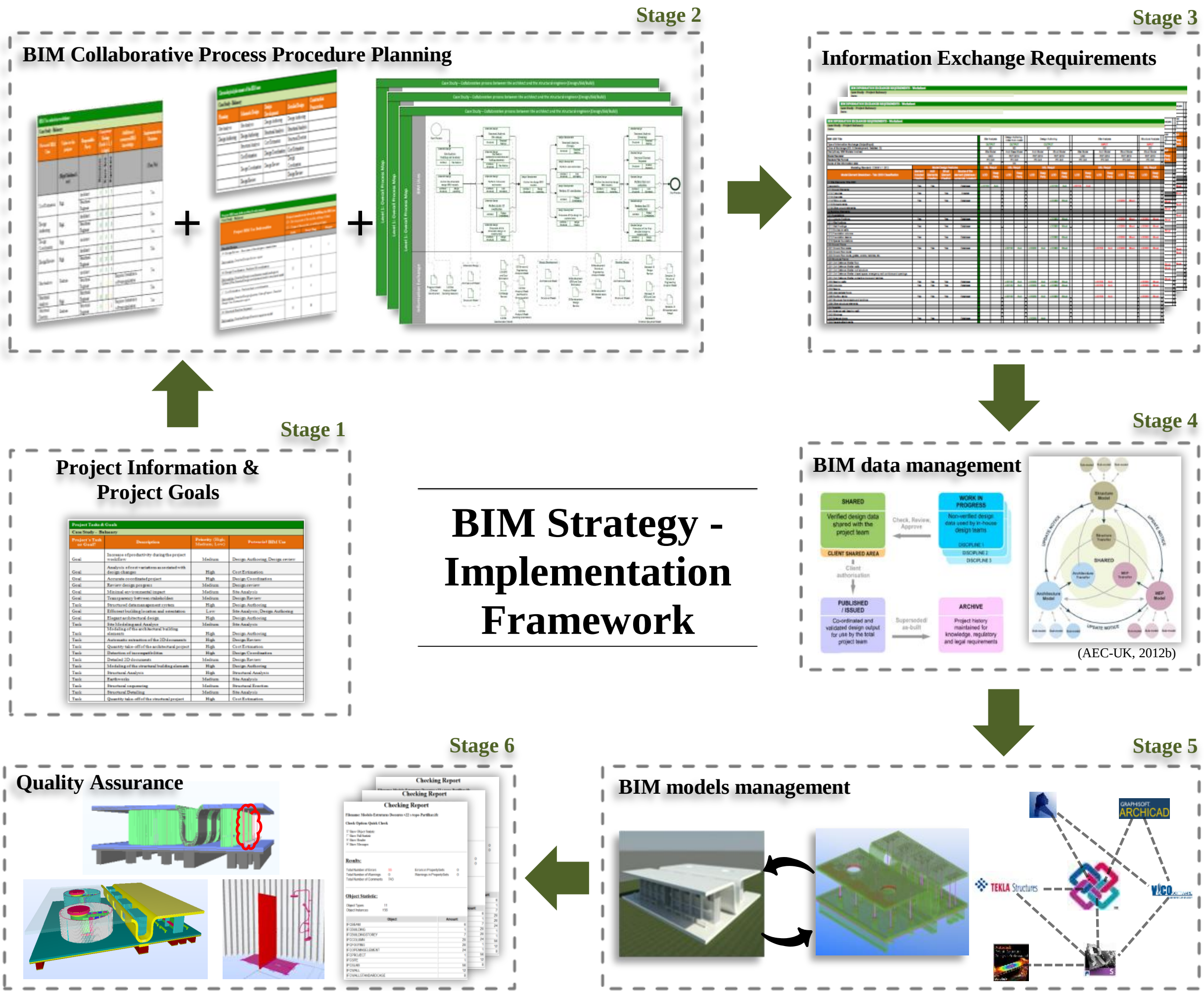


Figure 4.1 – BIM Execution Plan: Implementation Framework.

In each of the following sections it will be firstly presented the description of the implementation methodology needed to follow by the planning team when applying this BEP framework. Subsequently and to facilitate the perception of the reader a practical application of those suggested guidelines in a case study are illustrated.

4.2. Project information and project tasks/goals (Stage 1)

When initiating the BIM Execution Plan the leading team should document the essential project information for the stakeholders involved in the project to reference throughout the building´s lifecycle. Table 4.1 recommends the necessary information, divided under 3 categories that are to be discussed and documented by the planning team.

Table 4.1 – Recommended project information to document for future reference.

Project Information		
Generic Project Information	**Technical Information**	**Project Team Information**
- Name of the project; - Project Owner; - Projects localization; - Project scope; - Description of the project by owner´s perspective (preliminary programme); - Deadlines/schedule; - Project budget; - Funding status; - Clients Requirements; - Contractual project delivery agreement; - Unique project challenges.	- Modelling unit system; - Project coordinates; - Adopted BIM modelling Standard; - Project BIM maturity level; - Exchange information format (direct/indirect, if indirect which?); - Posterior usage of the BIM model (e.g. BIM-FM).	- Stakeholders description; - Stakeholders contacts; - BIM level of competencies of each project party; - Identification of the leading team of the BEP.

Once assembled the document that retains the project´s information, the planning team should perform a comprehensive analysis identifying the project´s main objectives and tasks, which are consistent with the project´s scope, its description made by the owner and his specific requirements. It is important to evince both tasks and objectives of the project, due to the fact that some tasks are necessary to be performed and occasionally unrelated with project´s goals. Normally the designated project´s goals are associated with the general quality of the project design (e.g. increase the sustainability of the project) and the productivity of the project teams throughout the development of each task (e.g. analysis of cost variations associated with alternative designs). The identification of the tasks, should considerer the project elements that are necessary to be delivered throughout the phases of the project, which are generally specified in national regulations. Furthermore, the leading team should measure the priority (High/Medium/Low) of the project´s tasks/objectives that were previously outlined in order to have a superior grasp of the significance of each task/objective to pursue.

At this point it is imperative for the team to underline the purpose of implementing BIM in the specific project, by identifying the appropriated BIM uses to fulfil the project´s tasks/goals that were outlined. This procedure of corresponding and associating potential BIM uses with the proposed project´s tasks/goals is a complex process that the planning team needs to undertake. Thereby, to facilitate this operation this BEP framework resorts to the study developed by the Computed Integrated Construction (CIC) Research Program (Messner, 2011), which identifies twenty-five generic BIM uses that can be practised throughout the main phases of the lifecycle (see section 2.2.3.1). Each BIM use that is referenced in this research programme is characterized by its description, potential value/benefits, necessary resources and BIM competencies required. With the broad information associated to each BIM use it is conceivable to cross-reference the task and objectives to be performed with potential BIM uses. If necessary, other BIM uses which are not evidenced by the research programme can be added in order to accomplish certain criteria of a specific project. It should be noted, that the achievement of some project goals can imply the employment of more than one BIM use.

At the conclusion of stage 1, the planning team should be able to understand how and in what way (potential BIM uses) the BIM methodology may assist the development of a specific project. The resulting elements that are produced by the leading team is a document that incorporates the information of the project and a table that specifies each task and goal to deliver, with a classification of its priority and the associated potential BIM uses (see table 4.2).

Case Study – (*Stage 1)*

- **Project Information**

This case study was performed under an academic scope, so the definition of the project information, specifically the category of the generic project information, will be equipped with fewer details when compared to a real project. It should be noted, that throughout the development of this case study the owner was assumed as a realistic figure. In summary, the case study consists on the development of a male and female sanitary facility of a single floor to be situated in a camping site, where the topography of the terrain was disposed by the “owner” in a CAD 3D format. The “owner” requires an elegant and modern architectural design to integrate the surroundings of the landscape. In terms of the project´s budget there is some flexibility, though the “owner” demands transparency and an iterative process in order to obtain the design with the most economical solution. For the development of this case study it will be embraced a design-bid-build (DBB) contractual project delivery agreement, with the intent to simulate public constructions where this contractual agreement is mandatory accordingly to the Portuguese national regulation (code of public contracts (CCP), specified in Portaria nº18/2008).

Regarding the technical information, it was concurred that the unit system would be in meters (m), with exception of the structural metallic documentation in which it was agreed to be in millimetres (mm). As to the information exchange procedure, the planning team decided to embrace an indirect approach, by adopting the IFC 2x3 data exchange standard. The BIM models that were developed had solely the purpose of supporting the project´s execution, where the COBIM v1.0 was the selected as the main BIM standard to assist in the modelling procedure.

As already mentioned, this case study was developed by the lecturing team of the curricular unit described in chapter 3. The architectural team was led by Arch. Nuno Lacerda and Arch. Vanessa Tavares (both CNLL), the structural engineering team was composed by the author with guidance of Prof. Miguel Azenha e Eng. José Carlos Lino (UMinho and NEWTON-C), the MEP engineering was managed by Eng. Francisco Reis (EFACEC) and the construction management was directed by Eng. António Ruivo Meireles (Mota-Engil) and Prof. João Pedro Couto (UMinho).

Acknowledging that this dissertation aims to analyse with peculiar detail the collaborative processes among the architect and structural engineer, the implementation of this BEP framework in the specific case study was performed between the architectural team and the structural engineering team, where the last team was appointed the leading team, due to academic reasons.

- **Identification of the case study´s tasks and goals**

The following table presents the project´s tasks and objectives, with their respective priority classification and associated potential BIM uses assigned by the leading team, accordingly to methodology presented above. Once more, the project´s objectives and goals presented are relevant to the individual and collaborative workflows of the architect and structural engineer.

Table 4.2 – Projects Tasks & Goals, Case Study.

Project Tasks & Goals			
Case Study			
Project´s Task or Goal?	**Description**	**Priority** (High; Medium; Low)	**Potential BIM Use**
Goal	Increase of productivity during the project workflow	Medium	Design Authoring; Design review
Goal	Analyses of cost variations associated with design changes	High	Cost Estimation
Goal	Accurate coordinated project	High	Design Coordination
Goal	Review design progress	Medium	Design review
Goal	Minimal environmental impact	Medium	Site Analysis
Goal	Transparency between stakeholders	Medium	Design Review
Task	Structured data management system	High	Design Authoring
Goal	Efficient building location and orientation	Low	Site Analysis; Design Authoring
Goal	Elegant architectural design	High	Design Authoring
Task	Site Modelling and analysis	Medium	Site Analysis
Task	Modelling of the architectural building elements	High	Design Authoring
Task	Automatic extraction of the 2D documents	High	Design Review
Task	Quantity take-off of the architectural design	High	Cost Estimation
Task	Detection of incompatibilities	High	Design Coordination
Task	Detailed 2D documents	Medium	Design Review
Task	Modeling of the structural building elements	High	Design Authoring
Task	Structural Analysis	High	Structural Analysis
Task	Calculation of the earthworks	Medium	Site Analysis
Task	Structural construction sequencing	Medium	Structural Erection
Task	Structural Detailing	Medium	Site Analysis
Task	Quantity take-off of the structural design	High	Cost Estimation

As illustrated in table 4.2 the planning team briefly compiled the main objectives and tasks to be performed during the project delivery of the case study. It is evident that many tasks and objectives embrace the same BIM uses. The objective of this BEP format was to guarantee the identification of all the necessary potential BIM uses from a wide range of project tasks/goals.

As a result of this first stage of the BEP, the planning team determined seven potential BIM uses to be implemented in the project delivery process, where six of the seven BIM uses were obtained by referencing the BIM uses presented by Computed Integrated Construction (CIC) Research Program (CIC, 2008). Thus, to fulfil the requirement of analysing the structural construction sequence it was necessary for the structural engineering team to create a BIM use designated as “structural erection”.

4.3. Study of the BIM collaborative process procedure planning (Stage 2)

4.3.1. Selection of the BIM uses for a project

Stage 2 of this BEP framework commences by presenting a methodology in which is selected the BIM uses that are to be implemented throughout the project´s phases, from the potential BIM uses outlined in stage 1. In short, the selection procedure will considerate the characteristics of the project and the BIM competencies of the involved stakeholders regarding the implementation of the potential BIM uses. This is a critical point for the stakeholders to evaluate whether they have the capabilities to implement efficiently the BIM methodology in a specific project.

The selection methodology that is incorporated in this BEP framework is based on a similar procedure used in the BIM Project Execution Planning Guide Version 2.0 (CIC, 2010), in which it is created a BIM Use selection worksheet (see table 4.3). The BIM use selection worksheet of this BEP will contemplate the following details:

-Potential BIM uses under consideration and their value to the project: The potential BIM uses can be identified in stage 1 of this BEP. The value of each BIM use is defined by considering the classification priority appointed to each goal and task in which it is associated to, being also acknowledged in that stage;

-Responsible party: For each potential BIM use under evaluation, it is identified the stakeholder(s) who are responsible for its execution;

-BIM capability rating: The leading team of the BEP will need to evaluate each responsible party in terms of their BIM competency on delivering the appointed BIM uses. This evaluation of the stakeholders should incorporate the resources needed to implement BIM (software, staff BIM team, hardware, IT platforms, among others), their BIM knowledge relatively to the execution of the appointed BIM uses and the stakeholders experience in working with BIM. The evaluation will be quantified by attributing a number between the scale of 1 to 3 (1 is low and 3 is high). The criteria of evaluation performed by the leading team should be formulated collaboratively by the planning team, embracing in this way a transparent and fair procedure considering the suggestions of all involved stakeholders;

-Additional resources/BIM knowledge: The leading team if necessary will indicate for each BIM use under analysis, the additional resources/BIM knowledge that is needed by the respective responsible party in order to perform that BIM use with an adequate performance;

-Implementation decision: The planning team will need to discuss in detail the implementation of each BIM use, considering their benefits and risks in the project delivery process. This decision (Yes/No) relatively on the incorporation of the each BIM use should be based on a complete evaluation which considers the characteristics of the project and the BIM capability of each stakeholder involved. It should be noted, that at times the selection of a specific BIM use can influence the selection of other BIM uses.

Case Study – *(Stage 2, selection of the BIM uses)*

Table 4.3 illustrates the BIM use selection worksheet that was elaborated by the leading team of this case study, being developed in concordance with the procedure mentioned above.

Table 4.3 – BIM Use selection worksheet, Case Study.

BIM Use selection worksheet							
Case Study							
Potential BIM Uses	**Value to the project**	**Responsible Party**	**BIM Capability (Scale 1-3, 3 is high)**			**Additional resources/BIM knowledge**	**Implementation Decision**
	(High / Medium / Low)		Resources	Know-how	Experience		(Yes; No)
Cost Estimation	High	Architect	3	3	3		Yes
		Structural Eng.	3	3	2		
Design Authoring	High	Architect	3	3	3		Yes
		Structural Eng.	3	3	3		
Design Coordination	High	Architect	3	3	3		Yes
Design Review	High	Architect	3	3	3		Yes
		Structural Eng.	3	3	3		
Site Analysis	Medium	Architect	3	3	3		Yes
		Structural Eng.	3	2	2	Requires formation in software application	
Structural Analysis	High	Structural Eng.	3	3	2		Yes
Structural Erection	Medium	Structural Eng.	3	2	1	Requires formation in software application	Yes

As can be seen in table 4.3, the leading team firstly deliberated the value in integrating each potential BIM use in the project delivery procedure being appointed a grade of importance (high, medium or low), by analysing the attributed priority levels of the projects objectives and goals defined in stage 1 (see table 4.2). Thereafter, the leading team together with the other stakeholders discussed the scope of each potential BIM use, defining the responsible parties for their execution.

The quantification of the BIM capability rating of each responsible party regarding the development of their respective BIM use is a delicate procedure and if poorly managed by the leading team can originate conflicts within the project team. In this case study, the leading team and the remaining stakeholders, collaboratively, pre-established internally a fair and mutual criteria to evaluate the stakeholder's BIM resources disposed, BIM level of skill and experience in BIM projects. Henceforward and consequently, when the leading team attributed a BIM capability rating to the other involved stakeholders (architectural team) that are responsible for a certain BIM use, this process was transparent and founded on common criteria formulated by all the involved stakeholders. Equally important, if the leading team has an active role in the design procedure, which occurs in the case study, they too should be evaluated by the remaining planning team based on the same BIM capability rating criteria.

The results regarding the BIM capability rating of this case study indicated that the structural engineering team (the leading team of this BEP) presented some flaws regarding the development of the “site analysis” and “structural erection” BIM uses (see table 4.3). The leading team with contribution of the other members of the project recommended that the structural engineering team required formation in the area of software skills. To conclude, all potential BIM uses were approved by the leading team to be implemented in the workflow of the project.

4.3.2. Chronological placement of the BIM uses

Once defined the BIM uses to implement in the project delivery, the following issue to attend will be there chronological placement considering the phases of the project. In order to perform this procedure it is recommended for the leading team to study the elements to be delivered in each phase of the project, being generally specified in a national regulation. The set of deliverables associated to the BIM uses implemented in each phase of the project must correspond to the required regulatory elements of the project.

Case Study – *(Stage 2, chronological placement of the BIM uses)*

In this case study, being a construction work in Portugal it was consulted the Portuguese regulation (Portaria nº701-H/2008). Accordingly to this regulation, the design phases are divided into the planning phase, schematic design, design development and detailed design, where the elements to deliver are described in chapter 2 – literature review (see section 2.2.3.1). Due to the fact that in this case study it was solely analysed the relations between the architect and the structural engineer, and admitted a design-bid-build contractual agreement, the BIM collaborative process will exclusively cover the design phases leaving out the construction preparation phase. Table 4.4 presents the chronological placement of the BIM uses admitted in the case study throughout the phases of the project, developed by the leading team.

Table 4.4 – Chronological placement of the BIM uses, Case Study.

Chronological placement of the BIM uses				
Case Study				
Planning	**Schematic Design**	**Design Development**	**Detailed Design**	**Construction Preparation**
Site Analysis	Site Analysis	Design Authoring	Design Authoring	
Design Authoring	Design Authoring	Structural Analysis	Structural Analysis	
	Structural Analysis	Cost Estimation	Structural Erection	
	Cost Estimation	Design Coordination	Cost Estimation	
	Design Coordination	Design Review	Design Coordination	
	Design Review		Design Review	

As illustrated in the table above many BIM uses are recurrent in the various design phases, being justified due to the increment of detail that is needed in the delivery of the project´s elements during the progression of the design phases dictated in the Portuguese regulation. Lastly, by performing this procedure the planning team gains capacity to understand some dependencies between BIM uses, however this analysis will be developed with greater detail section 4.3.4.

4.3.3. Project BIM uses deliverables & roles matrix

For the BIM methodology to be successfully implemented in the collaborative process, it is essential for each member of the project team to understand the excepted deliverables and their respective roles in the development of the BIM uses that are outlined throughout the phases of the project. The definition of the deliverables to be obtained by each BIM use implemented in the project delivery must fulfil the requirements specified in the national regulation and the client´s particular requests, defined in stage 1 of this BEP framework. If this is not verified, the leading team should ponder on integrating supplementary BIM uses, being necessary to update the BIM Execution Plan developed by the leading team up to now.

This section presents a methodology that is based on the Singapore BIM Guide 2013 v2.0 (BCA, 2013f) and BIM Project Execution Planning Guide Version 2.0 (CIC, 2010) which facilitates the leading team to define the necessary deliverables to retrieve from each BIM use implemented throughout the phases of the project and the respective roles of each stakeholder involved in the BIM collaborative process. This BEP framework recommends that the leading team should commence by analysing the requirements needed in the final phases of the project to perform its respective BIM uses, in order to understand the future use of the information (deliverables) that are necessary to be developed. Consequently, with this downstream process of analysing the workflow of the collaborative project the dependencies between BIM uses are possible to be outlined. Regarding the definition of the involved stakeholder’s roles towards each BIM use, the leading team defines whether the stakeholder displays a role of a model developer or a model user. The role of model developer is when the stakeholder and his team is responsible in editing the BIM model considering a specific level of development (LOD) in order to achieve the deliverables stipulated for that BIM use (for more information see section 4.5). The role of a model user consists on the authorization granted to a stakeholder and his team to reference, without editing a BIM model, enabling the sharing of information. This methodology is materialized in the Project BIM uses deliverables & roles matrix, where it´s template of this BEP framework is presented in table 4.5.

Table 4.5 – Project BIM uses deliverables & role matrix, Template.

Project BIM uses deliverables & roles matrix					
Template					
Project BIM Use Deliverables	**Project members involved in fulfilling the BIM use** (D - Development of the model, editing of data) (U - Usage of the model, no editing of data)				
	Arch.	**Struct Eng.**	**MEP Eng.**	**Contractor**	**Owner**
Project Phase: ______________________________					
nº___ / BIM Project Use:______________________ Deliverables: _________________________________					

From the collaborative interviews that were performed with the AEC professionals, it was uttered several times the great importance of the owner´s incorporation in the collaborative process, in order to obtain a more gratifying project. Thus to foster the integration of the owner in the project delivery process, this BEP framework recommends the BIM use of "*design review*", where the owner can be a part of the review team and display a role as model user having access to the BIM models under revision.

The establishment of the Project BIM uses deliverables & roles matrix can be simultaneously realized with the previous procedure stipulated in the above section regarding the chronological placement of the BIM uses, because in both operations it is necessary to consider the deliverables of the selected BIM uses during the phases of the project.

Case Study – *(Stage 2, Project BIM uses & roles matrix)*

In appendix 8 is presented the Project BIM uses & roles matrix, which was developed by the leading team of the case study, considering the methodology presented above. For the development of this procedure the leading team collaborated with the other involved project members in the BIM project workflow to acknowledge the possible deliverables to be obtained for each BIM use. Thereafter, the leading team, in the detailed phase (final design phase), characterized each selected BIM use, indicating the necessary deliverables to be achieved and the role of each stakeholder.

As can be seen in appendix 8 all stakeholders involved in the BIM collaborative workflow, including the owner, have authorization to consult and perform analyses regarding the BIM models developed by other actors, which is an indication of open information sharing approach verified among the project team members.

4.3.4. BIM process mapping procedure

4.3.4.1. General considerations

The following procedure of this BEP framework to procure consists on mapping the processes and activities that ensue in the BIM workflow of a collaborative project. Once acknowledged the project´s BIM uses, their required deliverables and the roles of the involved stakeholders, the subsequent procedure aims to strategize the implementation process for each BIM use and for the BIM collaborative project as a whole. The process maps that result from this procedure enable the involved stakeholders to cognize the overall BIM workflow, with indication of the dependencies between BIM uses in terms of their information exchanges and the diverse activities to be performed associated to each BIM use. In short, the resulting process maps allow each stakeholder to perceive what information is necessary to perform a specific BIM use, who must share that information, when that information must be shared and how to execute the respective BIM use.

In this BEP framework the BIM process mapping procedure is based on the methodology presented in the BIM Project Execution Planning Guide Version 2.0 (CIC, 2010) that is integrated with the National BIM Standard (NBIMS) – United States Version 2 (NBIMS, 2013). In this methodology it is considered two levels of presentation. The first level, designated as the BIM Overview Process Map demonstrates the relationships between the BIM uses which will be established on the project´s workflow. This type of process map also emphasizes the information workflow to establish throughout the project´s execution. The second level, designated as the Detailed BIM Use Process Map illustrates the sequencing of the activities to be performed in order to achieve each BIM use. In each process map, particular to a specific BIM use, it is indicated the responsible party, the required information and the accomplished information deliverables. All process maps that originate from this BEP framework are based on the Business Process Modeling Notation (BPMN), which is described in greater detail in chapter 2 – literature review (see section 2.3.2).

In the following sections related to the BIM process mapping procedure it will be explained the methodology for the elaboration of the BIM Overview Process Map (level 1) and the Detailed BIM Use Process Map (level 2). The explanation of this methodology will be accompanied with practical implementations and respective analysis regarding the performed case study. Firstly, it will be analysed the developed BIM Overview Process Maps (level 1) considering the verified distinctions inherent when embracing different contractual project delivery agreements in which is included all the stakeholders of the case study. Thereafter the performed level 1 and level 2 process maps considering exclusively the collaborative process between the structural engineer and the architect that persist in the case study will be analysed. The intent of this last study is to comprehend generically the collaborative and individual BIM workflows intrinsic to these stakeholders.

From the interviews that were established with the AEC professionals it was systematically mentioned, namely by the architectural professionals, that mapping the collaborative processes of an AEC project should not be done with a vision to rigidly standardize those processes. The projects of the AEC industry are commonly unique products where its actors need to take in account multiple variables, such as the surroundings of the site, the client's requirements, project team members, economic flexibility, contractual project delivery agreements, among many more. Therefore, acknowledging the current culture of the AEC industry it will be complex to generate a process map that is able to cover and quantify this broad amount of peculiar variables that are all interrelated. Hence, this BEP framework presents a methodology that enables the leading team to develop singular process maps that considers the specific characteristics of a project, where the process maps that define the case study of this dissertation may be used as a practical reference.

4.3.4.2. BIM overview process map – Level 1

The BIM Overview Process Map (level 1) is composed by two horizontal lines, designated as "lanes" in the BPMN notation. The first lane is designated as "BIM Uses lane", which represents the logical sequence of the various BIM uses, where each BIM use is recorded as a process within the overview map. The second lane is designated as "Information Exchange lane" that identifies the BIM deliverables from one BIM use which may be required or relevant as a resource for future BIM uses. Other components such as the identification of the project´s name and type of process map should also be identifiable. Figure 4.2 identifies the above components mentioned.

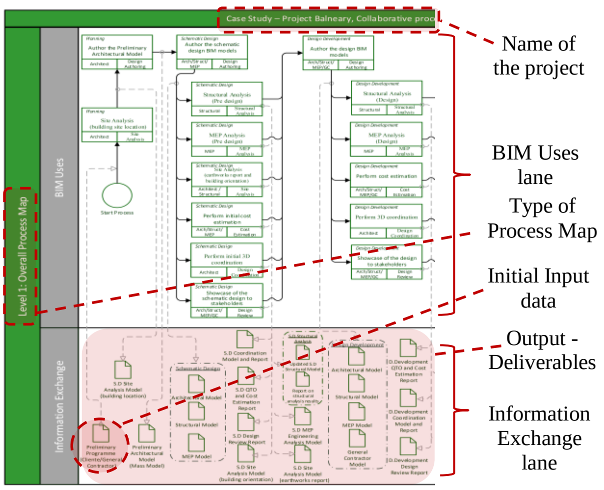


Figure 4.2 – Description of the components included in the BIM Overview Process Map.

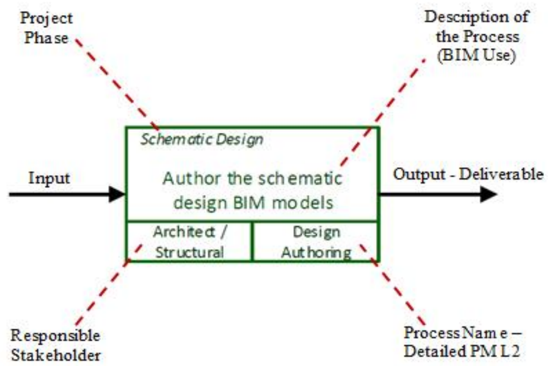


Figure 4.3 – Graphical notation of each BIM Use present in the BIM Overview Process Map.

Once developed the Project BIM uses deliverables & roles matrix, where it is characterized the BIM uses to be implemented in the project delivery, the leading team can initiate the structuring of the BIM Overview Process Map. They should commence with the placement of the final BIM uses to be implemented in the final phase of the project, arranging the remaining BIM uses of the project considering a downstream sequence being acknowledged the dependencies between BIM uses. Then the BIM uses are connected using the "sequence lines" of the BPMN mapping notation (see section 2.3.2) illustrating the predecessor and successor of the BIM workflow. Each BIM use should be presented in its graphical notation its respective description, indication of its Detailed BIM Use Process Map (level 2) and respective project phase of implementation (see figure 4.3). Furthermore, in each

BIM use it should be identified the responsible stakeholder(s) for its development, where the involved stakeholders of each BIM use will need to inform the leading team the required information (input) to implement the BIM use and as well as the produced information (output – deliverable) (see figure 4.3), being essential for the structuring of the BIM Overview Process Map.

The information exchange lane of the BIM Overview Process Map presents the information workflow through the deliverables of the various BIM uses ordered throughout the project´s workflow. Therefore all the involved stakeholders comprehend the available information for sharing, where the information exchanges can either be established between BIM uses/stakeholders or remain internally in the BIM use process. In addition, the available information for sharing can either originate within the project workflow being nurtured and maturated by previous BIM uses or can be obtained externally to the sequence line of the collaborative project. In stage 3 of this BEP framework the information exchanges will be explained with greater detail (see section 4.4).

The leading team of the BEP is responsible for the development of this procedure, though it is fundamental collaboration between the leading team and the involved stakeholder in order to effectively constitute a BIM Overview Process Map that satisfies all parties.

Comparison of the DBB, DB and IPD contractual agreement BIM workflows

As already mentioned in chapter 2 – literature review (see section 2.2.2) the contractual project delivery agreement has great influence on the project´s workflow, specifically in the collaborative process. It was also concluded that the BIM methodology can be implemented despite the adopted contractual agreement, although verifying certain reservations in the BIM collaborative workflow. Figures 4.4 and 4.5 present two BIM Overview Process Maps (level 1) that simulate the BIM collaborative workflow of all involved stakeholders throughout the various project phases of the performed case study considering, respectively, the design-bid-build (DBB) and design-build (DB) contractual agreement. These process maps were performed based on the interviews established with the AEC Professionals and presented accordingly to the Business Process Modeling Notation (BPMN), which is described in greater detail in chapter 2 – literature review (see section 2.3.2).

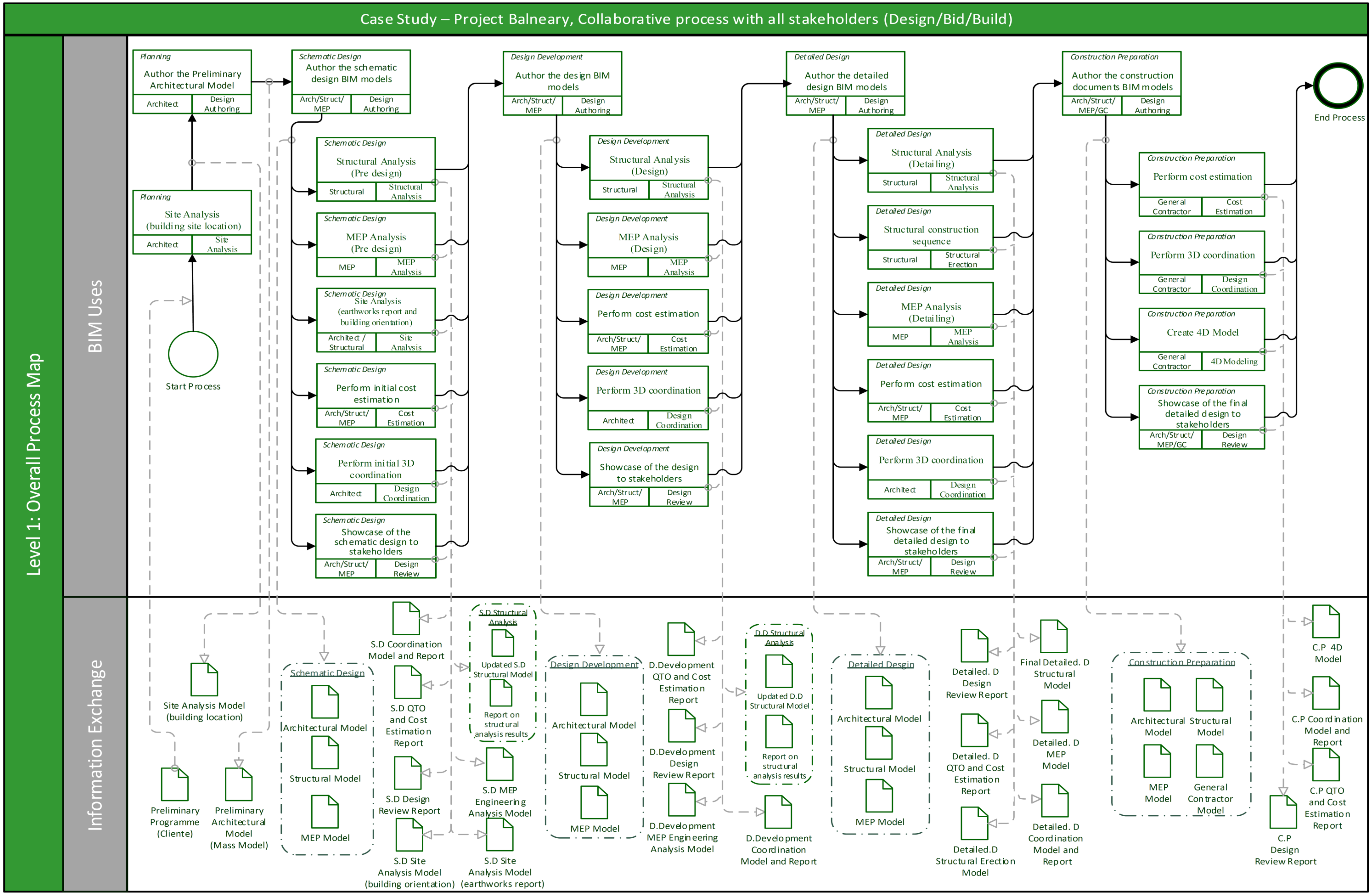


Figure 4.4 – BIM Overview Process Map (Level 1) – Collaborative process with all involved stakeholders with implementation of the Design-Bid-Build (DBB) contractual agreement, case study.

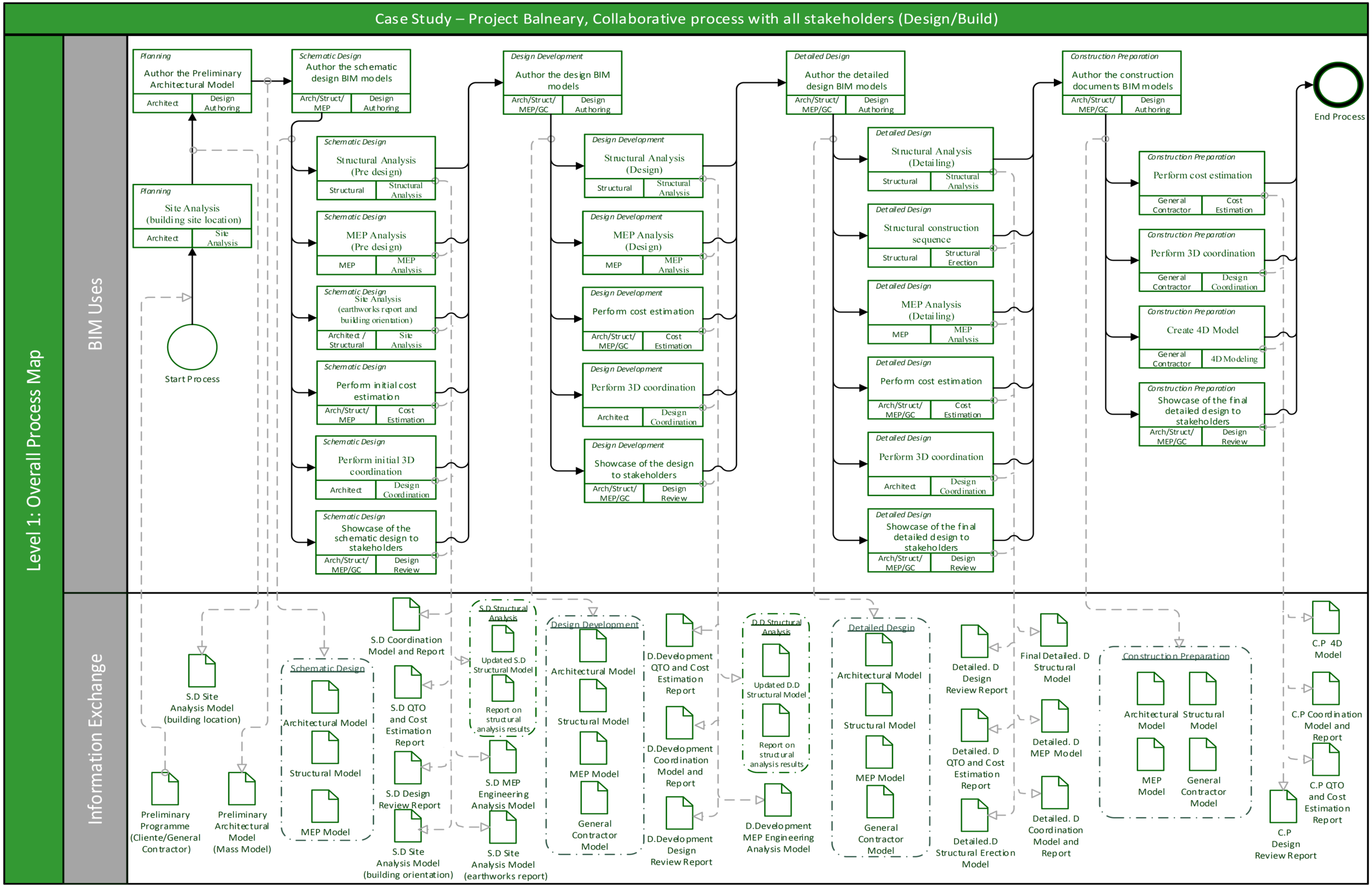


Figure 4.5 – BIM Overview Process Map (Level 1) – Collaborative process with all involved stakeholders with implementation of the Design-Build (DB) contractual agreement, case study.

Although both process maps, presented above, are very similar, there are core differences which will excessively alter the BIM project delivery characteristics. These specific differences are dependent on how the general contractor is involved in the project, where the main fields of alteration are on, how the BIM workflow is organized, on the management of the BIM models and on the scheduling of the project phases. Regarding on how the BIM workflow is organized it is perceptible on DB approach that in the project´s design phase the general contractor is involved in the “cost estimation” and “design reviews” BIM uses, consequently displaying an important role in the decision making of the project´s design (see figure 4.5). On the contrary, in the DBB approach the general contractor only in the bidding phase does this stakeholder have contact with the project (see figure 4.4). Accordingly to the performed interviews, in some practical cases of DB approaches the general contractor assumes a role of a coordinator during the phases of design, where if BIM is implemented the development of the BIM models will need to be managed accordingly to the internal BIM standards dictated by the respective contractor. In this case and citing the Singapore BIM Guide Version 2 (BCA, 2013f), embracing the DB method allows for a single model that is developed to produce the construction documents and detailing of the discipline designs. Thus, in the DBB approach the BIM process is divided into two models – design model and construction model (BCA, 2013f), due to the fact that each model is based on different management procedures. Relatively to the scheduling of the project phases, it is conclusive by adopting a DB contractual agreement the BIM workflow will be more productive due to the increased integration verified among the stakeholders, enabling in certain occasions the overlapping of the project phases, namely between detailed design and construction preparation phases.

It is conclusive that the DB contractual agreement fosters a more productive and integrative approach, establishing superior detailed BIM models when compared to the DBB approach. However, in accordance with performed interviews by adopting a DB approach where the general contractor is the main coordinator of the project´s delivery it is generally considered as priority the ration cost/benefit gains, where in some cases the client’s best interests, his involvement and the quality of the project are not properly attended.

The IPD contractual agreement is foreseen by the literature review as the approach where the BIM methodologies functionalities are fully potentiated. Currently, only on particular real cases has the IPD approach been implemented alongside BIM, being necessary elevated reliability and BIM competencies among stakeholders to perform such projects. To implement such characteristics in common BIM collaborative projects it is necessary to obtain a high BIM maturity level by the AEC firms (see figure 2.17), where all processes are integrated and all shared data is interoperable. Accordingly to the interviews performed, it was uttered that the current AEC industry is not prepared for the mass implementation of the IPD approach, due to the dissimilar work philosophies that are generally embraced by the architects and the engineers, where the architects follow a continue iterative process of maturation of the project and the engineers incorporate a more linear process of finalizing each task attributed. Thereby the architect during the project delivery will be faced with many requests of information formulated by the engineers, where in many times not being able to respond due to insufficient maturity of his respective project.

4.3.4.3. Detailed BIM use process map – Level 2

Each Detailed BIM Use Process Map incorporates three horizontal lines ("lanes"). The central lane is designated as "Process lane", which represents the ordering of the various activities that establishes a particular BIM use embodied in the BIM Overview Process Map (level 1). The inferior lane named as "Information Exchange lane" identifies all input and output information, where generally the input information is constituted by deliverables from previous BIM uses or external information and the output information consists of the deliverables acquired with the respective execution of the BIM use. Finally the superior lane entitled as the "Reference Information lane" indicates the information resources needed to perform the respective BIM use (e.g. cost database; material database; site conditions database; among others). Figure 4.6 illustrates the above components.

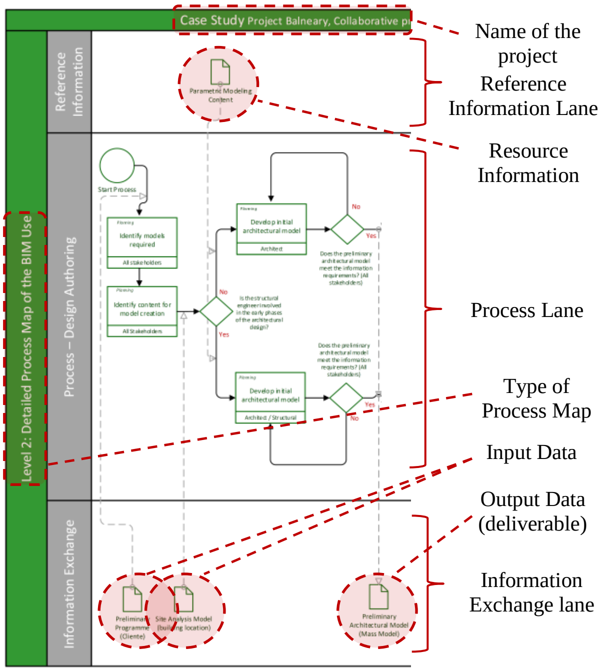


Figure 4.6 – Description of the components included in the Detailed BIM Use Process Map.

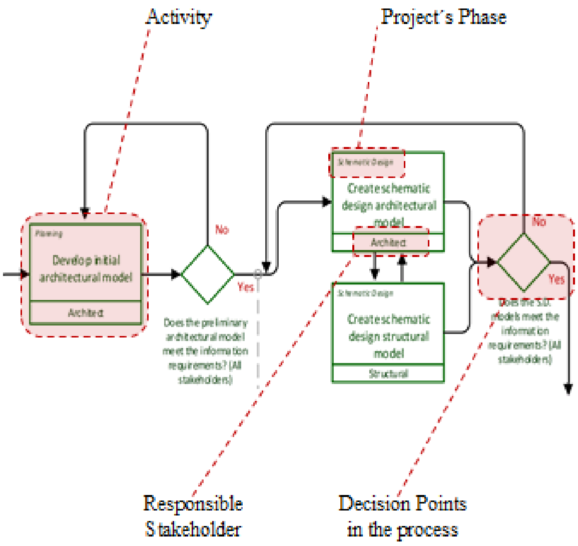


Figure 4.7 – Description of the components employed in the sequencing of the Detailed BIM Use Process Map.

These Detailed BIM Use Process Maps are created by the respective liable stakeholders involved in the execution of the respective BIM use(s) outlined and presented in the BIM Overview Process Map. It will need to present a set of tasks and decision points that enable the achievement of the respective BIM use, where it is documented the dependencies between the necessary activities (see figure 4.7). As there are BIM uses that are performed in various phases of the project, its activities should present the respective phase in which it is to be implemented (see figure 4.7). There are certain BIM uses that imply the contribution of more than one stakeholder, in which case the involved actors will need to cooperate in order to develop a process that fulfils the interests of all parties. The liable stakeholder(s) for the execution of each activity should be additionally indicated (see figure 4.7).

When identified all necessary tasks to perform a certain BIM use in the Process Lane, the involved stakeholders will need to document in the Information Exchange Lane the needed information and the produced information considering each activity. All required information (Input Data) and final deliverables (Output data – deliverables) of each specific BIM use need to be simultaneously documented in its Detailed BIM Use Process Maps (level 2) and in the BIM Overview Process Map (level 1), in order to simulate the information exchanges between different BIM uses and consequently among the involved stakeholders, thus performing the project delivery with the required information at the appropriated time. If not concordant, the leading team and the involved stakeholders need to reassess the sequencing of the BIM Overview Process Plan in order to obtain a convergence in terms of the disposed information to develop each BIM use with minimum information requirements of that specific BIM use, integrating in this way all BIM uses. This iterative process will grant the concordance between both levels of BIM process maps, consequently accomplishing an efficient and effective information workflow, approving the resultant BIM Overview Process Plan.

To summarize firstly the leading team should establish, as a first approach, the BIM Overview Process Map, based on the expected deliverables of each BIM use to be implemented in the project delivery. Then for each BIM use presented in the Level 1 process map, each stakeholder(s) responsible for its execution will present a BIM Detailed Process Map, emphasizing the required information and the outcome deliverables. It should be noted, that these level 2 process maps can originate from already internal processes of the involved AEC firm. Finally, the leading team and the involved stakeholders enter a phase of compatibility, re-arranging the BIM Overview Process Map and in extraordinary cases particular BIM Detailed Process Maps in order to obtain a consistent information workflow. All developed and approved BIM process maps should be saved and reviewed throughout the project delivery, being updated regularly in order to reflect the real workflows that are executed on the project.

4.3.4.4. Analysis of the BIM workflow process maps – case study

The following study aims to interpret the established BIM Overview Process Map (level 1) and Detailed BIM Process Maps (level 2) of the performed case study, in which it is outlined the collaborative process between the architect and the structural engineer. It will be reviewed the main information workflows verified between these two actors throughout the project delivery. Moreover, it will be described the essential individual workflows undertaken by these stakeholders. Figures 4.8 to 4.15 present the developed process maps of the case study, where all (level 1 and level 2 process maps) were created accordingly to the methodology presented in this BEP framework. Furthermore, all established process maps were discussed, optimized and approved during the performed interviews with the AEC professionals of the architectural and structural engineering fields.

Figure 4.8 illustrates the BIM Overview Process Map of the performed case study. As already mentioned it was adopted the design-bid-build (DBB) contractual agreement, therefore this process map only captures the collaborative workflow that persists in the design phase, where the design model is composed by the architectural BIM model and structural BIM model. This case study was performed at a level 2 BIM maturity level (see figure 2.17), where all collaborations were achieved by sharing the deliverables obtained from the developed BIM models under a common structured virtual environment (see section 4.5.3). All shared deliverables accomplished by the BIM uses are identified in the information exchange lane of that performed process map.

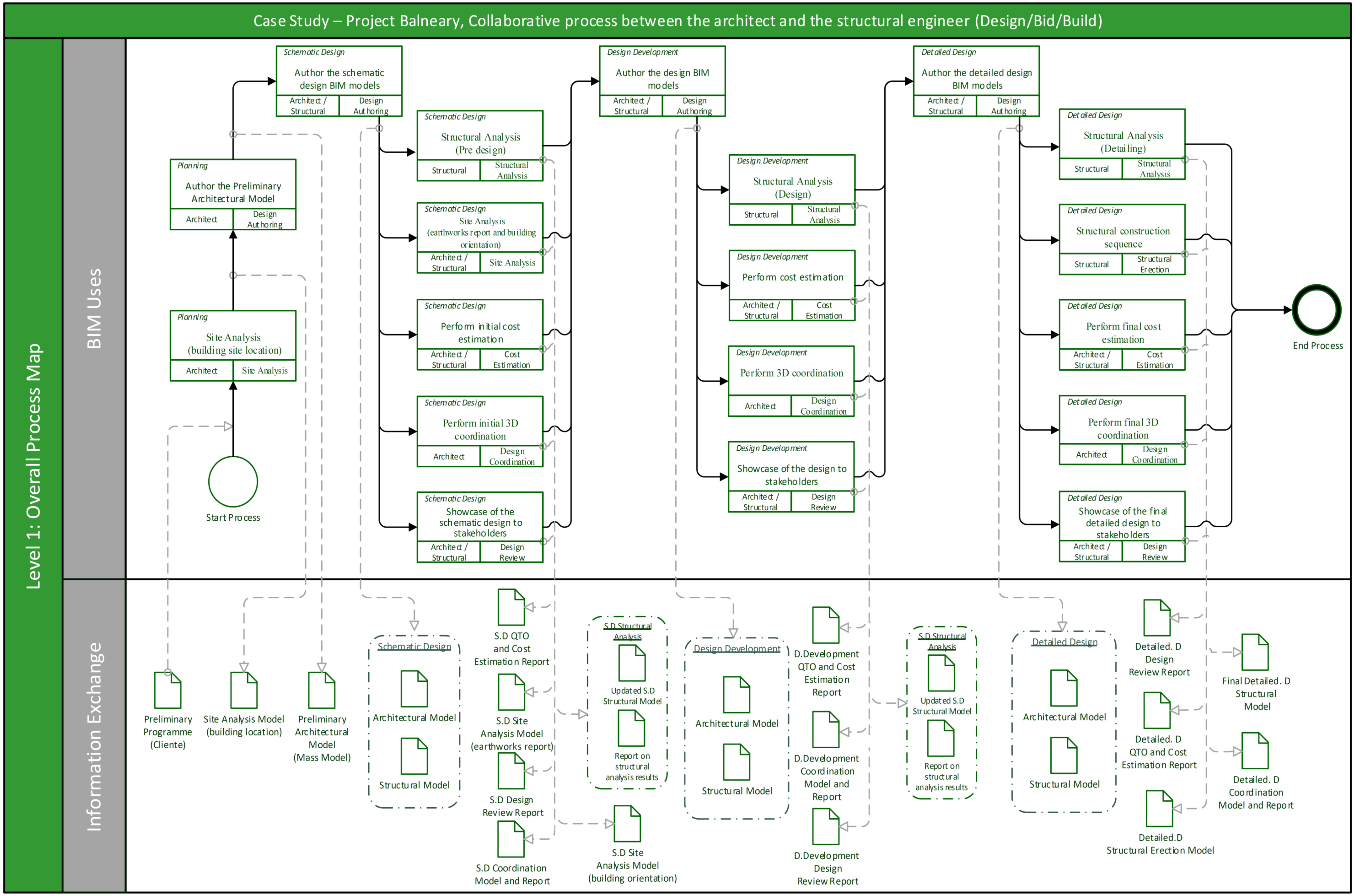


Figure 4.8 – BIM Overview Process Map (Level 1) – Collaborative process between the architect and structural engineer, case study.

In short, the performed BIM Overview Process Map presented in figure 4.8 initiates with the introduction of the preliminary programme stating the client´s requirements. Thereafter, the architect with or without the consultancy of other stakeholders, namely the structural engineer, will interpret those requirements and present a preliminary architectural model. When approved by the client the proposal of the initial architectural design, the collaborative process between the architect and the structural engineer formally initiates. Analogous in other phases of the project, the “design authoring” BIM use is generally the first to be commenced in a project phase, where based on the previous deliverables of the performed BIM uses attained in earlier phases of the project it is introduced all the necessary information and modelling requirements in order to deliver the remaining BIM uses of that respective project phase. To proceed with the development of the remaining BIM uses, it is necessary to assure that the delivered BIM models have the required characteristics (see section 4.4). Once guarantied the adequacy of the BIM models a set of BIM uses are simultaneously developed by the respective liable stakeholders. During the development of these BIM uses it is verified collaborative work and dialogue between the responsible stakeholders, in order to considerate the issues and constraints verified during the execution of the each BIM use. Once achieved the deliverables, it is shared with all stakeholders and if approved they are published as the final project files of that respective project phase, being posteriorly archived (see section 4.5.3).

The following paragraphs describe throughout the phases of the project the main occurrences verified among and during the execution of each BIM use, which are integrated in the BIM Overview Process Map. The respective Detailed BIM Use Process Maps when referred are presented in figures 4.9 to 4.15.

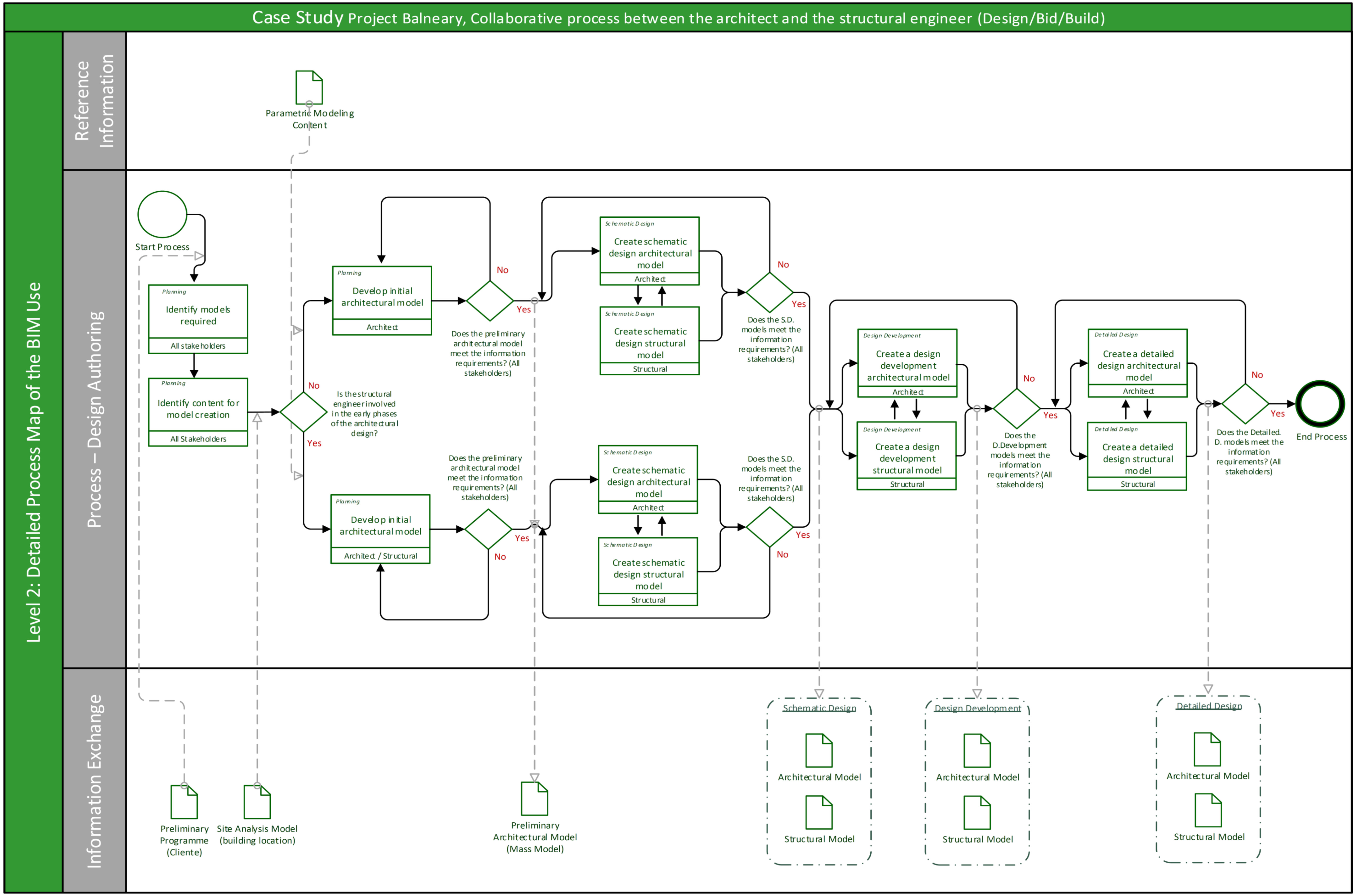


Figure 4.9 – Detailed BIM Process Map (Level 2) – “Design Authoring” BIM use, case study.

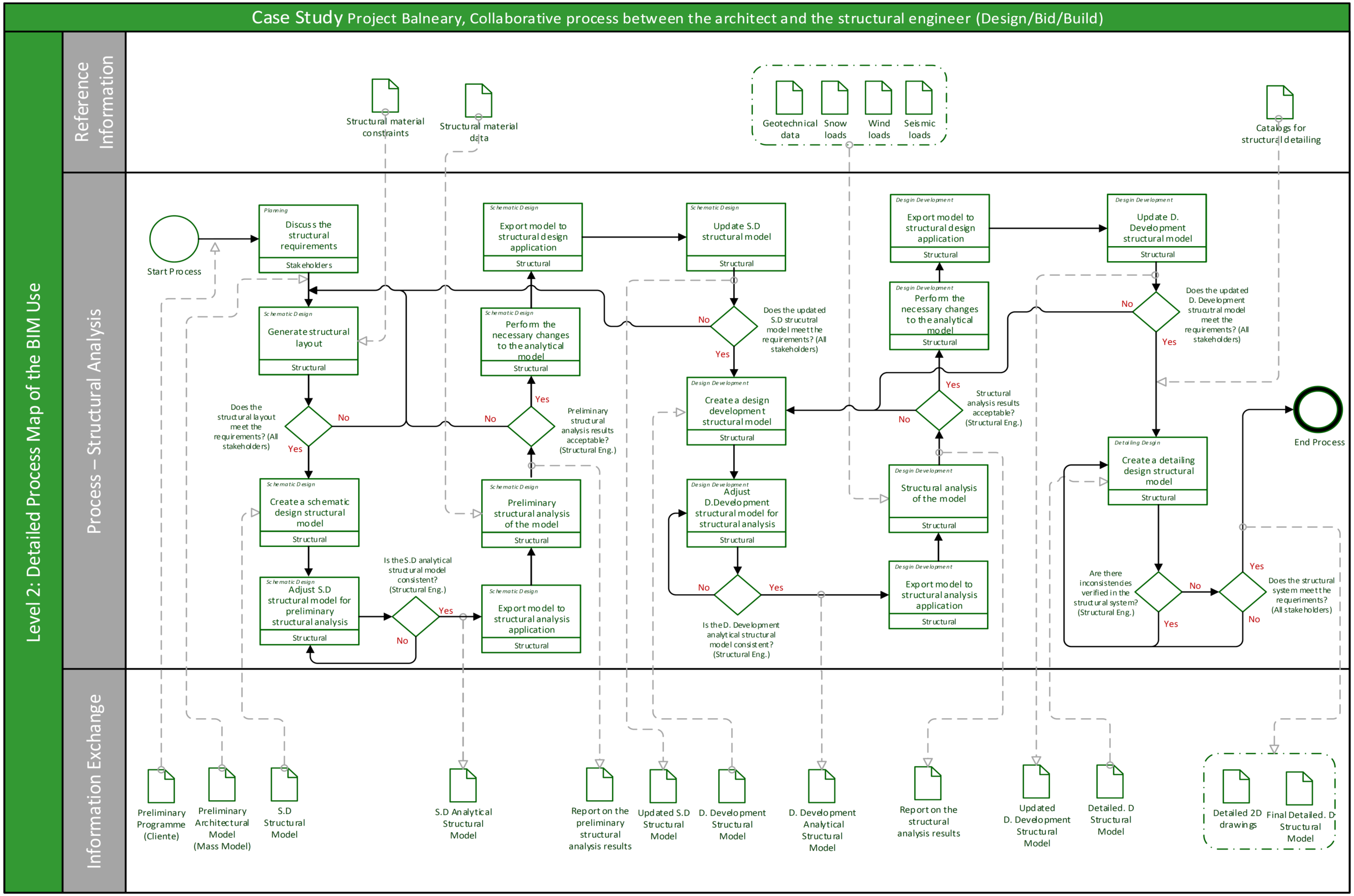


Figure 4.10 – Detailed BIM Process Map (Level 2) – “Structural Analysis” BIM use, case study.

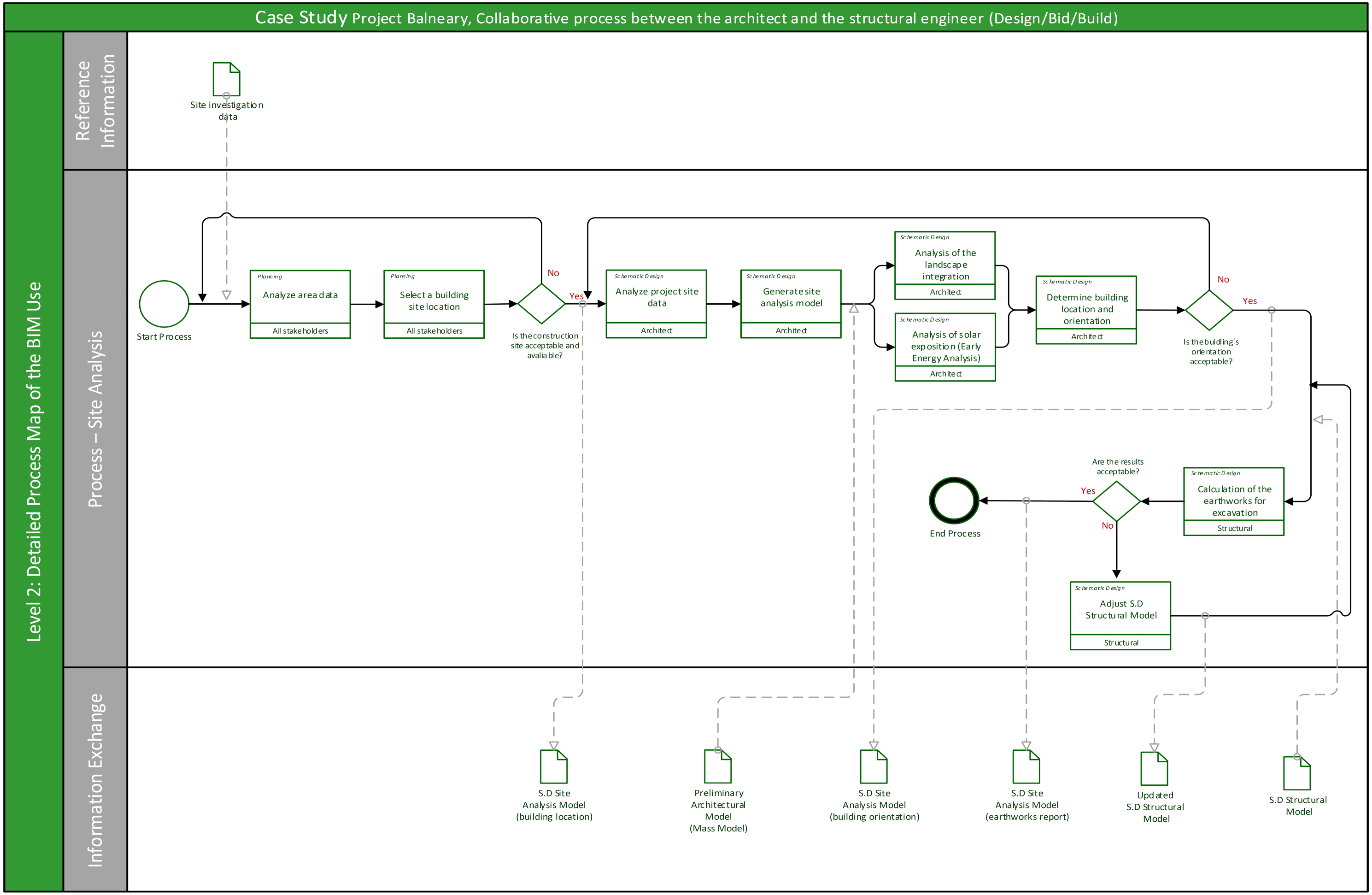


Figure 4.11 – Detailed BIM Process Map (Level 2) – "Site Analysis" BIM use, case study.

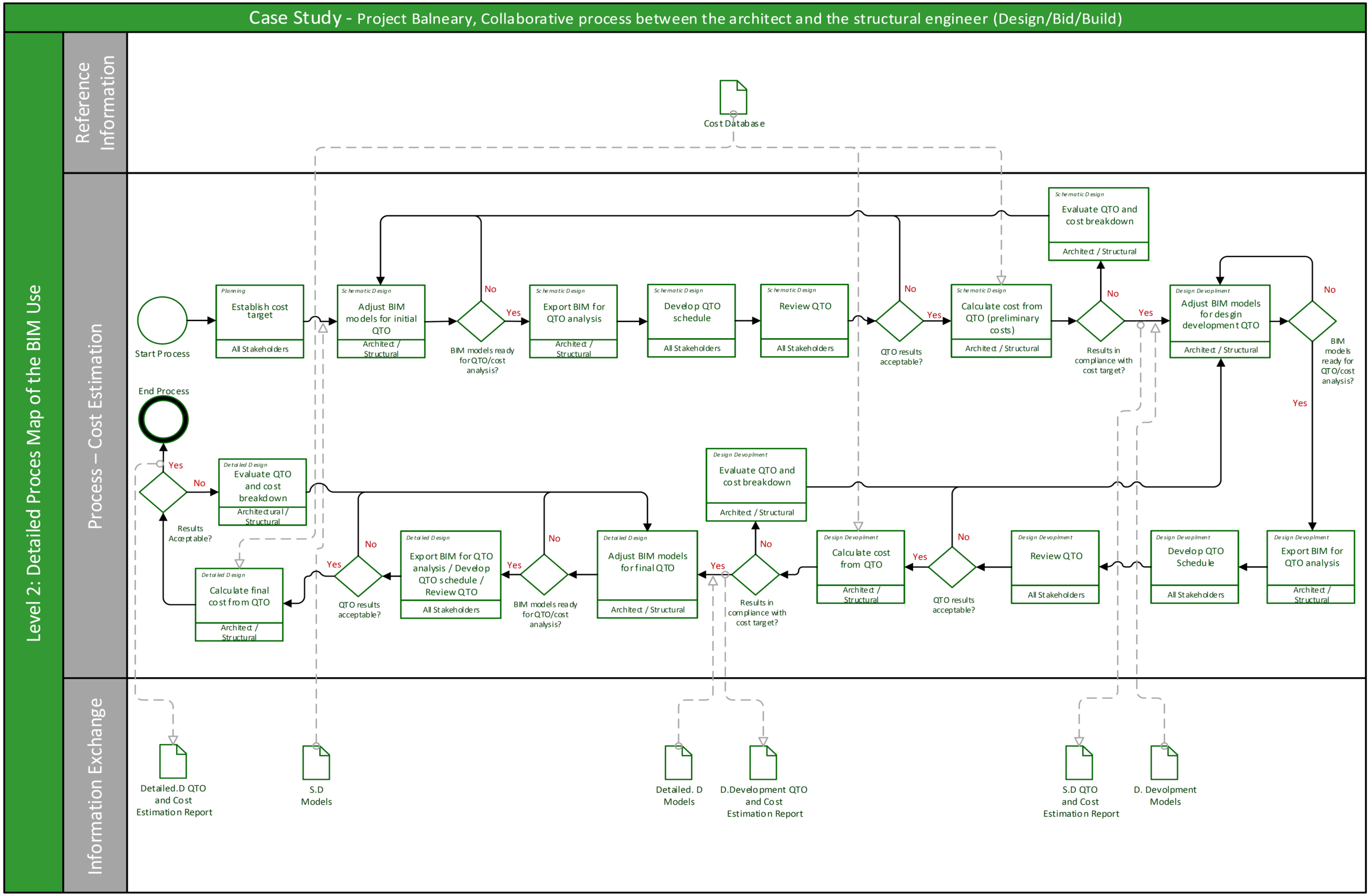


Figure 4.12 – Detailed BIM Process Map (Level 2) – “Cost Estimation” BIM use, case study.

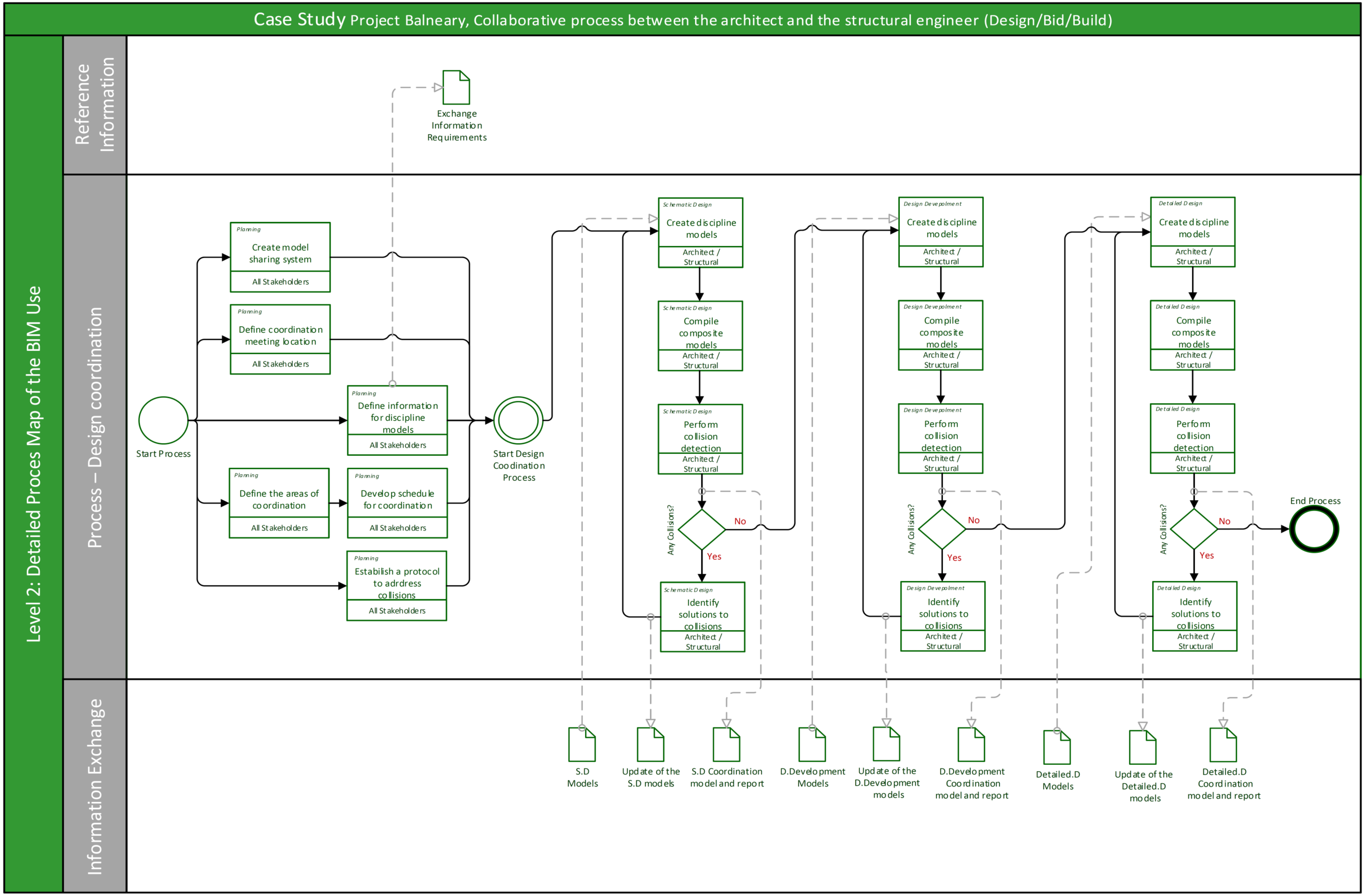


Figure 4.13 – Detailed BIM Process Map (Level 2) – "Design Coordination" BIM use, case study.

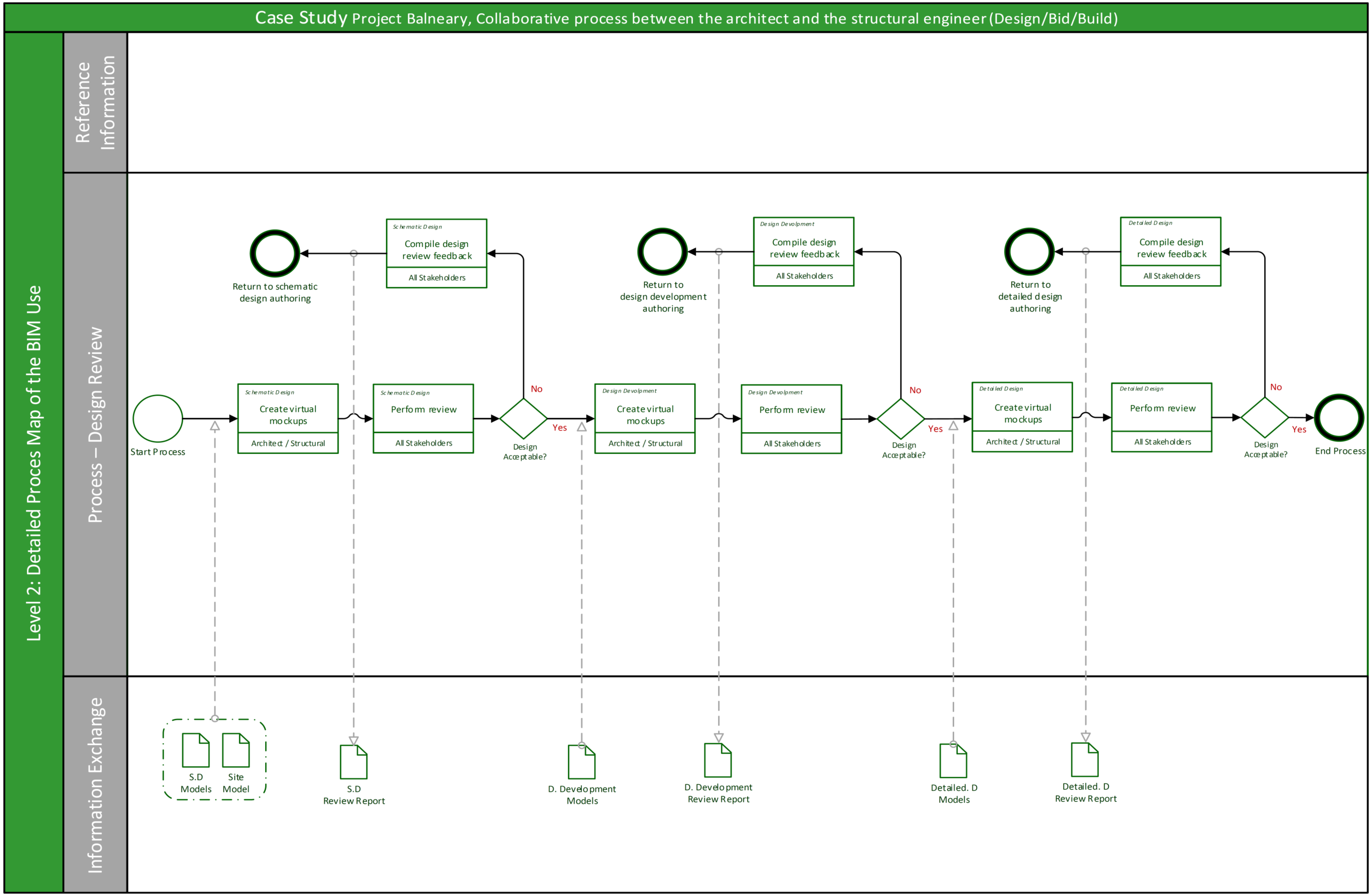


Figure 4.14 – Detailed BIM Process Map (Level 2) – “Design Review” BIM use, case study.

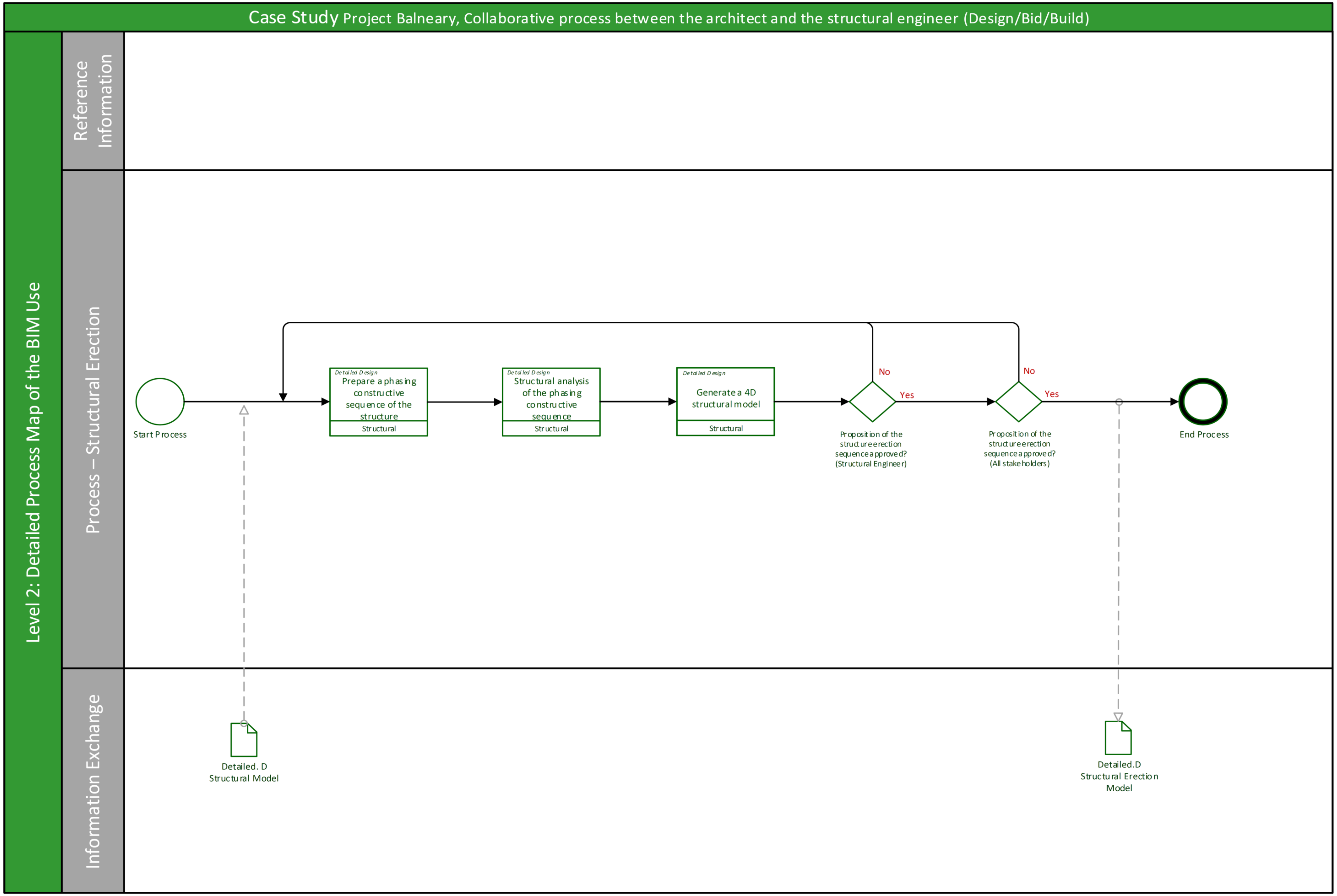


Figure 4.15 – Detailed BIM Process Map (Level 2) – “Structural Erection” BIM use, case study.

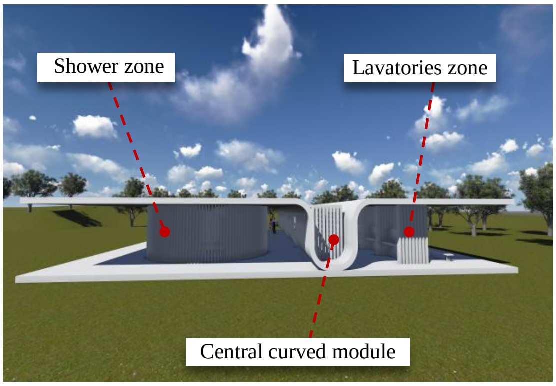
Planning Phase

- **Design Authoring (see figure 4.9)**

The sequence flow of the "design authoring" Detailed BIM Use Process Map, commenced with the influx of the preliminary programme that is individually developed by the client. Acknowledging the client´s requirements, the planning team of the BIM Execution Plan concurred on the necessary BIM models and deliverables to develop throughout the project delivery. As an essential pre-requisite, the site model that incorporates the topography of the construction area was handed over to the architect before commencing the project, where this actor analysed the surroundings and topographical characteristics in order to localise the building´s area of construction (see figure 4.8 and 4.11).

The architect to perform the programme base document and propose his solution to the client developed the preliminary architectural model. Generally this exercise is initially developed with manual sketches and later performed renders of a 3D digital model to enhance the perception of the architecture´s idea. However, recently mass modelling[2] has gained some significance in this phase of design, due to its preliminary analysis that can be done in such an early phase of the project, giving the architect more facts to support his decision making. In this case study it was adopted the first approach, where figure 4.16 presents the proposed rendered 3D model.

a)



b)

Figure 4.16 a) e b) – Preliminary architectural model, case study (developed by CNLL, 2013).

In the design authoring process map it is presented a decision point before commencing the development of the preliminary architectural model, by inquiring if the structural engineer is involved in that respective activity. It is defended by the literature review (Cavieres et al., 2011, Mora et al., 2008, BCA, 2013c) and also concurred during the performed interviews that the incorporation of the consultancy of the structural engineer in the primary stages of the architectural design will enhance the quality of the project. In this case study the structural engineer was only included in the schematic design phase.

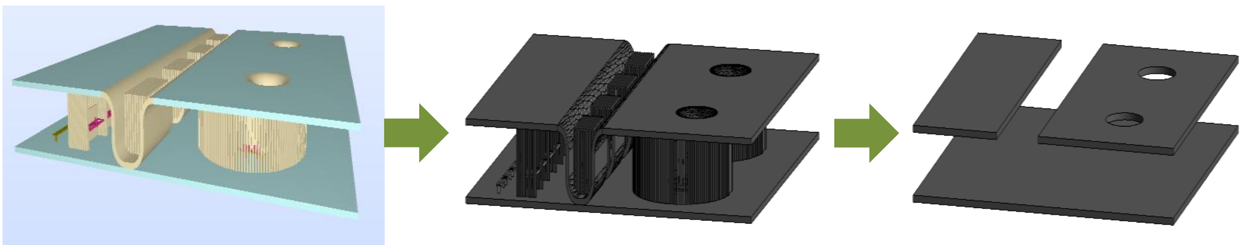
[2] Mass Modelling consists on physically representing a building design through a set of masses, which purely contains geometrical information, such as areas, volumes, geographical location and orientation.

Schematic Design Phase

- **Design Authoring (see figure 4.9)**

Based on the approved preliminary architectural model and site model, deliverables of the planning phase, the architect began the schematic design phase by developing the schematic design architectural BIM model, where it was modelled the information requirements relative to the level of development (LOD) established for that activity (see section 4.4). Thereafter, the architect shared the performed BIM model with the structural engineer in order to initiate the structural preliminary design analysis and the remaining BIM uses of the schematic design phase.

The structural engineer when received the architectural BIM schematic design model, imported the model from the IFC format into a selected native BIM platform (Revit Architecture). Then that actor, created a structural BIM model under the same BIM environment (Revit Structure), where it was referenced the architectural BIM model. Finally it was copied all structural building elements (load-bearing and non-load-bearing), sharing with architectural BIM model the copied objects, where now the responsibility of those objects was granted to the structural engineer (see section 4.6.3). Figure 4.17 summarizes the workflow followed.



Architectural BIM Schematic Design Model in the IFC Format (CNLL, 2013)

Imported Architectural BIM Schematic Model to a native BIM platform to be referenced

Structural model with copied structural building elements from the referenced architectural model

Figure 4.17 – Generation workflow of the structural BIM model from the architectural BIM model.

To finalize the structural BIM model of the schematic design, the structural engineer needed to include the remaining structural building elements, such as columns, foundations, beams, among others structural elements. Hence, the structural engineer required to collaborate with the architect to place the remaining structural elements in order to satisfy both parties. These collaborations were materialized by merging both structural and architectural schematic design BIM models in a central IFC model (see figure 2.34 b)), being exchanged between the involved stakeholders. All structural objects included in the structural BIM model needed to correspond to the information requirements dictated for that model in the schematic design (see section 4.4), in order to address the information requirements of the remaining BIM uses of that project phase. It should be noted, that it was necessary the creation of new parametric classes to include some singular structural building elements, such as the metallic structural columns RHS 250x100x8 which were incorporated in the slatted walls of the architectural design.

It was already predictable that the central curved module generated in the architectural design (see figure 4.18) would draw interoperability issues when sharing BIM models. As expected when imported the schematic architectural BIM model from the IFC format, that central curved module did not possess any semantic information, behaving as a mass object. Therefore, when developing the structural BIM model it was necessary to remodel that structural building element, where in this project phase it was admitted modelling simplifications which did not have great influence on the structural behaviour of the building. Figure 4.19 presents the final schematic design structural BIM model, with all included structural building elements.

When finalized both schematic design BIM models, these must be assured of sufficient quality to be used in the subsequent BIM uses (see section 4.7). If approved these models shall serve the remaining BIM uses of the schematic design phase, which are executed concurrently.

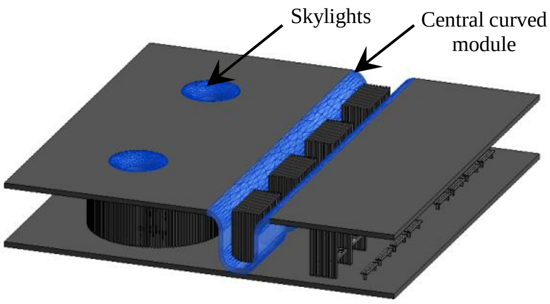


Figure 4.18 – Identification of flawed building elements due to issues of interoperability.

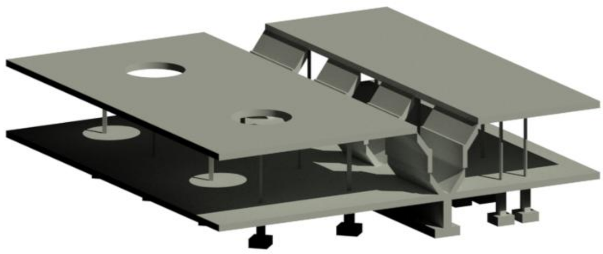


Figure 4.19 – Final schematic design structural BIM model.

- **Structural Analysis (see figure 4.10)**

With the schematic design structural BIM model obtained from the "design authoring" BIM use, it was performed the preliminary structural analysis. In this early design phase the structural engineer examined various solutions of possible structural layouts, in order to congregate the best solution that conjugated with the architectural design.

In order to convey the structural BIM model from the BIM platform (Revit Structure) into a structural calculation software (Robot Structural Analysis) it was necessary to grant consistency to the analytical structural model[3] which, consequently, implied alterations to the geometric structural model[4] (see section 4.6). It should be noted that when modelling a structural building element in a structural BIM platform, such as Revit Structure the geometric and analytical structural model are introduced concurrently. However when interconnecting with a structural analysis application, only the analytical model shall be issued. In the following illustrations, the left view presents the geometric structural model and the right presents the analytical structural model of the schematic design phase.

[3] Analytical structural model is a simplified 3D model that represents the characteristics of a structural geometric model, such as is geometry, mechanical material properties, support conditions and structural loads where all together originate an engineering system.
[4] Geometric structural model consists on the presentation of the real 3D model of the structure.

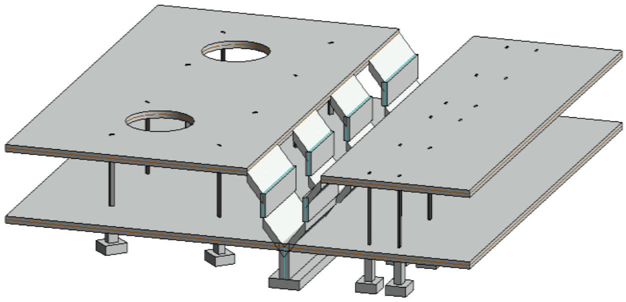


Figure 4.20 – Adjusted geometric structural model for the structural analysis occurred in the schematic design phase.

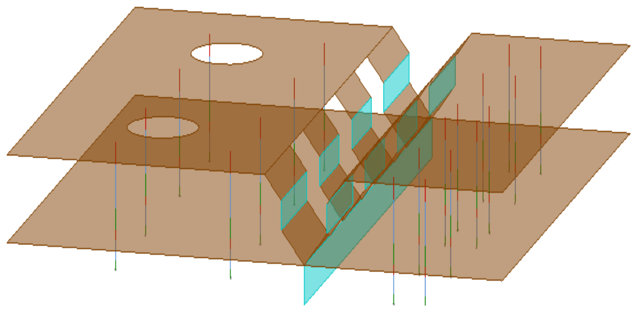


Figure 4.21 – Analytical structural model for the structural analysis occurred in the schematic design phase.

From this case study, it was perceived that the insertion of the mechanical properties and structural loads should be performed within the structural analysis software to avoid possible issues of interoperability. If already inserted before the exportation, these properties have to be confirmed in the structural analysis application.

The report of the preliminary structural analysis suggested some changes to the proposed architectural design, namely the increase of the roof´s and consequently central curved module´s thickness and the alteration of the original positioning of the structural columns located in the lavatories zone, in order to avoid the use of post tensioned tendons in that slab. Furthermore, in this preliminary analysis it was verified the need to employ post tensioned tendons on the roof of the shower zone.

This BIM use and the "design review" BIM use (see figure 4.14) occurred in parallel where the diverse structural solutions of this phase were discussed with the architect by virtually studying the conjugation of the updated structural BIM model with the architectural BIM model, where the "design coordination" BIM use (see figure 4.13) was also implemented to verify the compatibility among the BIM models. This collaboration among these two actors occurred in the work in progress (WIP) stage (see section 4.5.3), before formally sharing any BIM use deliverable.

- **Cost Estimation (see figure 4.12)**

This BIM use was required by other BIM uses, namely the "structural analysis" and "site analysis" BIM uses as a procedure to support the decision making regarding the economical facet of the possible design hypotheses. The incorporation of this BIM use was essential to rapidly obtain an efficient design solution in the early design stage.

An important deliverable obtained with this BIM use was the alteration of the foundation structural layout, being approved in the "design review" BIM use due to the inherent economic gains.

Design Development Phase

- **Design Authoring (see figure 4.9)**

Acknowledging the obtained deliverables of the schematic design phase and considering the necessary information requirements to insert in the design BIM models of the present phase (see section 4.4), the architect and the structural engineer upgraded the structural/architectural BIM models of the schematic design, where at the end of this BIM use it was achieved the design development architectural BIM model and the design development structural BIM model (see figures 4.22 and 4.23, respectively). During the development of these BIM models, there was cooperation among the stakeholders and informal model sharing, in order to clarify some doubts relative to certain BIM modelling aspects and specific characteristics of the project design that emerged during this BIM use.

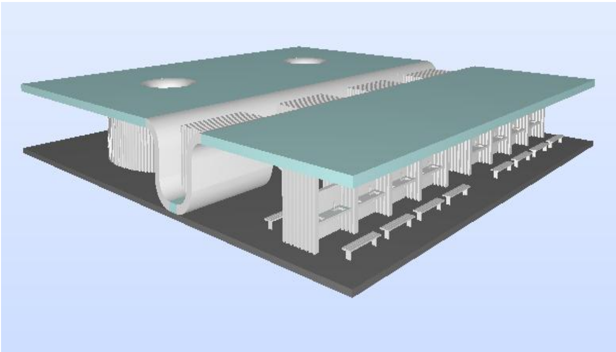


Figure 4.22 – Architectural BIM Design Development Model - IFC Format (CNLL).

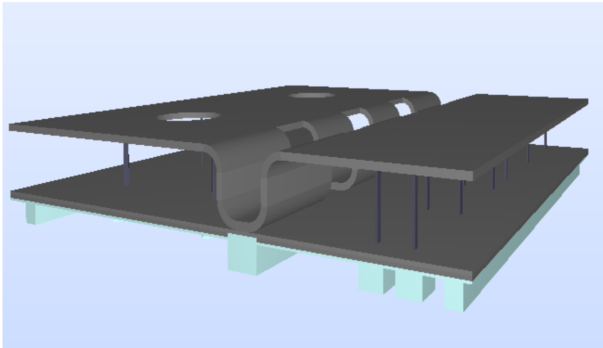


Figure 4.23 – Structural BIM Design Development Model - IFC Format.

It is notable the enhancement verified in the structural BIM model of this project phase when compared to the previous phase (see figures 4.23 and 4.19), which suggests that the core issues related to the structural design was addressed collaboratively with the architect in the schematic design phase. As already described in the previous project phase, when concluded the “design authoring” BIM use, the obtained BIM models must be subjected to quality assurance tests (see section 4.7) in order to guarantee the suitability to perform the succeeding BIM uses.

- **Structural Analysis (see figure 4.10)**

Based on the design development structural BIM model it was performed the “structural analysis” BIM use, that aimed to quantify the structural design considering the reinforcement of the structural concrete elements and the existent metallic connections.

The workflow followed by the structural engineer in developing the structural design analysis commenced with the preparation of the structural BIM model for its exportation to the structural analysis software. It was only selected the load-bearing structural building elements, in which were performed few adjustments to certify the consistency of the analytical structural model. All these modifications were materialized in a secondary structural BIM model, in order to effectively convey the structural model to the structural analysis application without impairing the remaining BIM uses of the present project phase.

One of the main constraints verified in this operation was the central curved module which did not contain an analytical model, being necessary to simulate with precision its curvature by applying a set of laminar structural elements that incorporated an analytical model (i.e. inclined slabs and vertical walls). Each inclined slab was modelled by employing a reference plan that detained the respective calculated inclination. It should be noted that the established solution of modelling is consistent with the BIM platform used (Revit Structure), thus when using a different BIM platform this solution should be revised its suitability considering the characteristics of that software. Figure 4.24 illustrates the described workflow of the case study regarding the preparation of the structural BIM model when exported to a structural analysis application during this project phase.

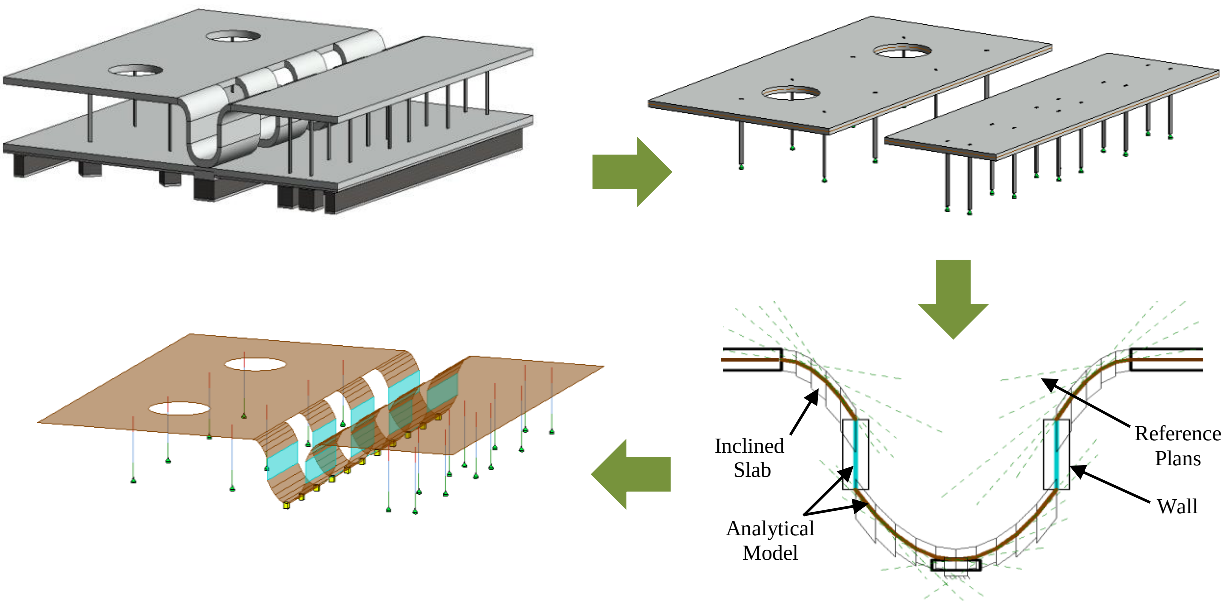


Figure 4.24 - Preparation workflow of the design development structural BIM model to be exported to a structural analysis application.

When prepared the analytical model it was exported to the structural analysis software, being then performed the respective structural analysis. All structural characteristics were defined within the structural analysis application, such as loads, mechanical material properties and support conditions (geotechnical data), in order to avoid interoperability issues.

As already verified in the schematic design phase, the initial results indicated that the roof of the shower zone needed the employment of post tensioned tendons. Numerous analyses and several approaches regarding the distribution of the tendons were studied, until obtaining the most adequate. This solution incorporated the usage of 48 post tensioned tendons where at the extremity of the roof, several voids within the slab were employed with the intent to lower its self-weight. Figure 4.25 illustrates the vertical deformation, being considered the service limit sate (SLS) and the equivalent load of the post tensioned tendons. In that figure the distribution of the tendons and the layout of the hollow slab are perceptible, where in this last an equivalent slab was used to simulate its expected structural behaviour. Figure 4.26 demonstrates the superior and inferior required reinforcement area along the x-axis, considering the ultimate limit state (ULS). Other structural calculations were performed relative to the steel connections and security checks regarding the punching shear capacity of the roof slabs.

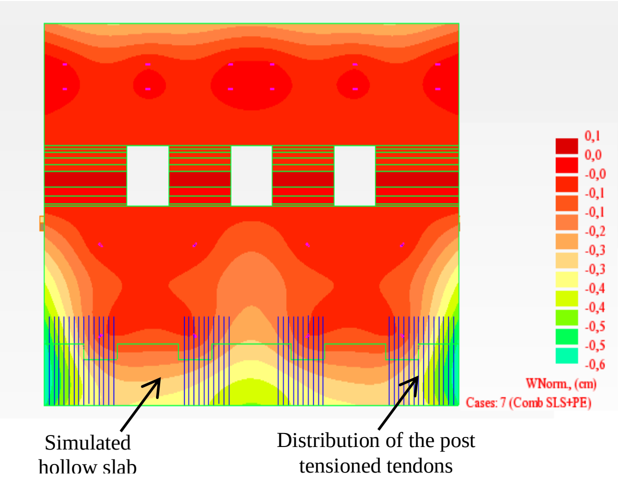


Figure 4.25 – Vertical deformation analysis - (SLS + Post Tensioning)

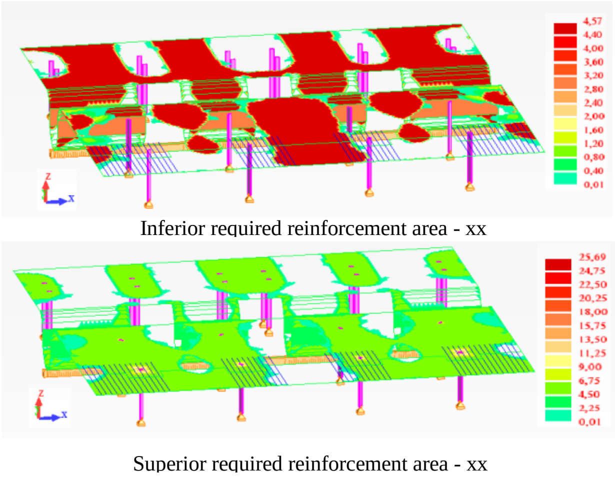


Figure 4.26 – Required reinforcement area along the x-axis - (ULS).

The main results which had interest to be shared with the architect, was the localization of the active and passive anchorages of the post tensioned tendons. This information was contemplated in the deliverable of this BIM use, being further discussed with the architect in the “design review” BIM use by analysing the possible solutions through the structural and architectural BIM models, judging their aesthetic and cost impacts on the architectural design.

- **Design Coordination (see figure 4.13)**

During the development of the BIM uses of this project phase, the “design coordination” BIM use was fundamental to establish a more productive workflow, by detecting minor incongruities between the structural and architectural BIM models of this phase. The architect was able to notify the structural engineer, still in the early stage of this project phase, optimizing his workflow regarding the “structural analysis” and “cost estimation” BIM uses. Section 4.5.4.2 indicates how the notification procedure was conveyed.

Detailed Design Phase

- **Design Authoring (see figure 4.9)**

In the detailed design phase, the “design authoring” BIM use had the objective to prepare the final design architectural and structural BIM models. Once again for this procedure, all obtained deliverables from the previous project phase and the necessary information requirements to deliver for the successive BIM uses (see section 4.4) were acknowledged. It should be noted, that in this final design phase, the architect and structural engineer cooperated in order to develop the final design BIM models that acknowledged the vital information so that the general contractor in the bidding phase of the DBB contractual agreement possessed the sufficient characteristics to develop his proposal.

Regarding the detailed design structural BIM model and according to the stipulated information requirements it was performed the structural detailing of the load-bearing and non-load-bearing structural building elements, based on the final results of the structural analysis performed in the design development phase. The following illustrations present some images retrieved from the detailed design structural BIM model.

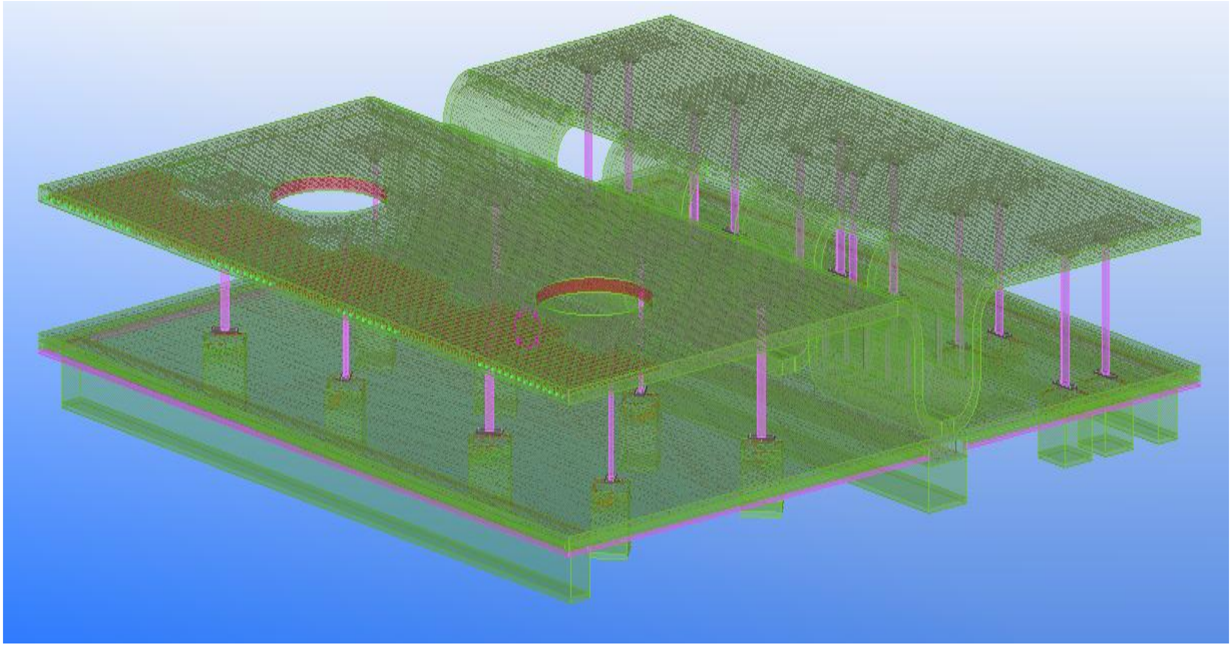


Figure 4.27 – Design Detailed Structural BIM Model.

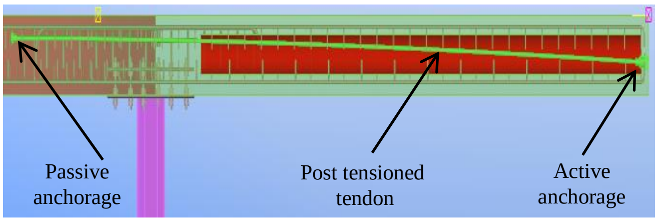


Figure 4.28 – Tracing of the post-tension tendons

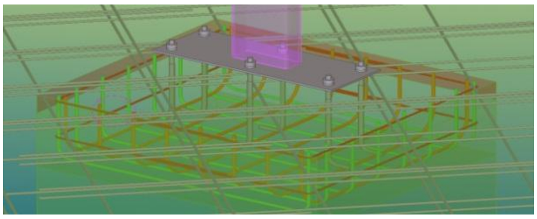


Figure 4.29 – Footing reinforcement & detail of a metallic connection.

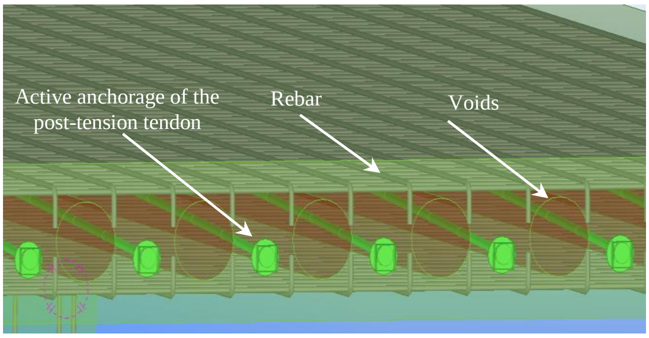


Figure 4.30 – Detailing of the post-tension tendons & voids of the slab.

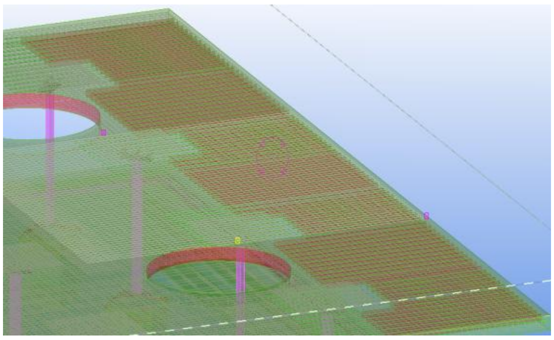


Figure 4.31- Outline of the hollow slab & reinforcement of the structural concrete.

- **Structural Analysis (see figure 4.10)**

Based on the detailed design structural BIM model, in this BIM use the structural engineer verified if the performed structural detailing complies with the constructive criteria established in the national regulations. Furthermore, the occurrence of conflicts between the rebar of the performed structural BIM model was verified, where only the significant conflicts were addressed.

- **Cost Estimation (see figure 4.12)**

The “cost estimation” BIM use displays an important role in this final design phase, by retrieving the final QTO analysis of both design models. Regarding the structural BIM model, all rebar elements of the structural reinforcement concrete building components and metallic steel connections were measured automatically.

- **Design review (see figure 4.14)**

To finalize the detailed design phase the structural engineer and the architect reviewed the final design BIM models and its information, by developing the final quality assurance tests with the intent to share these models in the bidding phase.

4.4. Study of the information exchange requirements (Stage 3)

4.4.1. General considerations

This stage of the BEP framework aims to present a method which quantifies the information exchanges (IE) among the BIM uses that prevail throughout the project delivery, in which are documented in the BIM Overview Process Map (level 1). The assessment of each information exchange should only commence once completed the BIM Overview Process Map and Detailed BIM Use Process Maps (Stage 2 of this BEP framework), where it is illustrated the “what”, “when”, “for whom” and “why” of each information exchange.

Throughout the collaborative BIM project delivery the information exchanges can be categorized in two groups. The first group of information exchanges occur in the transition between project phases (see figure 4.32 – red region), where the BIM uses of the forthcoming project phase are based on the deliverables accomplished by the BIM uses of the prior phase. The information that is generally exchanged refers to technical aspects of the project, such as approved design solutions which need to be contemplated in the BIM uses of the subsequent project phase (e.g. as already mentioned in the case study the “design authoring” BIM use of the detailed design phase had to acknowledge the approved results of the “structural analysis” BIM use established in the design development phase – see figure 4.32). The second category of information exchanges are verified within a project phase (see figure 4.32 – blue region), where it is established dependencies between BIM uses that are based on information exchange requirements that need to occur in order to develop all dependent BIM uses of that phase (e.g. as stated in the case study, the development of the “structural analysis” BIM use of the design development phase requires the BIM structural model that is performed by the “design authoring” BIM use of that same project phase – see figure 4.32).

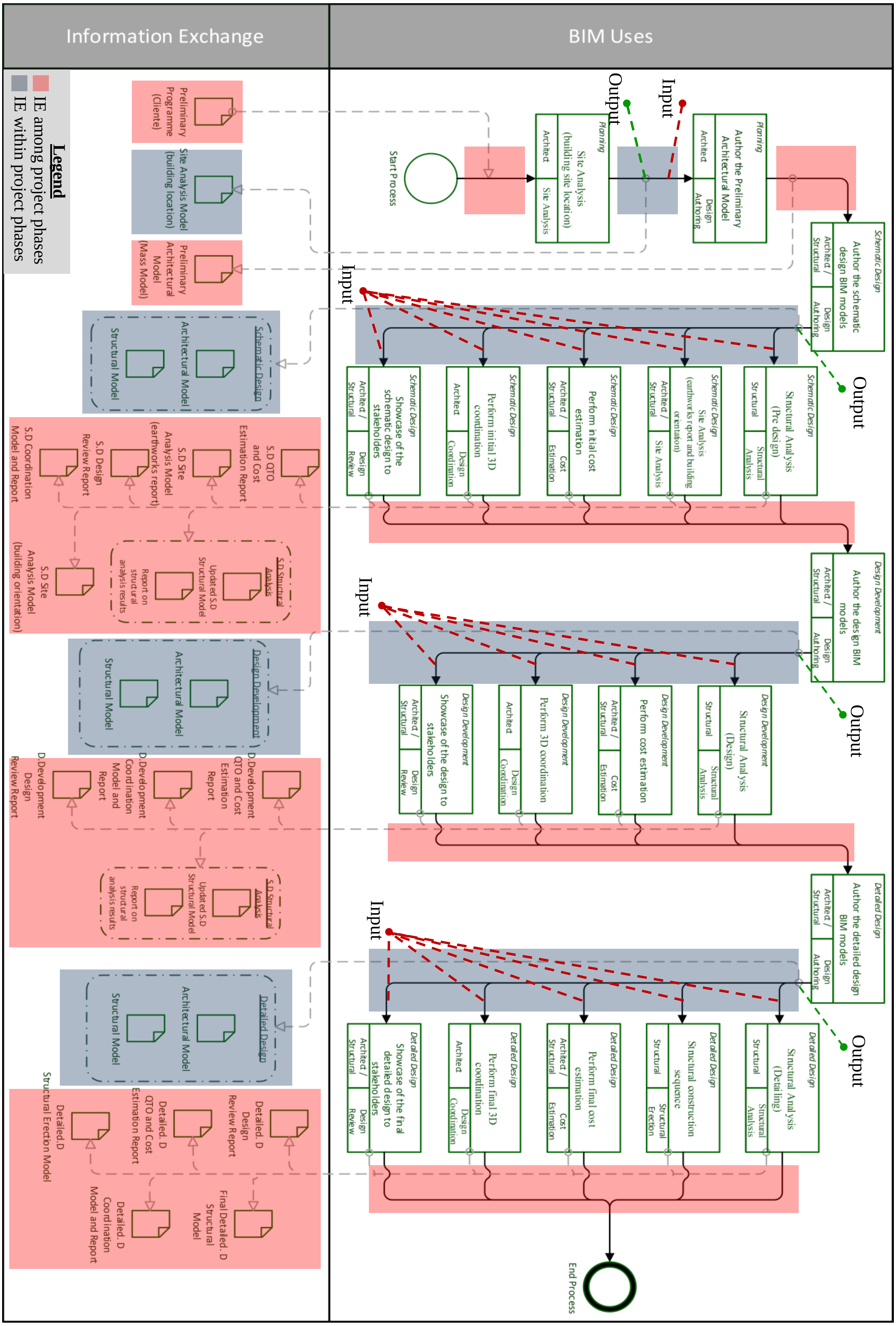


Figure 4.32 – Categorization of the information exchanges documented throughout the BIM Overview Process Map, with indication output/input information flows.

In summary, the method presented in this BEP framework addresses the information exchange requirements that are established during each project phase, by defining the minimum information necessary in each building element of the BIM models to capacitate the realization of the each BIM use. Once determined, that information will be quantified and graded accordingly to a BIM classification system. Thenceforth, when each stakeholder is editing or appending information inherent in a BIM model it shall be acknowledged the level of rigor (information and modelling requirements) to achieve, in order to serve as an adequate output deliverable to be exchanged when initiating the remaining subsequent BIM uses (see figure 4.32). This procedure is composed by four essential steps that are described in the subsequent sections. The produced results of this procedure are materialized in the BIM Information Exchange Requirements Worksheet (see table 4.6), which is compiled throughout these various steps:

- Step 1: Selection of a model building element structure;
- Step 2: Minimum information requirements of the selected BIM uses;
- Step 3: Minimum information requirements classification according to the LOD specification;
- Step 4: Definition of the information exchange requirements.

In appendix 9 it is presented the established the BIM Information Exchange Requirements Worksheets, regarding each project stage of the performed case study.

4.4.2. Selection of a model building element structure

The procedure of formulating the information exchange requirements within each project phase commences with selecting a model building element structure, which has the objective of representing all building elements intrinsic to the BIM model. The selected structure must be transversal and comprehensive to all construction disciplines, in order to embrace all BIM building elements. The OmniClass, CSI Uniformats II or Talo 2000 construction classification systems (see section 2.2.6) can be adopted by the planning team of the BEP as a model building element structure.

Case Study – (Stage 3, model building element structure)

In the performed case study, it was adopted the Talo 2000 construction classification system to represent the building elements incorporated in the developed BIM models. The main reason that lead to the adoption of this classification system is due to the fact that the COBIM 2012, being the main BIM standard followed in this project regarding modelling features, entails this model building element structure to specify its information and modelling requirements. As a less significant reason it was concluded that the Talo 2000 system was more accessible to identify building elements when compared to the OmniClass and CSI Uniformats II. Equally important, with the Talo 2000 system there is a clear understanding in the division of the structural building elements from the architectural building elements, being essential in the definition of the stakeholder´s responsibility regarding on the elaboration of each object throughout the project.

It should be noted, that in highly disciplined projects (e.g. hospital, industrial factories), this BEP framework recommends the adoption of the OmniClass or CSI Uniformats II, due to their more comprehensive model building element structure. In appendix 9 it is visible in the Information Exchange Requirements Worksheets of the case study the outline of the model building element structure adopted, where it is also included the indication of the selected elements and discipline model inclusion (structural/architectural building element).

4.4.3. Minimum information requirements of the selected BIM uses

The definition of the minimum information requirements of the selected BIM uses, in terms of the needed information and modelling features, should initiate by the stakeholders whom are responsible for their execution. Each liable stakeholder(s) should revise the already developed Detailed BIM Use Process Map (level 2) of each BIM use, with the intent to identify and comprehend each information exchange input verified throughout the sequencing of the activities intrinsic in each project phase. Based on the set of information exchange inputs in each phase of the project, the stakeholder will list the minimum required information and the necessary modelling features of each building element to execute that BIM use, acknowledging the projects characteristics, in terms of the client´s requirements, project´s objectives and the specifications of the national regulations. Simplistically, the listed minimum required information and necessary modelling features of the building elements developed by the responsible stakeholder of each BIM use, characterize the minimum information requirements of that BIM use relative to a specific project phase.

When listed the minimum information requirements (information and modelling) by each responsible stakeholder, those results should be cross-referenced with the specified BIM information and modelling requirements of the COBIM 2012 V1.0. In addition the BIM modelling guidelines of the Singapore BIM Guide 2013 Version 2 can also be referenced as an additional framework. With this analysis, the responsible stakeholders can confirm the delineated minimum information requirements with BIM standard references.

Case Study – (Stage 3, minimum information requirements)

A practical exemplification of the minimum information requirements that were established in the case study can be visible in the “structural analysis” BIM use, where in the schematic design it was admitted a modelling simplification regarding the central curved module (see figure 4.19). By determining this minimum information requirement it contributed to a simplification in terms of modelling that increased the productivity of the structural engineer in that project phase while executing that BIM use.

4.4.4. Minimum information requirements classification according to the LOD specification

Once, each liable stakeholder has documented for their BIM use(s) the minimum information requirements regarding the building elements of the BIM models, that information will be interpreted and appointed a grade accordingly to a BIM classification system. This BIM classification system enables the involved stakeholders to evaluate the appointed minimum information requirements regarding the level of modelling rigor and information detail of each building element.

Presently, there are various BIM classification systems addressed in national BIM standards. In this BEP framework it is adopted the Level of Development (LOD) Specification developed by the AIA and BIMFORUM (USA) organizations, being agreed in the performed interviews with the AEC professionals as the most fitted classification system available in the present market, in terms of BIM modelling and information detailing (see section 2.2.3.6. and 2.2.5).

The procedure of grading each defined minimum information requirement relative to a building element for a specific BIM use should commence by interpreting the definitions of each LOD category (see appendix 1). Thereafter, the LOD Specification should be consulted regarding the building element under analysis, where by correlating the already defined minimum information requirements of that element with the categorization patent in the LOD specification it is possible to grade the minimum information requirements under a LOD classification. This procedure must be amplified to all building elements and to each BIM use.

The following recommendations stated in this BEP framework aim to empower project teams to maximize the usage of the LOD classification system in the development of their projects. Accordingly to James Vandezande (member of the AIA and HOK), refers that the LOD classification should be looked at as a dictionary and as BIM collaborative language. When authoring BIM models the LOD Specification serves as a dictionary indicating exactly the information and modelling requirements to achieve a delineated LOD category, impeding in this way unnecessary modelling efforts. Therefore, an AEC firm can scope their modelling efforts by analysing the attributed LODs throughout the phases, which, consequently, assists in the internal work planning scheduling of that AEC firm agenda. When collaborating with other stakeholders in BIM, the LOD specification facilitates project team members to communicate regarding the technical aspects of the BIM models. In addition, the attributed LODs inherent to each BIM use can be programmed in the contractual agreement, formally obligating stakeholders to accomplish the stipulated minimum information requirements when sharing, thus defending the best interests of the project´s quality.

As a last conformity check regarding the definition of the minimum information requirements of each building element regarding a specific BIM use and project phase, the AIA Document G202 in which is dictated the authorized BIM uses considering the attributed LOD should be consulted to verify if the stipulated LODs relevant to a specific BIM use are sufficient to capacitate its execution. This conformation check should be performed in all BIM uses of the project delivery.

To summarize, up to now the establishment of the minimum information requirements of each building element inherent in each BIM use followed the subsequent sequence:

1- Manual definition of the minimum information and modelling requirements of each BIM use considering the building elements, by the respective liable author stakeholder(s);

2- Analogy with the information and modelling requirements specified in the guidelines of the COBIM V1.0 2012 national BIM standard. Singapore BIM Guideline V2.0 2013 can be considered if necessary;

3- Grading of the stipulated minimum information requirements accordingly to the LOD Specification 2013;

4- Final ascertainment regarding the attributed LODs relative do the BIM use with the authorized uses concerning the attributed model content, delineated in the AIA document G202.

Case Study – (Stage 3, minimum information requirements – LOD attribution)

In the BIM Information Exchange Requirements Worksheets of the performed case study presented in appendix 9, illustrates the LOD attribution and respective author member for the development of each building element included in the BIM models, serving as the minimum required information input to establish each BIM use at a specific project phase. This description is presented under the colour red in the Information Exchange Requirements Worksheets (see table 4.6).

The following figure presents a graph that illustrates the evolution of the average LOD attribution considering the BIM uses that are implemented in all design phases and require information input to be executed.

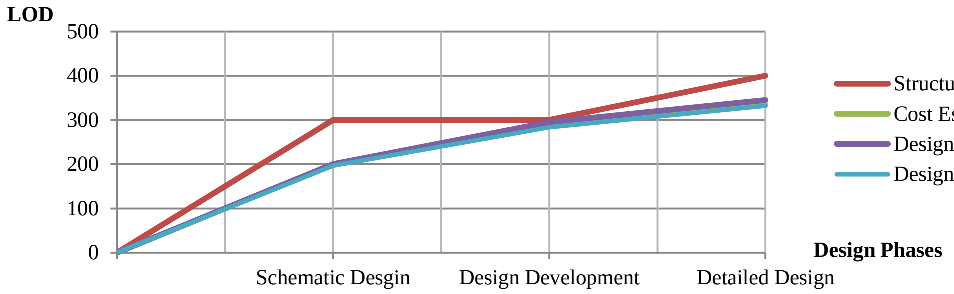


Figure 4.33 – Evolution of the average LOD attribution throughout the project phases regarding the repeated BIM uses in each phase.

From figure 4.33 it is perceptible that the “structural analysis” BIM use acquired in average more information requirements in relation to the remaining BIM uses. In this case study, having the opportunity to receive the architectural BIM model, it was possible in the schematic design phase to develop structural analyses assessing various possible structural solutions that conjugated with the architectural design, until obtaining the most optimized solution that satisfied both parties. This approach implied more BIM modelling effort from the structural engineer in the schematic design phase. However, having determined the main decisions in that early stage the subsequent phases revealed to be more productive, as predicated by Macleamy. It is observable that during the design development project phase it was needless the inclusion of additional information for the development of this BIM use. This approach has similarities with the statements delivered in the performed interviews by Structural Engineer José Carlos Lino where it was argued that a structural engineer with the capabilities of BIM can in early design phases collaborate with the architectural team by analysing, cooperatively, various design solutions, where the architect can benefit with the parallel structural engineering knowledge when crafting the architectural design.

The remaining BIM uses of the case study followed a gradual maturation regarding the average LOD attribution throughout the phases of design, presenting in average similar information requirements for their execution.

4.4.5. Definition of the information exchange requirements

Up to now it has been determined the minimum information input that is required to develop the BIM uses throughout the phases of the project. In this section it is presented a method of establishing the information output that is needed to complete the information exchange requirements of each BIM use regarding a specific project phase (see figure 4.32).

All information exchange requirements are incorporated in the BIM Information Exchange Requirements Worksheet (see table 4.6). This worksheet is defined by three parts, where the first indicates the building elements that are integrated in the BIM models, additionally referring if it is an architectural, structural and/or MEP component. Furthermore its source is referenced, i.e. if it originates from an internal/external database or if it is created specifically for the project. The second part characterizes the BIM uses, by illustrating whether the BIM use establishes (output) or requires (input) information. In addition other information regarding the project phase, necessary BIM models, native format and sharing format of the developed BIM models are also evidenced. Finally, the third part presents for each building element the LOD to accomplish and the stakeholder liable for its assembly. The format of the worksheet was based on a similar worksheet presented BIM Project Execution Planning Guide Version 2.0 (CIC, 2010).

Table 4.6 - Description of the BIM Information Exchange Requirements worksheet.

BIM INFORMATION EXCHANGE REQUIREMENTS - Worksheet																				
Case Study - Project Balneary																				
BIM USE Title					Design Authoring				Site Analysis						Structural Analysis		Cost Estimation			
Tipe of Information Exchange (Output/Input)					OUTPUT				INPUT						INPUT		INPUT			
Time of Exchange (Planning; SD; D.Development; Detailed. D)					SD				SD						SD		SD			
Disciplinary BIM Models Involved					Arch Model		Struct Model		Site Model		Arch Model		Struct Model		Struct Model		Arch Model		Struct Model	
Model Reciever					RVT 2014		RVT 2013		CAD		RVT 2014		RVT 2013		RVT 2013		RVT 2014		RVT 2013	
Recieve File Format					IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3	
Modeling Standard: COBIM 2012 V1.0	Model Design Features				Info. Requir				Info. Requir						Info. Requir		Info. Requir			
Model Builiding Element Structure - Talo 2000 Classification	Element Included (Yes/No)	Arch Elements (Yes/No)	Struct Element (Yes/No)	Source	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party
12 Building Elements																				
121 Foundations																				
1211 Column Footings	Yes		Yes	Database			300	Struct					200	Struct	300	Struct			200	Struct
1211 Pile Footings																				
1211 Wall Footings	Yes		Yes	Database			300	Struct					200	Struct	300	Struct			200	Struct
1212 Enclosure walls																				
1212 Foundation columns																				
1212 Foundation beams	Yes		Yes	Database			300	Struct					200	Struct	300	Struct			200	Struct
1219 Special foundations																				
122 Ground Floors																				
1221 Ground floor slabs	Yes	Yes	Yes	Database	200	Arch	300	Struct			100	Arch	200	Struct	300	Struct			200	Struct
1222 Ground floor ducts																				
1222 Ground floor ducts, grates, covers, hatches, etc.																				

Required Information Output

Required Information Input

To determine the required information output to complete the information exchange requirement of a specific project phase, the highest required information input is necessary to be achieved, regarding the immediate dependent BIM use of the project phase (see table 4.6). The "design authoring" BIM use is singular when compared to the remaining BIM uses, being the only dedicated exclusively in accreting information and modelling features to the BIM models with the aim to match the requirements (inputs) delineated by the remaining BIM uses of that project phase.

In order to obtain a more efficient and productive project delivery the stakeholders should share one another´s BIM objects, thereby avoiding duplication of modelling effort regarding the development of common building elements (e.g. the building element floor of the architectural model should reference the respective building element slab of the structural model, averting the creation of the same object on both models, which can lead to faulty QTO results). Equally important, the definition of the building element author should be well defined in the "design authoring" BIM use, being stipulated in the BIM Information Exchange Requirements Worksheet.

Case Study – (Stage 3, definition of the information exchange requirements)

Appendix 9 presents the BIM Information Exchange Requirements Worksheets relevant to each project phase of the performed case study, being stipulated the required output and input information regarding each building element. The following figure presents the average LOD attribution of the building elements grouped under the categories of the TALO 2000 construction classification system, regarding the required information output to be performed by the "design authoring" BIM use throughout the project phases.

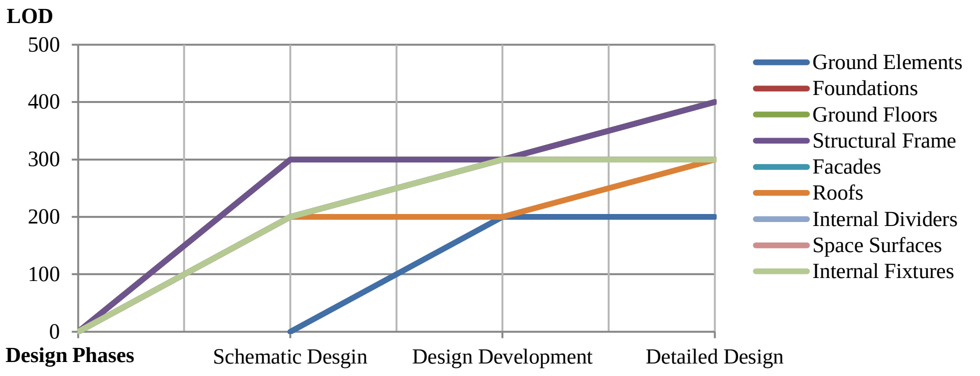


Figure 4.34 – Evolution of the average LOD attribution throughout the project phases regarding the building elements clustered under the groups defined by the Talo 2000 system.

It is clearly observable in figure 4.34, due to the heterogeneity evidenced in the evolution of the required information output during the project phases that in each building element category the LOD attribution is not established by phase, but yet by necessity. Therefore there is not a strict correspondence between the LODs an design phases, giving flexibility to optimize the modelling effort throughout the project delivery. This observation is also defended by the LOD Specification 2013.

Figure 4.35 illustrates the average evolution of the required information output considering the shared structural elements inherent in both architectural and structural BIM models. With this analysis, the aim is to demonstrate the gains obtained by the architectural team by sharing their BIM model with the structural engineer team and vice-versa. Not only was it not necessary for the architectural team to author the mutual structural elements, it was additionally possible to achieve in the architectural model more detailed structural building elements than the required (see figure 4.35, where the green region represents the increment of detail considering the minimum required information).

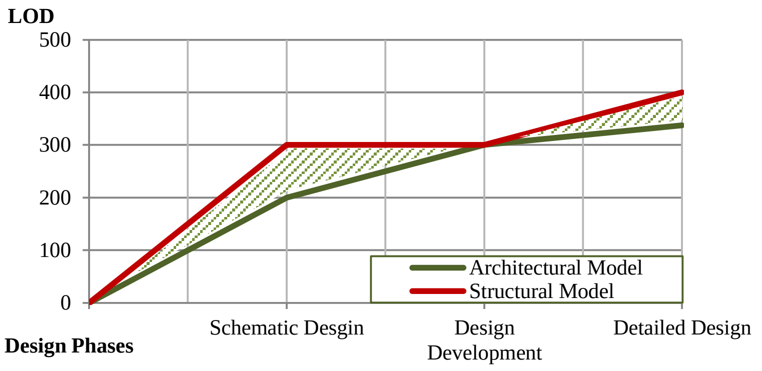


Figure 4.35 – Evolution of the average LOD attribution of the shared structural objects between the architectural and structural model.

Figure 4.36 demonstrates a practical example encountered during the case study, where only with a high LOD attribution delivered by the structural engineer would it had been possible to verify by the architectural team in an earlier phase of the project, the inconsistencies between the steel connections of the structural model with the architectural design.

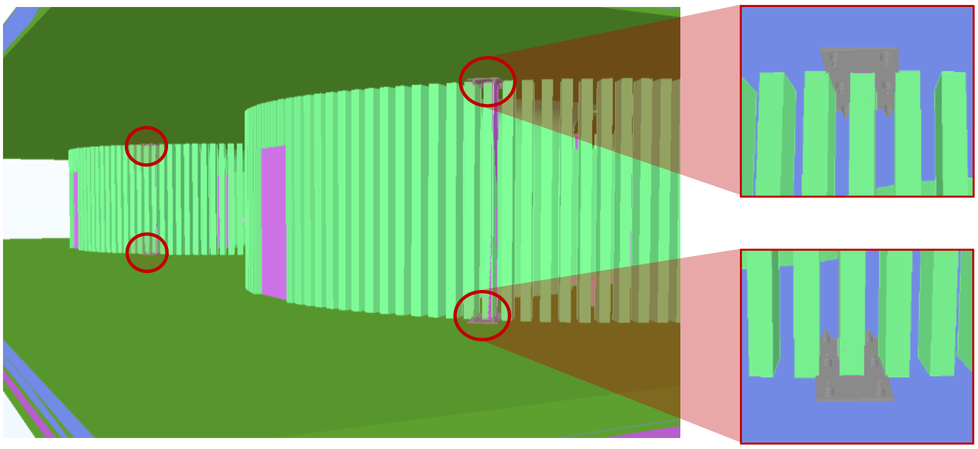


Figure 4.36 – Compatibility in a central IFC model, between a shared architectural and structural BIM models with a high LODs attributions.

It should be noted, that in this case study it was not stipulated information requirements to achieve at the completion of the design phase, in order to deliver the required information for the bidding phase of the DBB approach.

4.5. Study of the BIM data management (Stage 4)

4.5.1. General considerations

During the antecedent stages of this BEP framework it has been indicated on how to assemble and define the information workflow throughout the collaborative project delivery, capacitating a project team on outlining the when, what, who and why of each information exchange. In this stage of the BEP framework a set of recommendations on how a project team should manage the extensive information that is produced throughout the BIM project delivery and on how the collaboration should be undertaken with the BIM methodology are proposed.

In succinct, the suggestions presented throughout the following sections intend to embrace aspects related on how to manage the information of a project when implementing a BIM collaborative environment, being addressed the required subdivision of the BIM models and the organisation structure of the shared virtual platform. Equally important, it is proposed a method which defines the collaborative BIM working procedure for efficient data sharing during the lifecycle of a building that coincides with the recommended subdivision of the BIM models and organization structure of the shared virtual platform. To finalize it is addressed the required technological infrastructure to support the defined collaborative BIM working process. All proposals are adapted from the principles outlined in BS1192:2007 presented in the AEC (UK) BIM Protocol v2.0 2012 and from the Singapore BIM Guideline v2.0 2013.

4.5.2. Data segregation

As conferred in the performed interviews with the AEC professionals the common AEC community presently does not possess basis, in terms of contractual framework or culture to perform under single holistic BIM model the development of a complete multidisciplinary project. Other reasons namely inadequate hardware and software contribute as barriers to the implementation of the central BIM model. Therefore, the adoption of BIM shall be done by segregating the central BIM model into partial BIM models, that when linked up represent the totality of the project under development.

The AEC (UK) BIM Protocol v2.0 2012 suggests that no more than one building should be modelled in a single model and each partial model should contain data from one discipline or per stakeholder, where generally that single model is designated by its discipline (e.g. structural BIM model, architectural BIM model, among others). The MEP BIM model is an exception where customarily more than one building system is covered (e.g. plumbing, sanitary, pluvial, electrical, and mechanical). Furthermore, all discipline models should be referenced to one another, in order to promote inter-disciplinary collaboration (AEC-UK, 2012a), where a container model can be created to combine all discipline BIM models. The IFC central model or software that possesses multi-discipline BIM platforms can enable this task.

Case Study – (Stage 4, data segregation)

For the performed case study, the data segregation was established per discipline, being created at several times a container model to merge each single model in order to argue design compatibility issues. All practical projects performed by the students of the curricular unit BIM followed and identical logic to sub-divide the BIM data.

4.5.3. Methodology of the BIM collaborative working procedure

To effectively implement the BIM methodology in the collaborative processes of the project delivery it is imperative to establish a methodology that supports adequately the BIM collaborative working process. This methodology has the aim to avert miss communication and disorganized management of the BIM data.

The Common Data Environment (CDE) approach specified in the BS1192:2007 and presented in the AEC (UK) BIM Protocol V2.0 2012 is recommended by this BEP framework to be followed as the methodology that dictates the data BIM management of the collaborative process (see section 2.2.3.4). As already mentioned in chapter 2, the CDE method is composed by the sequencing of four areas of managing information – work in progress (WIP) area, shared area, published area and archived area. With the adoption of this method there is a process of maturation regarding the development of the information performed in the workflow of each project phase, being this approach defended in several occasion during the established interviews with the AEC professionals in order to obtain projects with additional quality. Furthermore, with the CDE methodology there are more opportunities to assure the quality of the BIM models and produced deliverables (see section 4.7). The CDE approach can be materialized in the BIM collaborative working procedure presented in figure 4.37, being recommended in this BEP framework and also defended in the AEC (UK) BIM Protocol v2.0 2012.

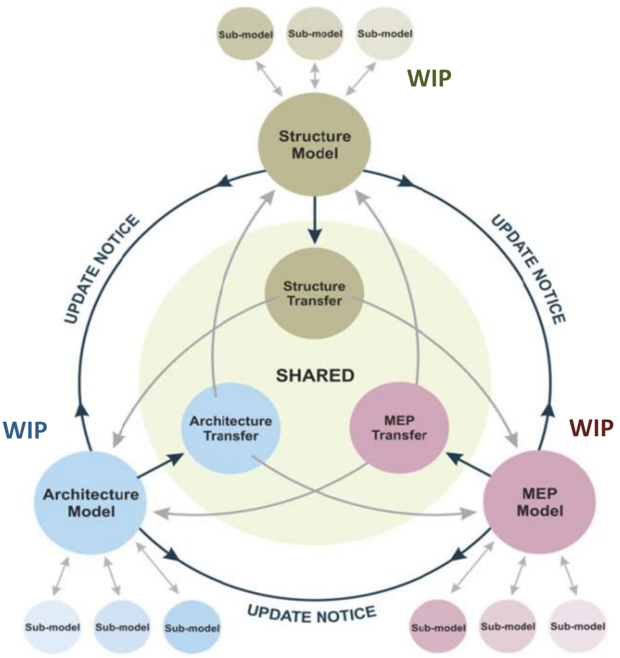


Figure 4.37 – BIM collaborative working method recommended for external firm use, BS119:2007, adapted (AEC-UK, 2012a).

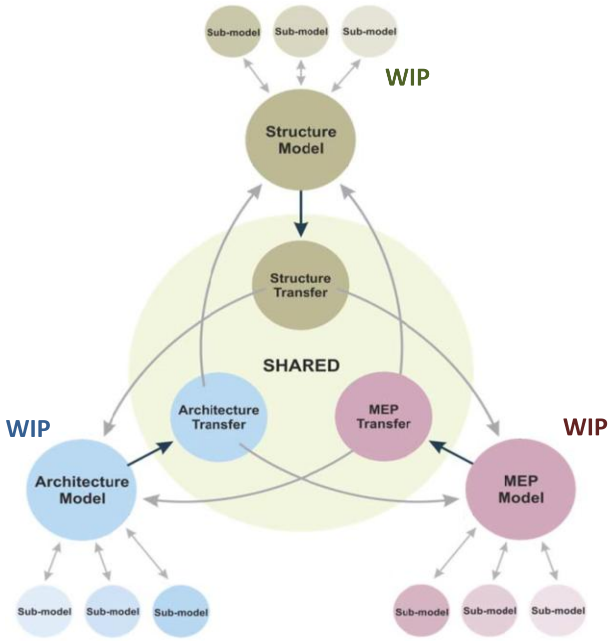


Figure 4.38 – BIM collaborative working method recommended for internal firm use, adapted from (AEC-UK, 2012a).

The BIM collaborative working method presented in figure 4.37 is recommended to be implemented in each project phase, where it is suggested to be employed the following collaborative working procedure:

i- From the commencement to the completion of each BIM use, all produced elements such as BIM models, reports, sheets, created families, CAD drawings, among other are retained in the WIP area of the respective stakeholder. This area is only authorized to the members of a specific discipline team. This private area enables each stakeholder to test various design solutions without affecting the workflows of the other stakeholders;

ii- When various project members are executing the same BIM use (e.g. “design authoring” BIM use) and/or simultaneous BIM uses (see figure 4.32), it is imperative to verify update communications between stakeholders and informal sharing of BIM data, in order to create a productive project delivery, where the stakeholders develop their work based on the latest known information. Accordingly to the COBIM 2012, during the WIP their can de informal sharing of BIM models, where extensive quality assurance assessments are dispensable;

iii- When completed a BIM use the obtained deliverables are transferred to the shared area, being accessible to all involved stakeholders of the project enabling, multidisciplinary, revision. Before formally sharing the resultant BIM data, it is necessary to perfume quality assurance checks to confirm the viability of the obtained deliverables (see section 4.7);

iv- Once revised and validated all BIM data of the shared area it is transferred to the published area, being accessible to be referenced during the project delivery. Once completed the project all BIM data is conveyed to the achieved area.

Figure 4.38 presents a secondary BIM collaborative working procedure that should only be ensued if all disciplines of the project are executed by one single AEC firm. The main difference verified towards the already mentioned BIM collaborative working method is the absence of update notices and sharing of BIM data during the development of the BIM uses, where all these activities are developed directly within a firm.

Case Study – (Stage 4, BIM collaborative working method)

The collaborative process between the architect and structural engineer of the performed case study followed the BIM collaborative working procedure presented in figure 4.37.

As to the projects developed by the students of the performed curricular unit BIM, it was adopted a similar BIM collaborative working procedure presented in figure 4.38.

4.5.4. Technology infrastructure needs

4.5.4.1. Virtual interactive platform

To support the BIM collaborative working process it is essential that a project team possesses a virtual interactive platform in order to exchange efficiently information, with the intent to simulate a Common Data Environment mentioned in section 2.2.3.4. Accordingly to the AEC (UK) BIM Protocol Project BIM Execution Plan v2.0 2012 a shared network location, online project portals or cloud based collaborations tools could materialize a CDE, being accessible to all involved stakeholders. Section 2.2.3.7 presents some possible commercial solutions.

All BIM projects delivered by the students of the curricular unit BIM, with inclusion of the performed case study resorted to the Dropbox to support the BIM collaborative project delivery.

4.5.4.2. Communication procedure

As mentioned in the explanation of BIM collaborative working process, during the execution of each BIM use there should be update notices among the involved stakeholders. These communications are generally performed by email, being considered by the AEC professionals that were interviewed an out-dated communication procedure when embracing the BIM methodology. Therefore, this BEP framework recommends the usage of the BIM collaboration format (BCF) as an additional approach to interact, where all communications are established within the BIM models (see section 2.2.4.5).

Case Study – (Stage 4, communication procedure)

In the subsequent paragraphs it is analysed the electronic communication procedure occurred during the “design coordination” BIM use of the design development phase, regarding incongruities verified between the structural and architectural BIM model, specifically between the metallic structural columns with the slatted walls of architectural design. It was implemented both email and BIM collaboration format (BCF) as communication tools, with the intent to posteriorly compare the outcomes.

The incompatibility between the architectural and structural BIM models was confirmed in both IFC central model and on native platform (Revit Architecture), by the architectural team. When accounted all conflicts, an email was sent to the structural engineering team discussing the possible solutions, where the inconsistencies were demonstrated with print screens of the BIM model (see figure 4.39 and 4.40).

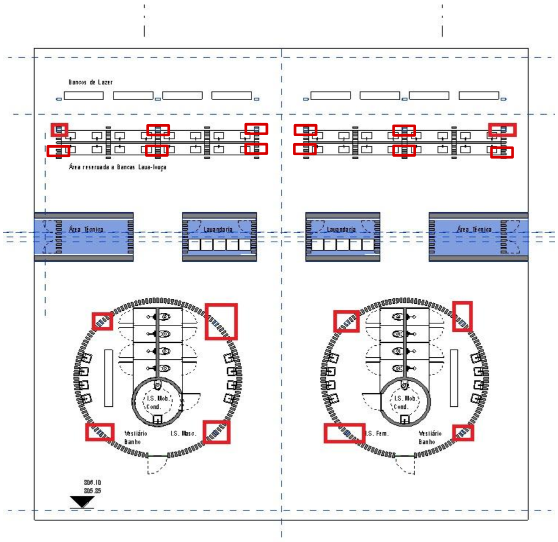


Figure 4.39 – Localization of incongruities among the structural & architectural model (native format).

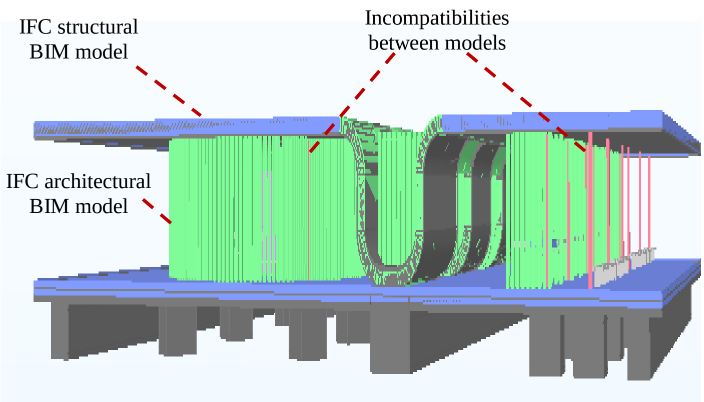


Figure 4.40 - Localization of incongruities among the structural & architectural model (central IFC model).

As can been seen by using the images of the BIM models to manually appoint the verified conflicts facilitated the discussion via email of the possible solutions.

Figure 4.41 demonstrates the communication workflow when adopting the BCF as a communication tool. By applying the BCF Revit plugin it enabled the creation of a workflow communication between different BIM software tools, enabling the architect to communicate from the IFC central model or from his native model with the structural engineer, entirely through the BIM environment without exchanging models. Compared to the email communication procedure, the BCF approach foments a more holistic vision of the issues under discussion, enabling the stakeholders to virtually explore them. Furthermore, each BCF communication can be stored in the interactive virtual platform being organized under the CDE method, in the WIP area (WIP_TSA, see figure 4.42), allowing the project teams to have accessibility to all their communications performed during the project delivery and within the BIM environment avoiding miscommunications.

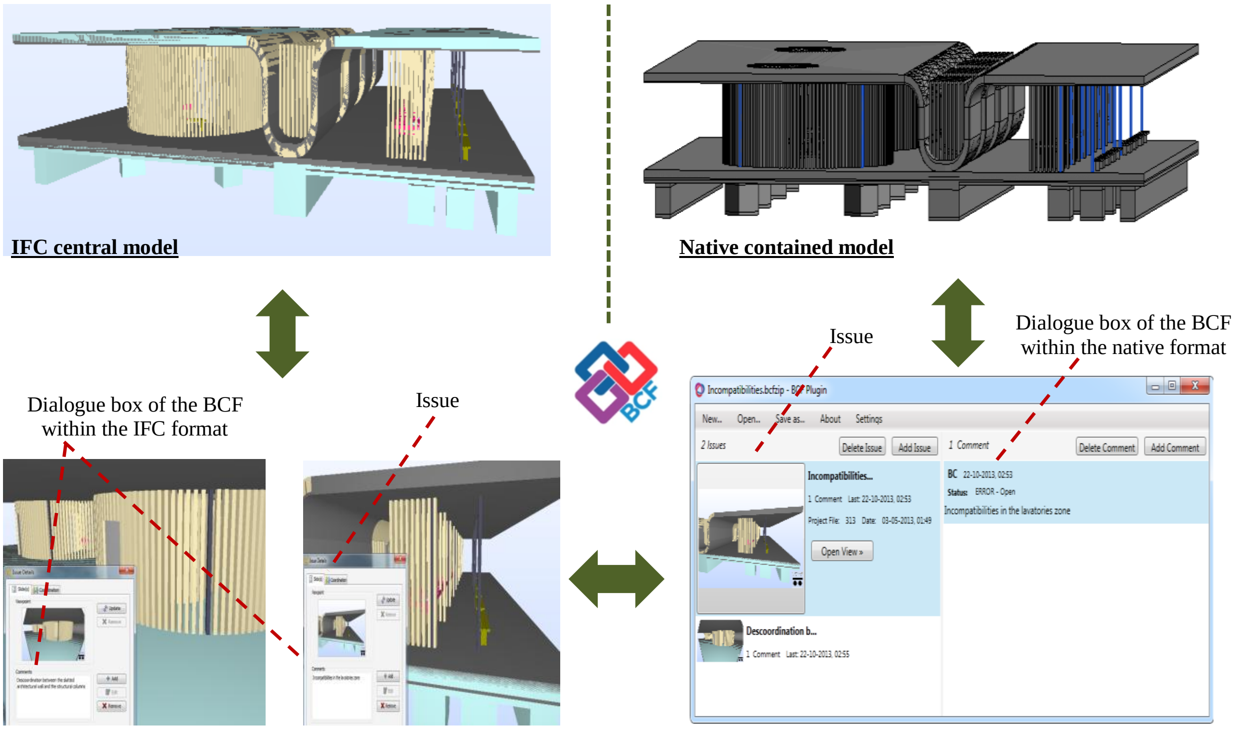


Figure 4.41 – BIM Collaboration Format (BCF) communication procedure.

4.5.5. Folder structure and naming conventions

The folder structure organization of the virtual interactive platform shared among the involved stakeholders is essential to support the collaborative process, where during the performed interviews with the AEC professionals it was defended that the accessibility to the information influences the productivity of a project team.

The following figure presents a suggestion of a project folder structure organization, which is recommended by the AEC (UK) BIM Protocol v2.0 2012, being based on the principals of the BS1192:2007. By adopting this folder structure the project team is able simulate the Common Data Environment approach suggested in the above sections, within a virtual interactive platform accessible by the involved stakeholders.

(Project Folder)

BIM (BIM data repository)

01_WIP Area	**(WIP data repository)**	**02_Shared Area**	**(Verified Shared data)**
CAD	(all CAD files)	CAD	(CAD data/output files)
BIM Models	(all design BIM model)	BIM Models	(Design Models)
Sheet Files	(Sheet/schedules/dwg. files)	CoordModels	(Compilation models)
Export data	(export data)		
Families	(created BIM components)		
WIP_TSA	(WIP Temporary shared area)		
03_Published Area	**(Published data)**	**04_ Achieved Area**	**(Achieved data)**
YYY.MM.DD_ Description	(Sample submission folder)	YYY.MM.DD_ Description	(Archive folder)
…	…	…	…
05_Incomming	**(Incoming data repository)**	**06_BIM Resources**	**(Resource data library)**
Source	(Data originator)	Title blocks	(Drawing borders)
YY.MM.DD_ Description	(Incoming folder)	Logos	(Project logos)
Source	(Data originator)	BIM Standards	(Project BIM Standards)
YY.MM.DD_ Description	(Incoming folder)	Presenting Styles	(Project Standard Presenting Styles)

Figure 4.42 – Recommended folder structure organization, adapted (AEC-UK, 2012a).

4.6. Study of the BIM models management (Stage 5)

4.6.1. General considerations

In this stage of the BEP framework useful recommendations regarding the administration of the BIM models developed throughout the collaborative project shall be appointed. All conveyed suggestions are based on the performed research on BIM Standards and BIM modelling guides, specifically the COBIM v1.0 2012, Statsbygg BIM Manual 1.2 2011 and Singapore BIM Guide v2.0 2013. In addition, it will be acknowledged the perfumed case study.

4.6.2. Model description document

The COBIM v1.0 2012 recommends that each discipline has to maintain a Model Description Document. In brief, this document pronounces the content of the model, the BIM uses dependent on its development and the LODs that is needed to be achieved at each project phase. Furthermore, in this document it should be indicated the applied BIM modelling software, the versions created from the original model and singularities/exceptions verified during the modelling process. This BEP framework suggests that the degree of readiness, in which is indicated the progression of the model´s development, and the results issued from the quality check tests (see section 4.7) should be additionally documented.

With this report other stakeholders can acknowledge the details related to the development of the model being useful when using that same model for a certain BIM uses. This document during the generation of the BIM model is suggested to be regularly updated and allocated in the WIP_TSA folder of the respective stakeholder (see figure 4.42), being thereby accessible to the remaining actors. When developed the BIM model, this document should accompany its location in the shared area, published area and finally achieved area.

4.6.3. Merging BIM models

As already stated, a BIM project is congregated by a set of partial BIM models that are generally divided in each discipline of the project. Thus, for a project team to endue inter-disciplinary collaboration by using the BIM models it is required for the planning team of BEP to define a strategy of linking models. The creation of a schema is recommended to illustrate the interconnections between BIM models, where its definition acknowledges the adopted exchange information format (API direct, IFC, CIS/2, among others), the considered BIM platforms and involved stakeholders. Each stakeholder, internally, can acquire more than one BIM model being dependent on the attributed BIM uses to deliver. By developing this schema the planning team of the BEP can foresee problematic situations of interoperability.

Case Study – (Stage 5, merging BIM models)

Figure 4.43 presents the schema that represents the interconnections between the BIM models (external and internal to each stakeholder), the information exchange format and the respective BIM platform.

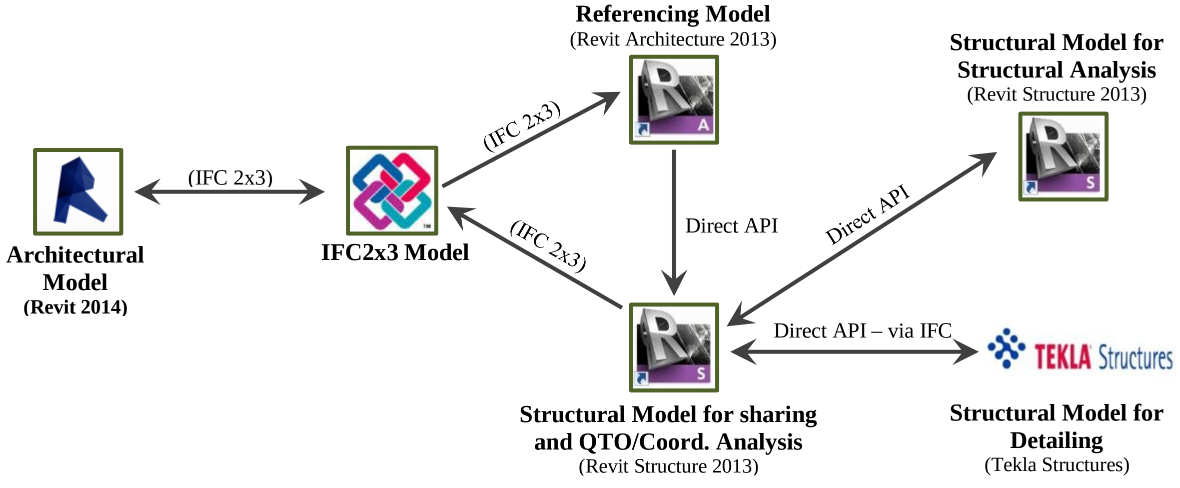


Figure 4.43 – Merging BIM model schema, case study.

As can been seen in figure 4.43 all external information exchanges between discipline models were developed under the IFC 2x3 format. Regarding the internal workflow of the structural engineer it was developed 4 different BIM models (see section 4.6.4.3), where all BIM platforms exchanges under the same environment (Revit) were handled through direct APIs links. As to the interconnection between different BIM platforms (Revit Structure and Tekla Structures) it was used plugin that granted a direct

API link via the IFC adapted data model, where the applications of import and export through the IFC were improved to grant better interoperability specifically between these two platforms.

4.6.4. Modelling approach recommendations

4.6.4.1. Generic modelling approach recommendations

The researched BIM Standards that specify modelling requirements dictate that all BIM modelling software implemented in a collaborative project must be capable to import/export the model in the IFC format. The buildingSMART International Council presents a list[5] of software products certified to be interoperable when using the IFC format.

Before initiating the project´s BIM modelling procedure, the planning team of the BEP should discuss the coordinates of the future models. Accordingly to the BS 1192:2007, indicates that a shared BIM project is to be presented with real coordinate systems and adopt the established coordinate system across all BIM files enabling them to be referenced without modification. In order to fulfil that requirement the BIM models shall initially be virtually constructed near the origin point (0;0;0) and to the positive side of the XY-axis (COBIM, 2012a), to avert issues of interoperability when exchanging models between different BIM platforms. Then in the detailed design phase, where all BIM models are properly coordinated and possess high LODs, the georeferencing coordinate system shall then be implemented in all project models. Moreover, a universal unit system should also be considered to homogenize the information format among the BIM models.

The definition of the building floor levels should be additionally discussed before initiating the modelling of the project. Generally there are different definitions, namely between the architect and structural engineer regarding this matter, where the COBIM v1.0 2012 indicates specifically how each actor should define the building floor level.

Modelling in BIM is different to modelling in 3D (mass modelling). All BIM building elements should be modelled using the intended components and tools (COBIM, 2012a), i.e. a slab is modelled with a slab tool, wall is modelled with a wall tool. If not possible to represent a unique object with the available BIM modelling tools, suitable workaround solutions should be established and documented in the Models Description Document (COBIM, 2012a). Generally in these cases it is customary to encounter interoperability issues.

Case Study – (Stage 5, generic modelling approach recommendations)

All BIM modelling applications that were implemented in the performed case study are certified by the buildingSMART International Council regarding the usage of the IFC format (see table 3.1). Conversely to the recommendations mentioned above, the case study was performed from its

[5]Certified software products: http://www.buildingsmart.org/certification/currently-certified-software-products

commencement with the georeferencing coordinates system of the project´s location, where throughout its development no issues of model referencing were verified, which can be justified due to the small-scale of this sanitary facility project. The following figure presents the IFC central model in which is compiled the architectural and structural BIM model with indication of the BIM modelling tools applied.

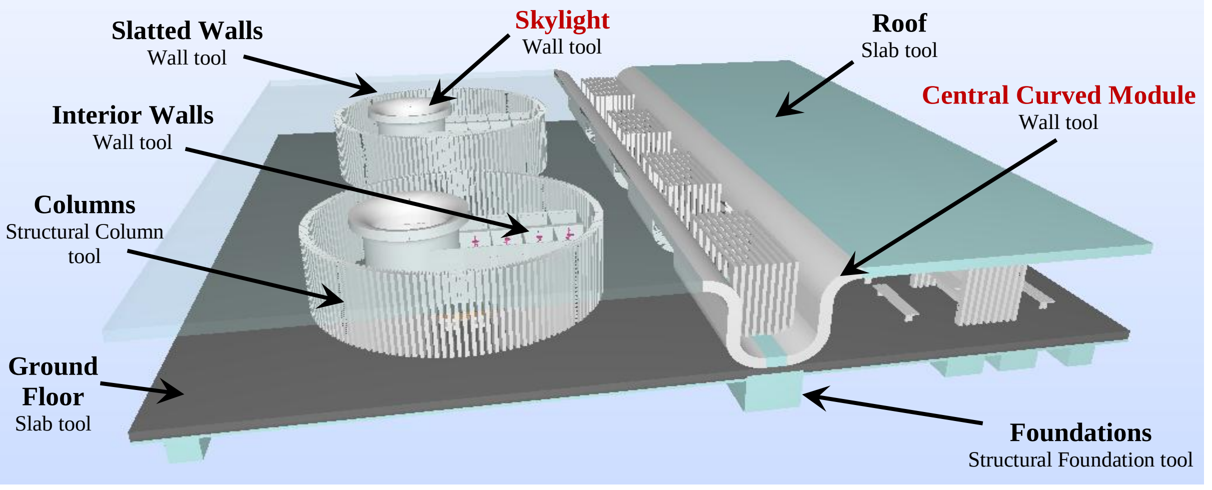


Figure 4.44 – Core building elements and associated BIM modelling tool, case study.

With the exception for the skylight and central curved module elements, the remaining building elements possessed a BIM modelling tool that enabled their correct modelling (see figure 4.44). Due to the singular forms of those first elements it was already expected by the project team barriers relatively to their accurate modelling and consequently sharing through the IFC format.

During the development of the case study, there was cooperative work between the architectural and structural engineering team to obtain a workaround solution regarding the sharing through the IFC format of those identified problematic components. It was developed various tests of interoperability regarding the import and export through the IFC format between the native BIM platforms of the architect (Revit Architecture 2014) and structural engineer (Revit Structure 2013). It was concluded, by using the BIM modelling wall tool it was enabled to export the information (geometry, positioning, materials and properties) without loss of information from the native file to the IFC model. On the other hand, when importing the information contained in the IFC model to the structural engineer native platform, these elements were received as masses being necessary their re-modelling. This suggests that the import IFC application of the BIM native platform of the structural engineer is not capacitated to retrieve from the IFC data structure that information.

4.6.4.2. Architecture modelling approach recommendations

Accordingly to the COBIM v1.0 2012 the architectural model is mandatory in all design phases, being the foundation for other models. The Stastbygg Manual 1.2 2011 states that the architect model usually contains by reference, building elements of other disciplines, being fundamental that the architectural model remains coordinated during the design phases with other domains to grant compatibility between the BIM models of the project. Therefore, it is imperative that the architectural model is technically viable in all design phases of the project (COBIM, 2012b), being recommended to consult the modelling guidelines specified in the COBIM v1.0 2012.

4.6.4.3. Structural engineering modelling approach recommendations

With the incorporation of BIM in structural engineering the following activities of that field were enhanced – coordination with the other members of the project team, 2D/3D documentation, structural detailing; automatic QTO; structural erection analysis and integration with structural analysis software (Lino et al., 2012). However the BIM tools have matured erratically regarding the various structural materials, where in structural steel, timber and precast concrete constructions there has been good indication regarding their implementation, contrary to what occurs on cast-in-place reinforced concrete structures (Barak et al., 2009).

Accordingly to the interview performed with structural engineer José Carlos Lino, it was stated the importance of a structural engineer to firstly define which BIM uses to perform, before commencing the modelling of the BIM structural model. The necessity to outline a modelling strategy which acknowledges the structural system, the modelling requirements and the limitations of the BIM software to undertake the attributed BIM uses, which perhaps could include the generation of more than one structural BIM model were additionally uttered.

As mentioned before, the structural engineer when modelling in BIM produces both the geometric model and analytical model, which are developed simultaneously by the BIM structural modelling software. The integration of the structural BIM model with the structural analysis software is still not mastered (Schinler and Nelson, 2008), being necessary in some cases the adaptation of the geometric model to grant a consistent analytical model for transfer. Therefore, it is recommended to verify the data before and after exporting the model and to considerate the effects on other BIM uses when altering the geometric model. To conclude, the (BCA, 2013c) suggests the all slabs should be modelled for every panel constrained by beams for adequate simulation of load transfer.

Case Study – (Stage 5, struct eng modelling approach recommendations)

As mentioned before, the structural design of the case study was a cast-in-place reinforced concrete structure with the exception of its columns that were steel framed. As illustrated in figure 4.43 it was incorporated four BIM models in the modelling strategy of the structural engineer. The “referencing model” had the aim to receive under an architectural BIM platform the model of the architect, enabling the structural engineer to study the design and check for possible errors of interoperability. Once checked, the “referencing model” was linked up to the main structural BIM model, to posteriorly be copied the structural building elements. This defensive approach is to certify that the structural building elements performed by the architect are equipped to be copied to the structural model.

The main structural BIM model was used to deliver the "design coordination" and "cost estimation" BIM uses, where it was followed the same modelling recommendations of the architectural model to avoid incompatibility issues between designs.

To establish the integration between the structural BIM model (Revit Structure) and the structural analysis application (Robot Structural Analysis) the adoption of an auxiliary BIM model was necessary due to two reasons. The first and as already explained was the necessity to generate the analytical model of the central curved module. The second reason was the need to modify the positioning of certain structural components, namely the structural columns to grant consistency to the analytical model, which, consequently, would provoke overlying between materials (see figure 4.45) and incorrect 2D/3D documentation. To conclude, the bi-directionality of the integration between the structural BIM platform and structural analysis software was used, where it was not verified any limitations. Nevertheless, the effort needed to obtain a consistent analytical model and its influences on the geometric model is identified as the counterproductive aspect of this workflow. Thus, the alterations inherent to the structural design due to the results obtained from the structural analysis were manually inserted in the main structural BIM model, in order to be incorporate in the delivery of the remaining BIM uses.

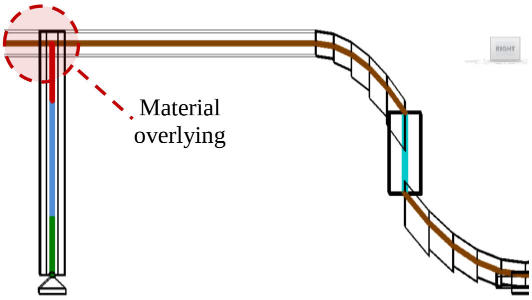


Figure 4.45 – Material overlying due to required consistency of analytical model, case study.

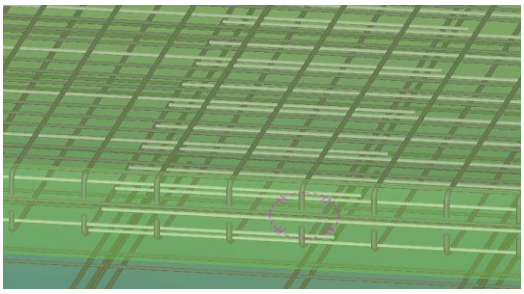


Figure 4.46 – Singular situations of detailing that required manual modelling, case study.

Finally, it was developed a fourth BIM model to perform the structural detailing. The main reason of separating this model from the main model was to use a more sophisticated BIM platform for structural detailing (Tekla Structures). When detailing, there was a clear difference between the gained productivity of the modelling tools regarding the steel structural elements when compared to the modelling tools for reinforcement concrete structures, where for singular situations it was needed to be manually modelled (see figure 4.46).

4.6.4.4. Release of a BIM model

The COBIM v1.0 2012 recommends that when shared a BIM model it should be delivered in the IFC format and native file format. Furthermore, it is suggested that at formal realise points all components and information which are not relevant to the respective BIM model should be removed. It is recommended in large projects to use compressed IFC files (e.g. ifcZIP) when shared with the project team, where generally this procedure can reduce the file size by 80% (COBIM, 2012b). The Solibri IFC Optimizer is recommended for that operation (COBIM, 2012a).

4.7. Quality assurance of the BIM models (Stage 6)

4.7.1. General considerations

This final stage of this BEP framework aims to analyse the viability of the produced BIM models of each discipline regarding its usability in the collaborative project. The efficiency of a BIM collaborative working procedure is dependent if the required information inherent in a BIM model is available at the delineated time, if it is accurate, and if it follows the proposed modelling requirements (Eastman et al., 2011), where by developing quality assurance evaluations the model receiver can verify the possible deficiencies detected and alert the model author.

The quality assurance testing is normally performed in two situations. The first is during the development or usage of the BIM models, where up-date communications and preliminary sharing of BIM models persist. Accordingly to the COBIM v1.0 2012 during the work in progress stage the quality requirements should be more lenient. When formally exchanging BIM models, a more rigorous quality check should be performed with the intent to grant an effective information exchange. All results obtained from the quality checks should be documented in the Model Description Document (see section 4.6.2).

The following sections debate possible quality control checks that can be implemented. The first section presents the generic quality assurance assessments that can be easily performed. The subsequent section presents more sophisticated quality analyses of BIM models regarding information take-off accuracy, deficiency detections and interoperability issues detection. All quality assurance checks presented were based on the researched BIM standards.

4.7.2. Generic quality control checks

The generic quality control checks are recommended to be performed whenever the BIM model is shared, where the succeeding quality control checks should be elaborated.

a) Visual Checks:

By virtually navigating the BIM models enables to verify the positioning of the building elements and confirm the concordance with the design intent;

b) Interference Checks:

By employing the conflict detection BIM tool allows verifying situations of clashing occurrences between components of a discipline BIM model.

4.7.3. Enhanced quality control checks

The subsequent quality assurance checks are recommended to be implemented in formal sharing of the BIM model, i.e. when commencing and finalizing each BIM use. All quality assurance evaluations were performed on the case study, being used the most recent BIM tools for that effect.

a) Information Take-off (ITO) Accuracy

The definition of the Information Take-off (ITO) was created by Solibri. In summary, the ITO enables users to collect information from the BIM models, categorize the information, visualize the respective building elements and develop reports, automatically (Kulusjärvi et al., 2010). Once the information is inserted in the BIM models, the ITO tool enables the user to capture all information in whatever intended arrangement. The BIM tool that is capable on developing such analysis is the Solibri Model Checker v8.1.

The ITO tool can display an interesting role to assist each liable stakeholder of a BIM use to ensure if the BIM models have the needed (input) or accomplished (output) the information and modelling requirements that were delineated for a specific project phase. Hence, by analysing each building element category the model author/user can verify if the geometry detail and information requirements are in concordance with the stipulated LODs for that specific BIM use.

Case Study – (Stage 6, information take-off accuracy – quality assurance)

The following figure presents a quality assurance evaluation regarding the ITO accuracy that was performed on the BIM models of the case study at the completion of the “design authoring” BIM use of the design development phase regarding the structural columns. This evaluation had the aim to verify if the output information requirements were accomplished in each discipline model. Both architectural and structural models were sent via the IFC format to the application of Solibri Model Checker v8.1. It should be, noted that generally this analysis is preformed separately on each discipline model by the respective liable stakeholder.

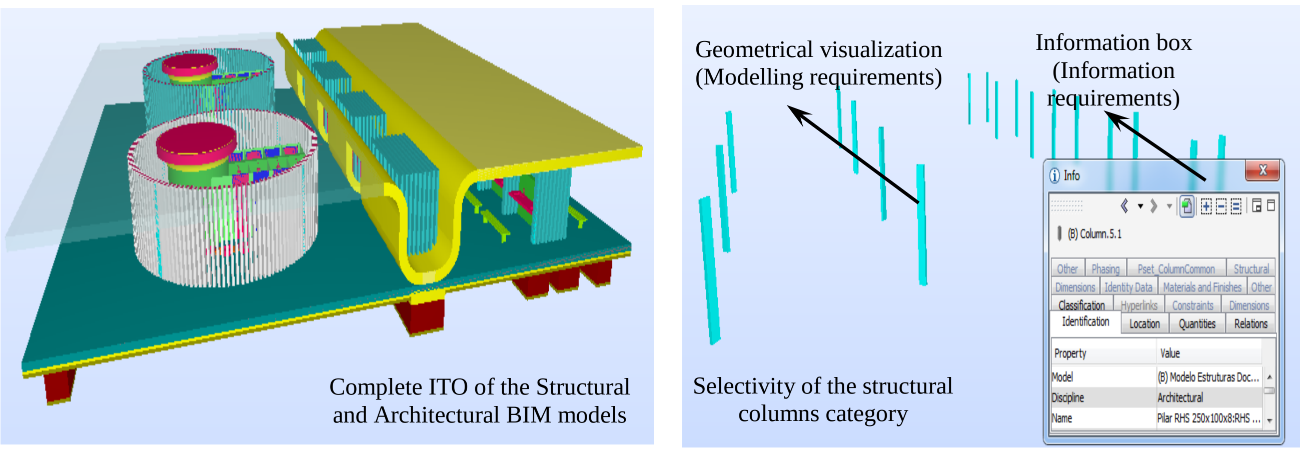


Figure 4.47 – Quality assurance of the information take-off accuracy regarding the structural columns of the “design authoring” BIM use at the design development phase, case study.

The structural engineering team concluded by manually verifying the results of the ITO in comparison with the LOD Specification, that the modelled structural columns achieved the stipulated LODs of the "design authoring" BIM use.

b) Deficiency Detection

In brief, the deficiency detection quality control checks consists in verifying the relationships within a BIM model, such as absent building elements, discrepancies of the building elements towards the considered specifications and the relations between building elements (Kulusjärvi and Widney, 2010). Solibri created this type of quality assurance where Solibri Model Checker is the only BIM application in the current market that is able to perform automatically this type of quality control check on BIM models.

To perform this type of quality analysis Solibri established a set of core rulesets based on specific parameters which are definable by the user. These rulesets congregate the dependencies and relationships among the components of the BIM model (objects and spaces) (Kulusjärvi and Widney, 2010), which enable to obtain the expected verifications.

Case Study – (Stage 6, deficiency detection – quality assurance)

At the finalization of the "design authoring" BIM use verified in the design development project phase the performed BIM models were subjected to the deficiency detection quality assurance evaluation. Figure 4.48 shows the set of pre-defined rulesets inherent in the application of Solibri Model Checker that were analysed, with the indication of the scale of severity regarding the nonconformities verified. Figure 4.49 demonstrates an example of one of the nonconformities variegated.

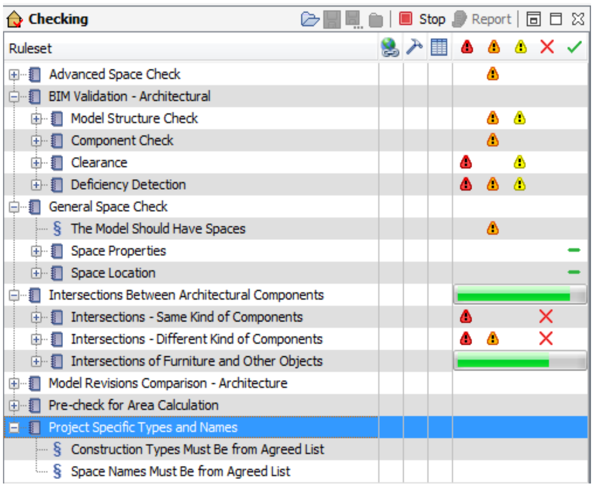


Figure 4.48 – Analysis of the selected rulesets with indication of the degree of severity.

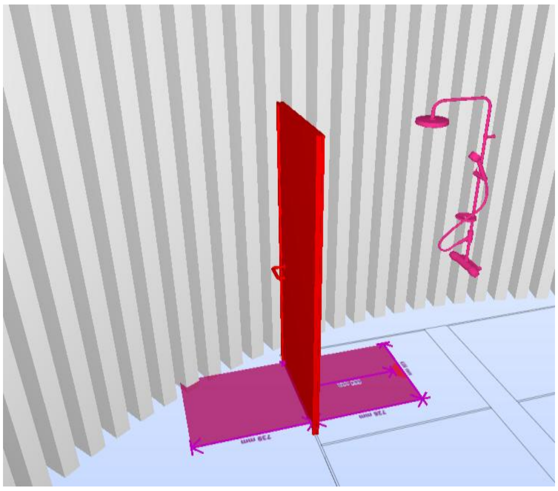


Figure 4. 39 – Case of nonconformity obtained by the deficiency detection analysis.

c) Interoperability issues detection

When embarking on a multi-disciplinary project, where various stakeholders possess variant BIM platforms, interoperability becomes a relevant issue to acknowledge. Being the IFC format the most implemented interoperability exchange format within the BIM methodology the following quality control recommendations shall only consider that format. In short, a project team should evaluate and record the interoperability issues verified in each discipline model throughout the project delivery, where based on these analyses possible alternative solutions can be fomented.

To quantify the errors that occur when importing a native model to the IFC model during this study it was applied the IfcObjectCounter developed by the Karlsruhe Institute for Technology. This BIM tool serves as an IFC file checker which indicates the number of interoperability issues when importing the IFC file. Another interesting BIM tool that examines the IFC file is the IFC FILE Analyzer developed by the NIST. This tool generates a spreadsheet from an IFC file, which presents worksheets relative to each IFC entity of that file, where the user can detect which information was not conveyed. This last quality IFC check tool enables a more rigorous interpretation when compared to the first tool presented.

Case Study – (Stage 6, interoperability issues detection – quality assurance)

During the detailed design phase the structural engineering team had the prospect of exporting the structural detailing outlined to an IFC model. It was generated an IFC model where only the steel connections where properly imported. As to the rebar of the cast-in-place reinforced concrete structure it was verified severe issues of interoperability.

Therefore, the structural engineering team applied the IfcObjectCounter to verify the quality of the structural model in terms of interoperability issues. Before commencing the structural detailing the IFC model presented 55 issues of interoperability, when imported the structural detailing model to the IFC model it was detected 2798 issues being clearly evidenced that the IFC 2x3 is not equipped to exchange information regarding reinforcement.

CHAPTER 5

5. CONCLUSIONS AND FUTURE DEVELPMENTS

5.1. General conclusions

This work was outlined accordingly to three domains, being resumed in the following paragraphs the main conclusions achieved.

The main domain and core purpose of this dissertation was to contribute for a proposal of a framework that conveys a set of methodologies that enables project teams to strategize the implementation of BIM throughout the collaborative project delivery. The suggested framework is based on six stages which address the essential elements to scrutinize when implementing a level 2 BIM maturity project, to be articulated in a BIM Execution Plan. In practical terms, the proposed BEP framework was based on a process of benchmarking regarding existing BIM standards/guidelines/execution plans and interviews established with AEC professionals regarding the fields of architecture, engineering and BIM. Furthermore, a case study was performed regarding the collaborative project between the structural engineer and architect to optimize and validate the suggested methodology. The following main conclusions can be highlighted:

- The developed process of benchmarking of the current bibliographical references revealed that at this present time there are sufficient BIM standards that are equipped with the necessary requirements to implement BIM projects under a collaborative environment, being emphasized the COBIM v1.0 2012, Singapore BIM Guide v2.0 2013, Statsbygg BIM Manual 1.2 and AIA document E203/G202 2013 for modelling and information requirements. Regarding the collaborative requirements the AEC (UK) BIM Protocol and Singapore BIM Guide are highly suggested and very similar in specific topics. On the other hand it was verified a lack of detailed BIM Execution Plan guides to facilitate the implementation of BIM under a collaborative scope;
- The performed case study between the architectural team and structural engineering team achieved all complexities of the architectural design, where the current BIM software applications revealed on not being prohibitive or counterproductive during the collaborative working procedure. Some software incongruities regarding interoperability issues between BIM platforms and limitations within the structural engineer workflow were verified and resolved with workaround modelling strategies;
- During the description of the various methods that compile the established BEP framework in many cases the role of the leading team was referred. Its conclusive that the leading team is essential to guarantee the homogenization of the workflows of the involved stakeholders in order to obtain a productive and synchronized collaborative workflow;
- The importance of grading the competencies of an AEC firm to execute a specific BIM use was acknowledged, regarding the selection of the BIM uses to be implemented in the project delivery. Its conclusive and irrevocable the need of a reputable national/international entity capable of

certifying and categorizing the capabilities of an AEC firm towards specific BIM uses. Regrettably, at this present moment there is not a clear recognisable organization on delivering such services under an impartial manner, which consequently, vastly, influences negatively the BIM collaborative process;

- The incorporation of the Level of Development Specification 2013 document revealed to be a key element to classify under a vivid simple grading scale the minimum modelling and information requirements of each BIM use. The implementation of the level of development classification enabled each stakeholder (architect and structural engineer) to define what their models can be accounted for, consequently conveying to other stakeholders a clear understanding of the limitations and usability of the developed BIM models, being an imperative factor to develop a transparent and efficient collaborative project in BIM;
- It is cogent from the BIM Information Exchange Requirement Worksheets of the performed case study that there is no strict association between the LOD attribution and design phases or the existence of the a “LOD model” of a specific project phase. It was concluded that the LOD attribution of each building element acknowledges the minimum requirements necessary to develop the BIM uses of a specific project phase, consequently, enabling to simply develop the necessary BIM modelling effort required ;
- With the adoption of BIM, structural engineers are equipped with more means to collaborate and support the architect from initial design phases. This was verified in the developed case study, where the structural engineer in an early phase analysed various structural design solutions, by applying BIM applications, assisting the architect with more rigorous information. Consequently, the structural building components of the structural BIM model were more refined, requiring more modelling effort in those initial design phases;
- It is concluded during the explanation of the case study that BIM modelling is modelling building components that are “rich” in information. Being the architectural BIM model the foundation of other discipline models, it was conclusive the importance of architects when crafting the initial BIM models to incorporate BIM objects to represent their design. This aspect is essential to foment in initial design phases the collaborative work in BIM between the architect and the structural engineer.
- It is acknowledged that the architect displays a fundamental role to implement BIM in the collaborative projects. The case study showed that by sharing his BIM model with the structural engineer the architect attains several gains, mainly during the modelling and coordination procedures throughout the project delivery.

The remaining two domains of the work performed in this thesis had the aspiration to manifest the importance of the current and future stakeholders of the AEC Portuguese industry in attaining education in BIM competencies. The first of the referred domains consisted in the development of promotional initiatives of the BIM concept within the academic environment, where during the period of this thesis the author was associated in ten promotional events and in the genesis of the BIMCLUB initiative being recognized as one of the founding members. The last domain resides in the establishment of a BIM curricula unit, where the author contributed in the preparation and monitoring of this educational initiative. From the work developed under these two domains the subsequent conclusions are emphasized:

- All promotional initiatives held at the University of Minho were highly attended serving as a clear indication that the majority of the students of that university recognize the significance of this concept and the importance of acquiring BIM competencies as a differential factor, which is perceived by the current/future market;
- The BIMCLUB initiative has revealed enthusiastic indications since its genesis, being considered as a national promotional initiative of BIM, empowered by bottom-up approaches. However, from the statistical analysis performed on the members incorporated in its virtual community and the attendees of the events sponsored by this initiative, it is conclusive the necessity of comprehending other disciplines, such as architecture, mechanical engineering and computer engoneering;
- Regarding performed curricular unit of BIM in the school year 2012/2013, the strategic decision of not incorporating the specific formation in BIM software skills in the lecturing contents revealed to be effective where the majority of the groups were able to retrieve sufficient information from online sources, enabling the teaching staff to concentrate on essential concepts of the BIM methodology.

5.2. Acknowledged limitations and proposed future developments

Taking in account the work commenced with this thesis and being conscious that by no means can any of the covered subjects be considered solved of finished, a list of the most relevant acknowledged limitations (and future developments) are presented in this section:

- The proposed BIM Execution Plan framework of this thesis did not analyse the protection of the intellectual property of each stakeholder´s BIM model. It is suggested that this subject should be analysed in detail to complement the methodologies already presented;
- During the development of the case study various issues of interoperability of the IFC2x3 exchange format version regarding curved elements and rebar of reinforced concrete structures were outlined, affecting negatively the collaborative process. As a future development it should be analysed the capabilities of the IFC4 version as an exchange format of the collaborative environment between the structural engineer and architect, and in the individual workflow of the structural engineer;
- During the development of the case study many technical limitations were verified regarding the implementation of BIM in reinforced concrete structures. Software producers should provide more optimal solutions relatively to the automatic regulation of the analytical model without compromising the positioning of the geometric model, enabling to retrieve form a singular structural BIM model several BIM uses;
- Several limitations regarding the rebar modelling were verified during the case study, being a counterproductive aspect of the BIM structural workflow. The main limitation verified consisted in the lack of parametric elements to cover more singular design occurrences, being suggested the incorporation of more modelling solutions in the standard database of the software application;

- Acknowledging that the proposed BEP framework only was implemented and analysed in a case study that solely involved two stakeholders and performed during the design phase, as a future development it is suggested to analyse and optimize the presented set of methodologies regarding a project that incorporates more disciplines of the project and/or more phases of the building lifecycle;
- The evaluation of the LOD of each building element is an essential quality assurance check, where at the present time this evaluation is developed manually. The incorporation of the LOD specification, by the software producers within their systems is suggested, enabling modelling users to automatically check the maturity of each building element;
- A study that is able to quantify the required modelling effort in achieving the various LODs regarding common building elements of a specific discipline and project category could reveal to be of great importance for AEC firms to acknowledge when commencing BIM modelling procedures;
- The initial architectural design phases are of great importance to the project, however it is verified few BIM applications that assist the architect in that phase, specifically in structural engineering concepts. The future development of a software application based on the BIM methodology that enables to automatically evaluate the structural design solutions (positioning of the structural elements, cost, section dimensioning, structural material and others) regarding the requirements of the architectural design could reveal to be of great importance to obtain more optimized and integrated workflows from initial design phases.

REFERENCES

AEC-UK 2009. AEC (UK) BIM Protocol - Implementing UK BIM Standard fo the Architectural, Engineering and Construction Industry. Version 1.

AEC-UK 2012a. AEC (UK) BIM Protocol - Implementing UK BIM Standard fo the Architectural, Engineering and Construction Industruy. *Version 2*.

AEC-UK 2012b. AEC (UK) BIM Protocol - Project BIM Execution Plan. Version 2.0. *Implementing UK BIM Standards for the Architectural, Engineering and Construction Industry*.

AGC 2006. Contractor´s Guide to BIM. *Associated General Contractors of America,* 1st Edition.

AHMAD, A. M., DEMIAN, P. & PRICE, A. D. F. 2012. BIM Implementation Plans: A Comparative Analysis. *28th Annual ARCOM Conference, Edinburgh, UK*.

AIA 2007. Integrated Project Delivery: A Guide. *The American Institute of Architects - AIA National & AIA California Council,* version 1.

AIA 2013. AIA Document E203 - 2012; G201 - 2012; G202 - 2012. *Building Information Modeling and Digital Data Exhibit,* The American Institute of Architects.

ANGL. 2011. *j-curve* [Online]. Available: http://anglconsulting.com/?attachment_id=537 [Accessed 21/02/2013].

ARAYICI, Y., KHOSROWSAHAHI, F., PONTING, A. M. & MIHINDU, S. 2009. Towards Implementation of Building Information Modelling in the Construction Industry. *Fifth International Conference on Construction in the 21st Century (CITC-V) - "Collaboration and Integration in Engineering, Management and Technology".* Istanbul, Turkey.

AUTODESK 2011. The Power of BIM in structural engineering. *Structural engineering brochure*.

AZENHA, M., LINO, J. C. & CAIRES, B. 2013a. Building Information Modeling - Conceção, Project e Construção. Capítulo 2 - Modelação Paramétrica e Objetos, Slides de apoio às aulas. Universidade do Minho, Mestrado em Construção e Reabilitação Sustentáveis.

AZENHA, M., LINO, J. C., COUTO, J. P., COSTA, A. A., COSTA, D. D., MAIA, L. D., MARTINS, J. P., LOPES, N. L., COSTA, M. C. D., COUTO, P. & TAVARES, V. 2013b. BIM in Arch./Eng. Education Portugal - The BIMClub initiative. *I BIM Internacional Conference - Porto*, 20 & 21 June 2013.

AZHAR, S. 2011. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for he AEC industry. *Leadership and Management in Engineering, 11, 241-252*.

AZHAR, S., HEIN, M. & SKETO, B. 2009. Building Information Modeling (BIM): Benefits, Risks and Challenges. *Mc Whorter School of Buildign Science*.

BARAK, R., JEONG, Y. S., SACKS, R. & EASTMAN, C. M. 2009. Unique Requirements of Building Information Modeling for Cast-in-Place Reinforced Concrete. *Journal of computing in civil engineering* 23**,** 64-74.

BARLISH, K. & SULLIVAN, K. 2012. How to measure the benefits of BIM - A case study approach. *Automation in Construction,* 24**,** 149 - 159.

BCA 2013a. BIM Essential Guide - For Architectural Consultants. BCA - Building and Construction Authority.

BCA 2013b. BIM Essential Guide - For BIM Execution Plan. BCA - Building and Construction Authority.

BCA 2013c. BIM Essential Guide - For C & S Consultants. BCA - Building and Construction Authority.

BCA 2013d. BIM Essential Guide - For Constructors. BCA - Building and Construction Authority.

BCA 2013e. BIM Essential Guide - For MEP Consultants. BCA - Building and Construction Authority.

BCA 2013f. Singapore BIM Guide, Version 2. BCA - Building and Construction Authority.

BECERIK-GERBER, B., ASCE, A. M. & KENSEK, K. 2010. Building Information Modeling in Architecture, Engineering, and Construction: Emerging Research Directions and Trends. *Journal of Profissional issues in Engineering Education and Practice*

BEDRICK, J. 2008. *Organizing the Development of a Building Information Model* [Online]. *AECbytes* Available: http://www.aecbytes.com/feature/2008/MPSforBIM.html [Accessed 15/02/2013].

BEDRICK, J. 2013. *A Level of Development Specification for BIM Processes. AECbytes* [Online]. Available: http://www.aecbytes.com/viewpoint/2013/issue_68.html [Accessed 15/08/2013].

BERARD, O. & KARLSHOEJ, J. 2012. Information Delivery Manuals to Integrate Building Product Information into Design. *Journal of Information Technology in Construction* 17**,** 64-74.

BIMCLUB. 2013. *O que é o BIMClub?* [Online]. *The BIMClub Initiative*. Available: http://www.bimclub.pt/index.html [Accessed 24/09/2013].

BIMFORUM 2013. Level of Development Specification - For Building Information Models. Version 2013.

BONGIORNI, M. J. 2011. Integrated Project Delivery. *Interdisciplinary Design for the Built Environment - Essay One,* Unversity of Cambrige.

BRYDE, D., BROQUETAS, M. & VOLM, J. M. 2012. The project benefits of Building Information Modelling (BIM). *Internacional Journal of Project Management***,** 1-10.

BUILDINGSMART. 2013. Available: http://www.buildingsmart.org/ [Accessed 01/09/2013].

CARMONA, J. & IRWIN, K. 2007. *"BIM: Who, what, how and why." Building Operation Management.* [Online]. Available: http://www.facilitiesnet.com/software/article/BIM-Who-What-How-and-Why--7546 [Accessed 18/02/2013].

CAVIERES, A., GENTRY, R. & AL-HADDAD, T. 2011. Knowledge-based parametric tools for concrete masonry walls: Conceptual design and preliminary structural analysis. *Automation in Construction,* 20**,** 716 - 728.

CHEN, P.-H., CUI, L., WAN, C., YANG, Q., TING, S. K. & TIONG, R. L. K. 2005. Implementation of IFC-based web server for collaborative building design between architects and structural engineers. *Automation in Construction*, 14, 115-128.

CHUANG, T.-H., LEE, B.-C. & WU, I.-C. 2011. Applying cloud computing technology to BIM visualization and manipulation.

CIC. 2008. *Computer Integrated Construction(CIC) Research Program's BIM Planning Website.* [Online]. Available: http://bim.psu.edu/Uses/default.aspx [Accessed 15/09/2013].

CIC 2010. BIM Execution Planning Guide - Version 2.0. *The Computer Integrated Construction Research Program,* July, The Pennsylvania State University, University Park, PA, USA.

COBIM 2012a. Series 1 - General Parts. *Common BIM Requirements 2012. V 1.0. COBIM Project - Finland.*

COBIM 2012b. Series 3 -Architectural design. *Common BIM Requirements 2012. V 1.0. COBIM Project - Finland.*

COBIM 2012c. Series 6 - Quality Assurance. *Common BIM Requirements 2012. V 1.0. COBIM Project - Finland.*

CONSTRUCTION, M. H. 2009. SmartMarket Report: The busniess Value of BIM

CONSTRUCTION, M. H. 2010. SmartMarket Report:The Business Value of BIM in Europe - Getting Building Information Modeling to the Bottom Line in the United Kindom, France and Germany.

CRC 2009. National Guidelines for Digital Modeling. *CRC for Construction Innovation,* Australia: Cooperative Research Centre for Construction Innovation.

EASTMAN, C., TEICHOLZ, P. & SACKS, R. 2008. *BIM Handbook: A guide to building information modeling for owners, managers, designers, engineers, and constructors*, s.1. : John Wiley and Sons.

EASTMAN, C., TEICHOLZ, P., SACKS, R. & LISTON, K. 2011. *BIM handbook: a guide to building information modeling for owners, managers, designers, engineers, and constractors,* Hoboken, NJ, Wiley.

EASTMAN, C. M., JEONG, Y. S., SACKS, R. & KANER, I. 2010. Exchange Model and exchange object concepts for implementation of nation BIM standards. *Journal of computing in civil engineering***,** 25-34.

ESTEVES, A. 2012. *A Metodologia BIM aplicada à preperação de obra.* Engenharia Civil, Tese de Mestrado, Instituto Superior de Engenharia do Porto - Instituto Politécnico do Porto.

FERRAZ, M. & MORAIS, R. 2012. O conceito BIM e a especificação IFC na indústria da construção e em particular na indústria de pré-fabricação em betão. *Encontro Nacional de Betão Estrutural - BE2012.* Faculdade de Engenharia da Universidade do Porto.

FERREIRA, B. F. V. 2011. *Aplicação de Conceitos BIM à Instrumentação de Estruturas.* Engenharia Civil, Tese de Mestrado, Faculdade de Engenharia da Universidado do Porto.

FEUP. 2011. *WIKI GEQUALTEC, Projeto SIGABIM* [Online]. Available: http://paginas.fe.up.pt/~gequaltec/w/index.php?title=BIM [Accessed 18/02/2013].

FONSECA, A. R., SANTOS, H., FERNANDES, J. & SANTOS, L. 2013. Pratical work of the Curricular Unit - Grupo nº1. *Building Information Modeling: Conception, Design and Construction.,* University of Minho. Master in Sustainable Construction and Rehabilitation programme.

FONTES, H., AZENHA, M. & VAZ, R. S. 2010. Potencialidades de aplicação de ferramentas "Building Information Modelling" no apoio à transmissão de conhecimento relativo a estruturas de betão armado. *Encontro Nacional de Betão Estrutural - BE2010, Lisboa*.

GRAY, C. & HUGHES, W. 2001. Building Design Management. Butterworth Heinemann, Oxford.

GRILO, A. & JARDIM-GONCALVES, R. 2010. Value proposition on interoperability of BIM and collaborative working environments. *Automation in Construction,* 19, 522-530.

GROUP, B. I. W. 2011. Strategy Paper for the Government Construction Client Group.

GSA 2007. GSA BIM Guide For Spatial Program Validation. GSA BIM Guide Series 02.

GU, N. & LONDON, K. 2010. Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction 19, 988 - 999*.

HAMMAD, D. B., RISHI, A. G. & YAHAYA, M. B. 2012. Mitigating construction project risk using building information modeling (BIM). *College of Education Azare, Bauchi State, Nigeria*.

HAMMND, S. 2007. Getting to BIM. *Structure magazine***,** 50-51.

HENRIQUES, A. F. P. 2012. *Integração do ProNIC em ambiente BIM - UM modelo para o trabalho colaborativo.* Engenharia Civil, Tese de Mestrado. Instituto Superior Técnico.

HERGUNSEL, M. F. 2011. Benefits of Building Information Modeling for Constructors Managers and BIM based scheduling. MSc Thesis in Civil Engineering. Worcester Polytechnic Institute.

HOWARD W. ASHCRAFT, J., ESQUIRE 2008. Implementing BIM: A report from the Field on Issues and Strategies. *Th 47th Annual Meeting of Invited Attorneys.*

HUNG, T. 2011. *Software development process - Connexions* [Online]. Available: http://cnx.org/content/m14619/latest/ [Accessed 15/09/2013].

ISIKDAG, U. & UNDERWOOD, J. 2010. Two design patterns for facilitating Building Information Model-based synchronous collaboration. *Automation in Construction,* 19**,** 544-553.

J.P. CULLEN & SONS, I. 2008. *Integrated Project Delivety* [Online]. Available: http://www.jpcullen.com/Services/IntegratedProjectDeliveryIPD.aspx [Accessed 22/02/2013].

JOENG, Y. S., EASTMAN, C. M., SACKS, R. & KANER, I. 2009. Benchmark tests for BIM data exchanges of precast concrete. *Automation in Construction,* 18**,** 469-484.

KHEMLANI, L. 2007. *Autodesk FM Desktop: Extending BIM to Facilities Management. AECbytes* [Online]. Available: http://www.aecbytes.com/buildingthefuture/2007/FMDesktop.html [Accessed 19/02/2012].

KHEMLANI, L. 2012. *Around the World with BIM. AECbytes* [Online]. Available: http://www.aecbytes.com/feature/2012/Global-BIM.html [Accessed 10/09/2013].

KIM, J.-L. 2011. Use of BIM Effective Visualization Teaching Approach in Construction Education. *Journal of Profissional issues in Engineering Education and Practice*.

KREIDER, R., MESSNER, J. & DUBLER, C. 2008. Determining the frequency and impact of applying BIM for different purposes on projects.

KRYGIEL, E., READ, P. & VANDEZANDE, J. 2010. *Mastering Autodesk Revit Architecture 2011,* Whiley Publishing Inc, Indiana.

KULUSJÄRVI, H. & WIDNEY, J. 2010. Introducing Deficiency Detection.

KULUSJÄRVI, H., WIDNEY, J. & JAUHIAINEN, J. 2010. Introducing Information Takeoff.

LANGDON, D. 2011. AECOM. Getting the most out of BIM: A Guide for Clientes.

LEE, S.-I., BAE, J.-S. & CHO, Y. S. 2012. Efficiency analysis of Set-based Design with structural building information modeling (S-BIM) on high-rise building structures. *Automation in Construction, 23, 20-32*.

LEWIS, J. & LOFTUS, W. 2008. Java Software Solutions Foundations of Programming Design. *6th ed. Pearson Education Inc. ISBN 0-321-53205-8.,* section 1.6 "Object-Oriented Programming".

LINO, J. C., AZENHA, M. & LOURENÇO, P. 2012. Integração da Metodologia BIM na Engenharia de Estruturas. *Encontro Nacional Betão Estrutural - BE2012*. Faculdade de Engenharia da Universidade do Porto.

LIU, Z., LU, X., LI, Y. & ZHANG, H. 2010. A software platform for information conversion from IFC-based architectural model to PKPM structural model. *Internacional Conference on Computing Civil and Building Engineering*, University of Nothingam.

LÖHNERT, G., DALKOWSKI, A. & SUUTER, W. 2003. Integrated Design Process - Task 23. *Internacional Energy Agency*.

LOVE, P. E. D., EDWARDS, D. J., HAN, S. & GOH, Y. M. 2011. Design error reduction: towards the effective utilization of building information modeling. *Research in Engineering Design, 22, 173-187*.

MACDONALD, J. A. 2011. BIM - Adding value by assisting collaboration.

MANZIONE, L. 2013. *Proposição de uma Estrutura Conceitual de Gestão de Processo de Projeto Colaborativo com o uso do BIM.* PHd Dissertation, Univeristy of São Paulo.

MARTINS, J. P. & MONTEIRO, A. 2013. LicA: A BIM based automated code-checking application for water distribuiton systems. *Automation in Construction,* 29**,** 12-23.

MARTINS, J. P. D. S. P. 2009. *Modelação do Fluxo de Informação no Processo de Construção Aplicação ao Licenciamento Automático de Projectos.* Tese de Doutoramento em Engenharia Civil, Faculdade de Engenharia da Universidade do Porto.

MATTEI, P. L. D. R. 2008. *BIM e a Informação no Subsetor de Edficações da Indústria da Construção Civil.* Trabalho de Diplomação, Universidade Fedral do Rio Grande do Sul.

MEIRELES, A. R. 2009. *Building Information Modeling na Mota-Engil Engenharia* [Online]. Available: http://armeireles.blogspot.pt/2009/02/building-information-model-na-mota.html [Accessed 18/02/2013].

MESSNER, J. 2011. *The Uses of BIM* [Online]. Available: http://bim.psu.edu/Uses/default.aspx [Accessed 12/08/2013].

MIENR, M. 2012. Building Information Modeling (BIM). Disponível em: http://www.neuralenergy.info/2009/06/building-information-modeling.html [Acedido em 15/02/2013].

MIRTSCHIN, J. 2012. Engaging Generative BIM Workflows.

MONTEIRO, A. & MARTINS, J. P. 2011. Building Information Modeling - Funcionalidades e Aplicação. *2ºForum Internacional de Gestão da Construção - GESCON 2011, Porto: Faculdade de Engenharia da Universidade do Porto*.

MONTEIRO, A. & MARTINS, J. P. 2012. SIGABIM: a framework for BIM application. *Proceeding of the XXXVIII IAHS World Congress,* April 16-19, 2012, Istanbul, Turkey.

MORA, R., BÉDARD, C. & RIVARD, H. 2008. A geometric modelling framework for conceptual structural design from early digital architectural models. *Advanced Engineering Informatics,* 22**,** 254-270.

MOUM, A. 2010. Design team stories - Exploring interdisciplinary use of 3D object models in practice. *Automation in Construction 19***,** 554 - 569.

MUSAYELYAN, H. 2009. *Architectural design decision suport system.* Master thesis, Faculty of the School of Architecture University of Southern California.

NBIMS 2013. National BIM Standard - United States Version 2. *National Institute of Building Sciences buildingSmart alliance.*

NEWTON 2012. Foundations and Structural Design of the Institute of Systems and Computer Engineering of Porto II. *NEWTON - Consultores de Engenharia Lda*.

NIBS 2007. National Building Information Modeling standard. *National Institute of Building Sciences.*

NIELSON, A. K. & MADSEN, S. 2010. *Structural modelling and analysis using BIM tools.* Dissertation for Master of Science in Civil Engineering, The School of Civil Engineering - Aalborg University.

NIROSH. 2011. *Introduction to Object Oriented Programming Concepts (OOP) and More* [Online]. Available: http://www.codeproject.com/Articles/22769/Introduction-to-Object-Oriented-Programming-Concep#OOP [Accessed 06/01/2013].

OAKLEY, J. 2012. *Getting a BIM Rap: Why Implementations Fail, and What You Can Do About It. AECbytes* [Online]. Available: http://www.aecbytes.com/viewpoint/2012/issue_65.html [Accessed 20/02/2013].

OMNICLASSS. 2013. *A Strategy for Classifying the Built Environment* [Online]. Available: http://www.omniclass.org/index.asp [Accessed 08/09/2013].

REN, Z., YANG, F., BOUCHLAGHEM, N. M. & ANUMBA, C. J. 2011. Multi-disciplinary collaborative building design - A comparative study between multi-agent systems and multi-disciplinary optimisation approaches. *Automation in Construction*, 20, 537-549.

SACKS, R. & BARAK, R. 2010. Teaching Building Information Modeling as an Integral Part of Freshman Year Civil Engineering Education. *Journal of Profissional Issues in Engineering Education and Practice*, 136**,** 30 - 38.

SACKS, R., EASTMAN, C. M. & LEE, G. 2004. Parametric 3D modeling in building construction with examples from precast concrete. *Automation in Construction,* 13**,** 291 - 312.

SALUJA, C. 2009. *A Process Mapping Procedure for Planning Building Information Modeling (BIM) Execution on a Building Construction Project.* Master Thesis, The Pennsylvania State University.

SATSBYGG 2010. Statsbygg BIM Manual 1.2. *Statsbygg Building Information Modelling Manual, Version 1.2.*

SCHINLER, D. & NELSON, E. 2008. BIM and the Structural Engineering Comunity. *STRUCTURE magazine*.

SHEN, W., HAO, Q., MAK, H., NEELAMKAVIL, J., XIE, H., DICKINSON, J., THOMAS, R., PARDASANI, A. & XUE, H. 2009. Systems integration and collaboration in architecture, engineering, construction and facilities managment. *Advanced Engineering Informatics* 24**,** 196 - 207.

SILVA, J. M. S. 2013. *Princípios para o Desenvolvimento de Projectos com Recurso a Ferramentas BIM - Avaliação de melhores práticas e propostas de regras de modelação para projetos de estruturas.* MSc Dissertation, Faculty of Engineering University of Porto.

SIMMONS, A. 2011. *Revit 2011 - Designers Essentials* [Online]. Available: http://simpledesignsense.com/blog/2010/08/27/designeressentials/ [Accessed 09/09/2013].

SINGH, V., GU, N. & WANG, X. 2011. A theoretical framework of a BIM-based multi-disciplinary collaboration platform. *Automation in Construction*, 20**,** 134 -144.

SOLIBRI. 2013. *Solibri and Tekla Leading the Way to BIM-based Collaboration* [Online]. Available: http://www.solibri.com/press-releases/solibri-and-tekla-leading-the-way-to-bim-based-collaboration-2.html [Accessed 19/09/2013].

SUCCAR, B. 2008. *Episode 10: Effects of BIM on project lifecycle phases. BIM ThinkSpace* [Online]. Available: http://www.bimthinkspace.com/2008/11/index.html [Accessed 12/02/2013].

SUCCAR, B. 2009a. Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, 18, 357-375.

SUCCAR, B. 2009b. *Episode 13: The BIM maturity index. BIM ThinkSpace* [Online]. Available: http://www.bimthinkspace.com/2009/12/episode-13-the-bim-maturity-index.html [Accessed 21/02/2013].

SUCCAR, B. 2011. *Episode 16: Understanding BIM Wash. BIM ThinkSpace* [Online].

SUCCAR, B. 2012. *Episode 17: Individual BIM competency. BIM Thinkspace* [Online]. Available: http://www.bimthinkspace.com/2012/08/episode-17-individual-bim-competency.html [Accessed 10/09/2013].

THOMASSEN, M. 2011. *BIM and Collaboration in the AEC Industry*. Master of Science in Engineering - Management in the Building Industry, Aalborg University, Department of Mechanical amd Manufacturing Engineering.

TRELDAL, N. 2008. Integrated Data and Process Constrol During BIM Design: Focuses on Integrated Design of Energy and Indoor Climate Conditions. MSc Thesis, Technical University of Denmark.

VENUGOPAL, M., EASTMAN, C. M., SACKS, R. & TEIZER, J. 2012. Semantics of model views for information exchanges using the industry foundation class schema. *Advanced Engineering Informatics*, 26**,** 411- 428.

WAGNER, L. A. 2002. U.S. Geological Survey Circular 1221. Denver.

WANG, L., SHEN, W., XIE, H., NEELAMKAVIL, J. & PARDASANI, A. 2002. Collaborative conceptual design - state of the art and future trends. *Computer-Aided Design*, 34, 981-996.

WIX, J. & KARLSHØJ, J. 2010. Information Delivery Manual - Guide to Components and Development Methods. *BuildingSMART International*.

WODDY, P. 2012. Introduction to the AEC (UK) BIM Protocols. *White Frog - ThinkBIM.*

WONG, A. K. D., WONG, F. K. W. & NADEEM, A. 2009. Comparative Roles of Major Stakeholders for the implementation of BIM in various countries.

WSP. 2012. *BIM around the world. WSP Group Limited* [Online]. Available: http://www.wspgroup.com/en/wsp-group-bim/BIM-around-the-world/ [Accessed 10/09/2013].

YOUBIM. 2013. *YouBIM - BIM for Facility Management Cloud-Based Solution* [Online]. Available: http://www.youbim.com/ [Accessed 10/09/2013].

ZHANG, J.-P., LIN, J.-R., HU, Z.-Z. & YU, F.-Q. 2012. Research on IDM-based BIM process information exchange technology. *14th International Conference on Computing in Civil and Building Engineering*.

APPENDIX 1 – LOD DEFINITION

The descriptions of the LOD definitions, accordingly to the LOD specification 2013 (BIMForum, 2013) are given bellow:

-<u>*LOD 100:*</u> *The model element may be graphically represented in the model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the model element (i.e., cost per square foot, tonnage of HVAC, etc.) can be derived from other model elements;*

-<u>*LOD 200:*</u> *The model element is graphically represented within the model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Nongraphic information may also be attached to the model element;*

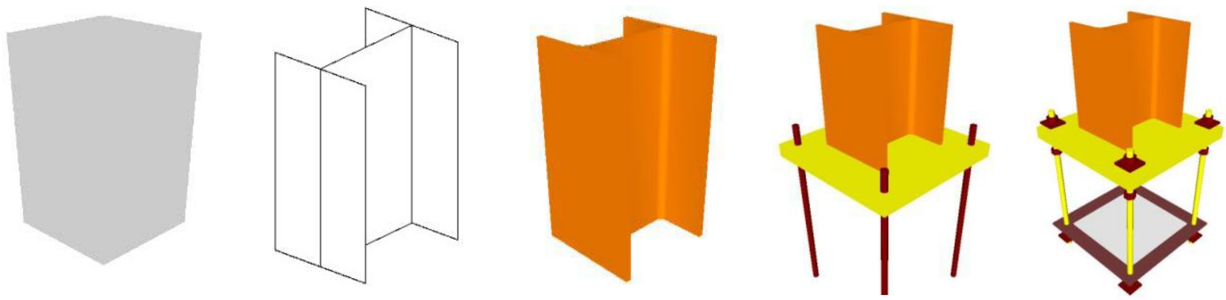
-<u>*LOD 300:*</u> *The model element is graphically represented within the model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the model element;*

-<u>*LOD 350:*</u> *The model element is graphically represented within the model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the model element;*

-<u>*LOD 400:*</u> *The model element is graphically represented within the model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the model element;*

-<u>*LOD 500:*</u> *The model element is a field verified representation in terms of size, shape, location, quantity, and orientation – as built. Non-graphic information may also be attached to the model elements.*

The following figure indicate an example for a steel framing column the, distribution of the LOD definitions:



LOD 100 LOD 200 LOD 300 LOD 350 LOD 400

Figure A.I - Visual comparison of the LOD definition, accordingly to the LOD specification 2013 (BIMForum, 2013).

APPENDIX 2 – MAIN NATIONAL BIM STANDARDS AND GUIDLINES UNDER DEVELOPLMENT

The subsequent table present the main national BIM initiatives, according to the AIA in 2012.

Table A.I – Main national BIM initiatives, according to the AIA in 2012.

Country	Organization	BIM National Standard/ Guidelines Designations	Publication Date
Australia	NATSPEC	NATSPEC National BIM Guide	19-Set-2011
		NATSPEC BIM Object/Element Matrix	
Denmark	Erhvervsstyrelsen (National agency for Enterprise and Construction)	Det Digitale Byggeri (Digital Construction)	01-Jan-2007
Finland	buildingSMART Finland	Common BIM Requirement 2012 (COBIM)	27-Mar-2012
United Kingdom	AEC (UK)	AEC (UK) BIM Protocols	07-Set-2012
Norway	Statsbygg	Statsbygg Building Information Modelling Manual	24-Nov-2011
Singapore	Building and Construction Authority	Singapore BIM Guide	15-May-2012
	CORENET e-submission System (ESS)	CORENET BIM e-submission Guidelines	25-Jan-2010
United States of America	National Institute of Building Science (NIBS) buildingSMART alliance (bSa)	National BIM Standard (NBIMS)	04-May-2012
	American Institute of Architects (AIA) Contract Documents	E202-2008 BIM Protocol Exhibit	2008
	New York City Department of Design + Construction	BIM Guidelines	01-Jul-2012
	United States Department of Veterans Affairs (VA)	The VA BIM Guide	02-Apr-2010
	Indiana University Architect´s Office and Engineering Services	IU BIM Guidelines & Standards for Architects, Engineers and Contractors	02-Jul-2012
	buildLACCD (Los Angeles Community College District)	BIM Design-Bid-Build Standards BIM Design-Build Standards	29-Jun-2011
		LACCD BIM Standards	02-Jun-2010
	United States General Services Administration (GSA)	National 3D-4D Building Information Modeling Program	15-May-2007

APPENDIX 3 – POSTER OF THE SEMINAR: "BUILDING INFORMATION MODELING: POSSIBILITIES AND CHALLENGES FOR THE ARCHITECTURE AND ENGINEERING SECTORS"

Figure A.II –Poster of the Seminar: "Building Information Modeling: Possibilities and challenges for the architecture and engineering sectors" (Sousa and Caires, 2013).

APPENDIX 4 – POSTER OF THE WORKSHOP: "BIM MODELING IN REINFORCED CONCRETE STRUCTURES"

Figure A.III - Poster of the Workshop: "BIM Modeling in Reinforced Concrete Structures" (Silva, Sousa and Caires, 2013)

APPENDIX 5 – SUMMARY OF THE REQUIREMENTS ACHIEVED IN THE PRACTICAL WORK OF THE CURRICULAR UNIT BIM – 2012/2013

The following table summarizes the performance of each group considering the main generic requirements and the essential specific requirements of each discipline outlined in the practical work of the curricular unit “BIM: Conception, Design and Construction” held at the University of Minho between the 20/04/2013 and 17/06/2013.

Table A.II - Generic and specific requirements achieved the groups of the curricular unit BIM: Conception, Design and Construction, held at the University of Minho 2012/2013.

	Group A	**Group B**	**Group C**	**Group D**	**Group E**	**Group F**	**Case Study**
Generic Requirements							
-Structured data management system	✓	✓	✓	✓	✓	✓	✓
-Utilization of classes to define each building element	✓	✓	✓	✓	✓	✓	✓
-Exchanging data between BIM platforms – interoperability		✓		✓		✓	✓
-Creation of IFC models and utilization of BIM viewers	✓	✓	✓	✓	✓	✓	✓
Architecture Requirements							
-Site Modeling and Analyse	✓	✓		✓	✓	✓	✓
-Modeling of the architectural building elements	✓	✓	✓	✓	✓	✓	✓
-Inclusion of the information that define the building elements created	✓	✓	✓	✓	✓	✓	✓
-Automatic extraction of the 2D documentation – architect. BIM model	✓	✓	✓	✓	✓	✓	✓
-Creation of a standard sheet and presenting styles	✓	✓		✓		✓	✓
-QTO analyse and presentation of the results in a defined standard schedule				✓		✓	✓
-Verification of incompatibilities / conflicts among the design specialties	✓	✓	✓	✓	✓	✓	✓
Structural Requirements							
-Modeling of the structural building elements	✓	✓	✓	✓	✓	✓	✓
-Inclusion of the mechanical properties of the objects created	✓	✓	✓	✓	✓	✓	✓
-Calculation of the earthworks						✓	✓
-Interconnection with structural analysis software	✓	✓		✓	✓	✓	✓
-Definition of the structural erection		✓				✓	✓
-Automatic extraction of the 2D documentation – structural BIM model	✓	✓	✓	✓	✓	✓	✓

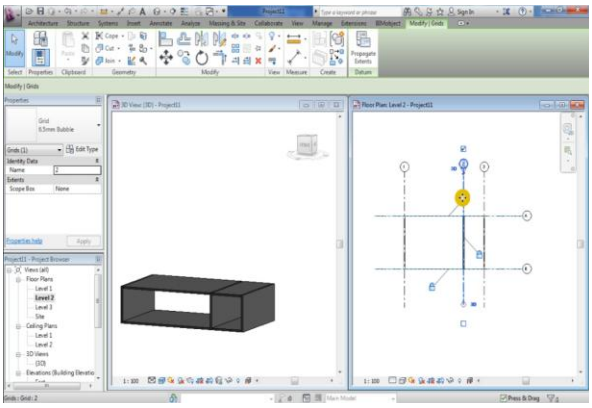
-Detailing of the structural elements (metallic connections/rebar-detailing)	✓	✓			✓	✓	✓
MEP Requirements							
-Detailed modeling of the MEP building elements	✓	✓	✓	✓	✓	✓	✓
-Conflict checking	✓	✓	✓	✓	✓	✓	✓
Contractor Requirements							
-Compilation of BIM models (architectural, structural and MEP)	✓	✓		✓		✓	✓
-QTO analysis	✓	✓		✓		✓	✓
-Segregation of the zones within the BIM model	✓	✓				✓	✓
-Construction management temporal planning (BIM 4D) applying to the Line of Balance Methodology	✓	✓		✓		✓	✓
-Construction management cost planning (BIM 5D)		✓					✓
Percentage of Performance	80%	92%	48%	80%	60%	96%	100%

APPENDIX 6 – AUTHOR´S CONTRIBUTIONS REGARDING THE CURRICULA UNIT BIM – 2012/2013

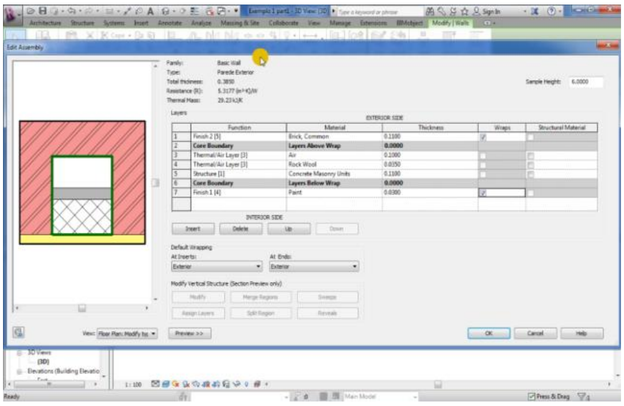
This appendix illustrates the main contributions that were materialized by the author for the development of the curricular unit “Building Information Modeling: Conception, Design and Construction”. All presented content was developed during the phase of preparation of this curricula unit, and guided by its coordinators. The following subsequent points are indicated the content performed:

- **Pedagogical Videos**

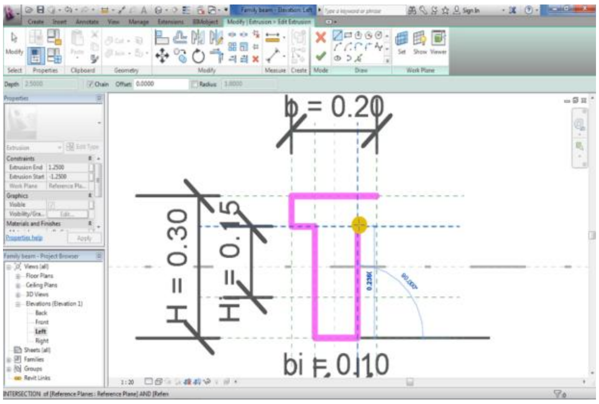
- Parametric modelling applied in BIM – Chapter 2 Parametric Modelling and Objects:



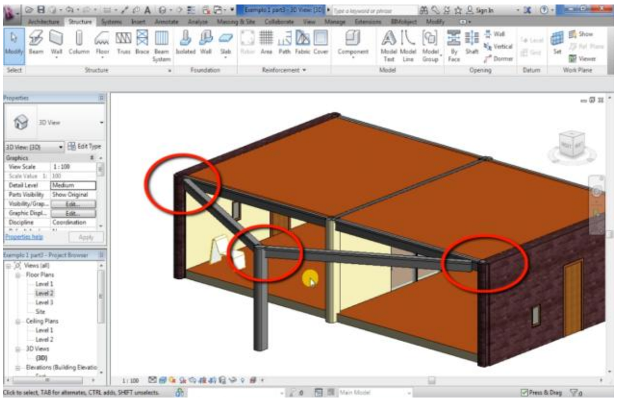
Part 1: Introduction to parametric modelling.



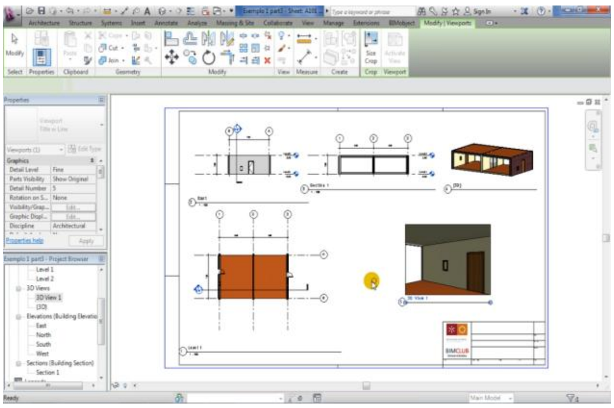
Part 2: Usability of parametric families.



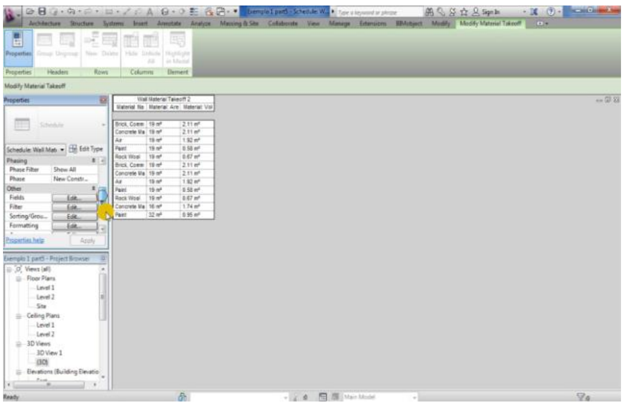
Part 3: Creation, modification and importation of parametric families.



Part 4: Cautions to consider in parametric modelling when applied in BIM.

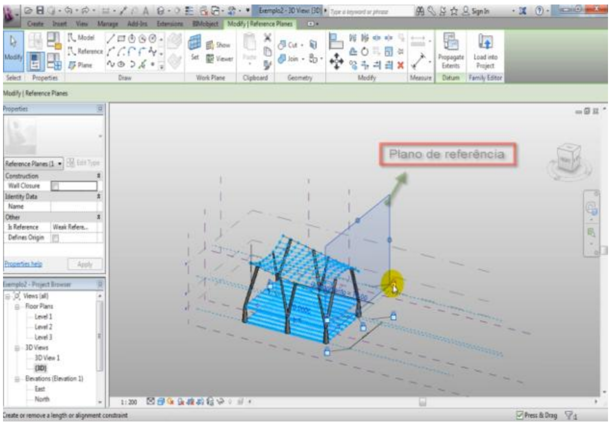


Part 5: Automatic generation of drawings.

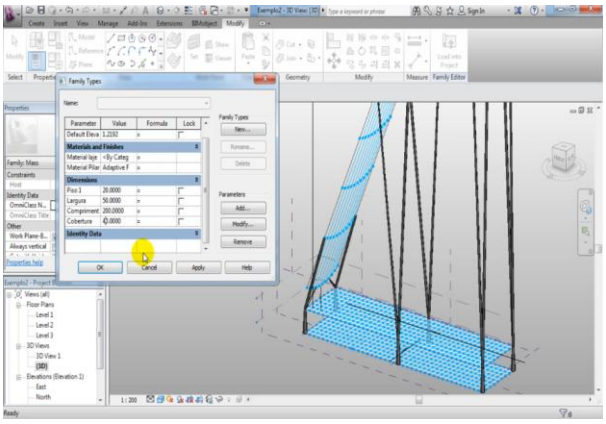


Part 6: Quantity-take-off analysis.

- Parametric model, example – Chapter 2 Parametric Modelling and Objects:

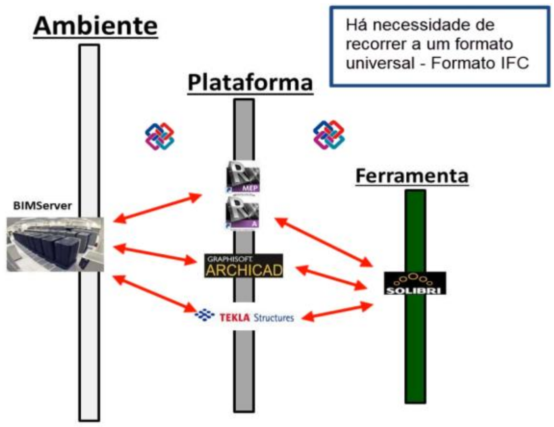


Part 1: Parametric relationships between elements.

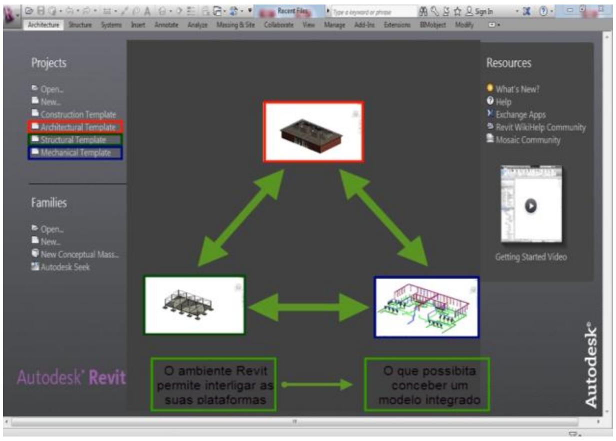


Part 2: Geometric editing using key parameters.

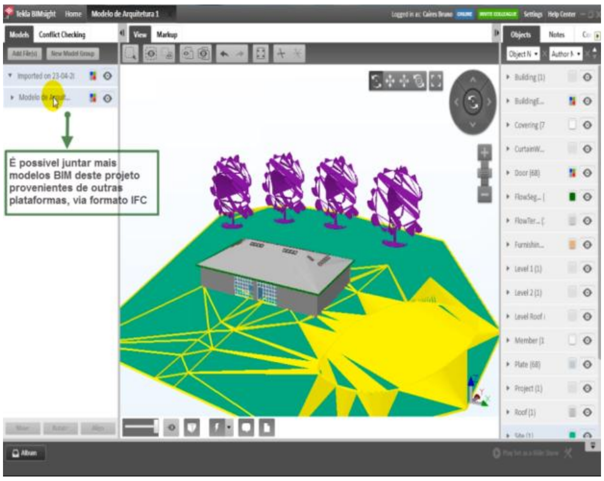
- Interoperability applied in BIM – Chapter 3 Interoperability:



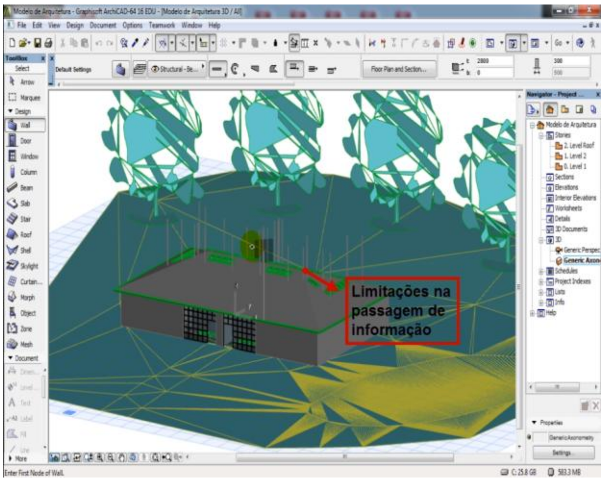
Part 1: Introduction – Concepts of environment, platform and tool.



Part 2: Interoperability between platforms of the same environment.

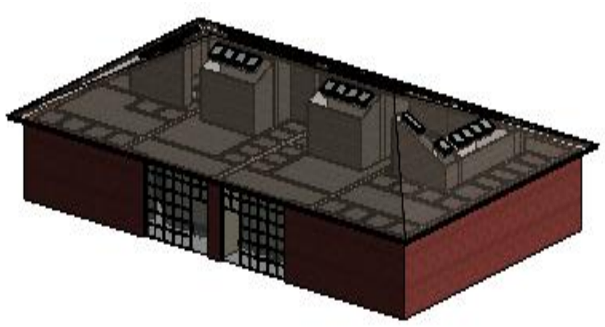


Part 3: Interoperability between platform and tool.

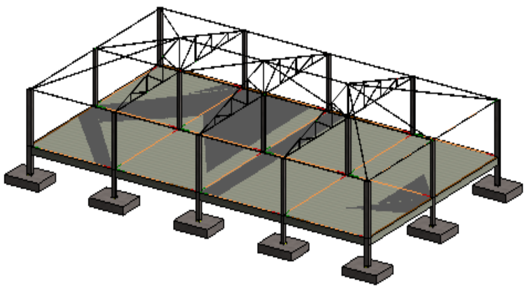


Part 4: Interoperability between platforms of different environments.

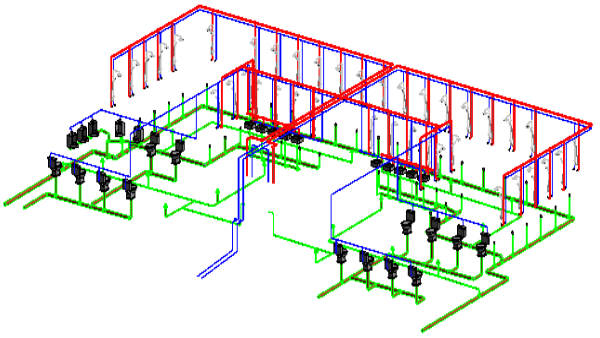
- **Initial project of a sanitary facility similar to that of the practical project, for referencing**



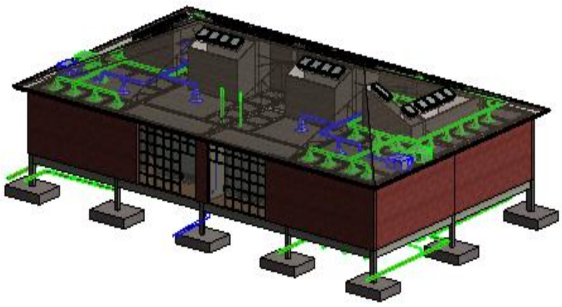
Architectural BIM model.



Structural BIM model.



MEP BIM model.



Central reference model.

APPENDIX 7 – BIM SOFTWARE SUMMARY

This appendix presents a brief summary of the most common BIM applications applied in the current market. These applications shall be organized accordingly to the field of employment, application name, software producer, IFC certification (only in regard to BIM platforms) and student licence availability (see table A.III). It should be noted by selecting the software the reader will be linked to the online website of the respective BIM software.

Table A.III – BIM software summary.

Field of Employment	Application Name	Software Producer	IFC Certification (Export/Import)	BIM Platform or BIM tool	Student Access
Architecture	ArchiCAD	GRAPHISOFT Virtual Building Solutions	Export/Import	BIM Platform	✓
	Revit Architecture	AUTODESK	Export	BIM Platform	✓
	Bentley Architecture	Bentley		BIM Platform	✓
	DDS-CAD Architecture	DDS-CAD		BIM Platform	
	Allplan Architecture	NEMETSCHEK Allplan	Export	BIM Platform	✓
	Vectorworks Architect	NEMETSCHEK Vectorworks	Export	BIM Platform	✓
	Gehry Digital Project	Gehry Technologies		BIM Platform	
Structural Engineering	Tekla Structures	TEKLA	Export/Import	BIM Platform	✓
	Revit Structure	AUTODESK	Export	BIM Platform	✓
	Bentley Structural	Bentley		BIM Platform	✓
	Allplan Engineering	NEMETSCHEK Allplan		BIM Platform	✓
	Scia Engineer	NEMETSCHEK Scia	Export/Import	BIM Platform	✓
	Robot Structural Analysis	AUTODESK		BIM Tool	✓
	CypeCAD	cype		BIM Tool	✓
	Tricalc	Arktec		BIM Tool	
Mechanical and HVAC System	DDS-HVAC	DDS-CAD		BIM Platform	
	Revit MEP	AUTODESK	Export	BIM Platform	✓
	Bentley Mechanical Systems	Bentley		BIM Platform	✓
	Vectorworks Architect	NEMETSCHEK Vectorworks	Export	BIM Platform	✓
	ADT Building Systems	ADT		BIM Platform	
Electrical System	Revit MEP	AUTODESK	Export	BIM Platform	✓
	Bentley - Building Electrical Systems	Bentley		BIM Platform	✓

	DDS-CAD Electrical	DDS-CAD		BIM Platform	
	Vectorworks Architect	NEMETSCHEK Vectorworks		BIM Platform	✓
Plumbing System	Revit MEP	AUTODESK	Export	BIM Platform	✓
	Bentley Mechanical Systems	Bentley		BIM Platform	✓
	DDS-HVAC	DDS-CAD		BIM Platform	
	Pipedesigner 3D	QuickPen		BIM Platform	
	GRAPHISOFT MEP Modeler	GRAPHISOFT Virtual Building Solutions		BIM Platform	
	MEP BIM Integration Suite	ENGworks		BIM Platform	
Infrastructure Planning	AutoCAD Civil 3D	AUTODESK		BIM Platform	✓
	Bentley PowerCivil	Bentley		BIM Platform	✓
Project Managing	DDS-CAD Building	DDS-CAD		BIM Tool	
	Navisworks	AUTODESK		BIM Tool	✓
	Synchro	SYNCHRO		BIM Tool	
	Solibri Model Checker	SOLIBRI		BIM Tool	
	Vico Office	VICO SOFTWARE		BIM Tool	✓
Construction Managing	Allplan BCM	NEMETSCHEK Allplan		BIM Tool	✓
	Vico Office	VICO SOFTWARE		BIM Tool	✓
Facility Management	ArchiFM	GRAPHISOFT Virtual Building Solutions		BIM Tool	
	Bentley Facilities	Bentley		BIM Tool	
	FMDesktop	AUTODESK		BIM Tool	
	Ecodomus	ecodomus		BIM Tool	
	YouBIM	ENGworks		BIM Tool	
	Allplan Allfa	NEMETSCHEK Allplan		BIM Tool	
	Maximo	IBM		BIM Tool	
BIM Open IFC Viewers	TeklaBIMsight	TEKLA		BIM Tool	✓
	BIMx	GRAPHISOFT Virtual Building Solutions		BIM Tool	✓
	Solibri Model Viewer	SOLIBRI		BIM Tool	✓
	DDS-CAD Viewer	DDS-CAD		BIM Tool	✓
	Nemetschek IFC Viewer	NEMETSCHEK Vectorworks		BIM Tool	✓
	Autodesk Design Review	AUTODESK		BIM Tool	✓

APENDIX 8 – PROJECT BIM USES DELIVERABLES & ROLES MATRIX – CASE STUDY

The subsequent table illustrates the project BIM uses deliverables & roles matrix performed by the leading team of the case study, where it was followed the methodology presented in the BIM execution plan framework addressed in chapter 4 of this dissertation, in section 4.3.3.

Table A.IV - Project BIM uses deliverables & roles matrix, case study.

Project BIM uses deliverables & roles matrix			
Case Study			
Project BIM Use Deliverables	**Project members involved in fulfilling the BIM use** (D - Development of the model, editing of data) (U - Usage of the model, no editing of data)		
	Arch.	**Struct Eng.**	**Owner**
Detailed Design			
19. Design Review - Showcase of the design to stakeholders Deliverables: *Detailed Design Review report*	U	U	U
18. Design Coordination - Perform 3D coordination Deliverables: *Detailed Design coordination model and report; Update of the Detailed Design architectural and/or structural model*	U	U	
17. Cost Estimation - Perform final cost estimation Deliverables: *Detailed Design Quantity Take off report; Detailed Design Cost Estimation report*	U	U	
16. Structural Erection Sequence Deliverables: *Detailed Design Erection sequence model*	U	D	
15. Structural Analysis - Structural Analysis (Detailing) Deliverables: *Final detailed design structural model; Detailed 2D drawings*	U	D	
14. Design Authoring - Author the Detailed Design BIM models Deliverables: *Detailed Design Architecture Model; Detailed Design Structural Model*	D	D	
Design Development			
13. Design Review - Showcase of the design to stakeholders Deliverables: *Design Development Review report*	U	U	U
12. Design Coordination - Perform 3D coordination Deliverables: *Design Development coordination model and report; Update of the Design Development architectural and/or structural model*	U	U	
11. Cost Estimation - Perform cost estimation Deliverables: *Design Development Quantity Take off report; Design Development Cost Estimation report*	U	U	

10. Structural Analysis - Structural Analysis (Design) Deliverables: *Design Development analytical structural mode; Report on the structural analysis results; Update of the Design Development structural model*	U	D	
9. Design Authoring - Author the Design Development BIM models Deliverables: *Design Development Architecture Model; Design Development Structural Model*	D	D	
Schematic Design			
8. Design Review - Showcase of the schematic design to stakeholders Deliverables: *Schematic Design Review report*	U	U	U
7. Design Coordination - Perform initial 3D coordination Deliverables: *Schematic Design Coordination Model and Report; Update of the Schematic Design architectural and/or structural model*	U	U	
6. Cost Estimation - Perform initial cost estimation Deliverables: *Schematic Design Quantity Take off report; Schematic Design Cost Estimation report*	U	U	
5. Site Analysis - Site Analysis (earthwork for excavation and building orientation) Deliverables: *Building orientation; Earthwork excavation report; Update of the schematic design structural model*	D	D	
4. Structural Analysis - Structural Analysis (Pre design) Deliverables: *Schematic Design analytical structural model; Report on the preliminary structural analysis results; Update of the schematic design structural model*	U	D	
3. Design Authoring - Author the schematic design BIM models Deliverables: *Schematic Design Architecture Model; Schematic Design Structural Model*	D	D	
Planning			
2. Design Authoring - Author the schematic design BIM models Deliverables: *Preliminary Architectural Model (Mass model)*	D	U	
1. Site Analysis - Site Analysis (building site location) Deliverables: *Site model; Building Location*	D	U	

APPENDIX 9 – BIM INFORMATION EXCHANGE REQUIREMENTS WORKSHEETS – CASE STUDY

In the following tables it is presented the BIM Information Exchange Requirements Worksheets of the performed case study, regarding each project phase. All worksheets were formulated accordingly to the methodology presented in this BEP framework (see section 4.4).

BIM INFORMATION EXCHANGE REQUIREMENTS - Worksheet																																
Case Study - Project Balneary																																
BIM USE Title					Site Analysis		Design Authoring - Initial Arch model		Design Authoring				Site Analysis						Structural Analysis		Cost Estimation				Design Coordination				Design Review			
Tipe of Information Exchange (Output/Input)					OUTPUT		OUTPUT		OUTPUT				INPUT						INPUT		INPUT				INPUT				INPUT			
Time of Exchange (Planning; SD; D.Development; Detailed. D)					Planning		Planning		SD				SD						SD		SD				SD				SD			
Disciplinary BIM Models Involved					Site Model		Arch Mass Model		Arch Model		Struct Model		Site Model		Arch Model		Struct Model		Struct Model		Arch Model		Struct Model		Arch Model		Struct Model		Arch Model		Struct Model	
Model Reciever					CAD		RVT 2014		RVT 2014		RVT 2013		CAD		RVT 2014		RVT 2013		RVT 2013		RVT 2014		RVT 2013		RVT 2014		RVT 2013		RVT 2014		RVT 2013	
Recieve File Format					IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3	
Modeling Standard: COBIM 2012 V1.0	Model Design Features				Info. Requir		Info. Requir		Info. Requir				Info. Requir						Info. Requir		Info. Requir				Info. Requir				Info. Requir			
Model Builiding Element Structure - Talo 2000 Classification	Element Included (Yes/No)	Arch Elements (Yes/No)	Struct Element (Yes/No)	Source	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party
11 Site Elements (Site BIM)																																
Topography	Yes	Yes		Database	100	Arch	100	Arch	100	Arch			100	Arch															100	Arch		
111 Ground Elements																																
1112 Trenches	Yes		Yes	Created																												
1113 Channels																																
1114 Filling on site	Yes		Yes	Database																												
1115 Embankments																																
1119 Other ground elements																																
12 Building Elements																																
121 Foundations																																
1211 Column Footings	Yes		Yes	Database							300	Struct					200	Struct	300	Struct			200	Struct			200	Struct			200	Struct
1211 Pile Footings																																
1211 Wall Footings	Yes		Yes	Database							300	Struct					200	Struct	300	Struct			200	Struct			200	Struct			200	Struct
1212 Enclosure walls																																
1212 Foundation columns																																
1212 Foundation beams	Yes		Yes	Database							300	Struct					200	Struct	300	Struct			200	Struct			200	Struct			200	Struct
1219 Special foundations																																
122 Ground Floors																																
1221 Ground floor slabs	Yes	Yes	Yes	Database			100	Arch	200	Arch	300	Struct			100	Arch	200	Struct	300	Struct			200	Struct			200	Struct	200	Struct	200	Struct
1222 Ground floor ducts																																
1222 Ground floor ducts, grates, covers, hatches, etc.																																
123 Structural Frame																																
1231 Civil Defence Shelter floor																																
1231 Civil Defence Shelter walls																																
1231 Civil Defence Shelter roof structure																																
1231 Civil Defence Shelter closed space, emergency exit corridors and openings																																
1231 Civil Defence Shelter protective doors and hatches																																
1232 Bearing walls	Yes	Yes	Yes	Database			100	Arch	200	Arch	300	Struct			100	Arch			300	Struct			200	Struct			200	Struct	200	Struct	200	Struct
1233 Columns	Yes	Yes	Yes	Database			100	Arch	200	Arch	300	Struct			100	Arch			300	Struct			200	Struct			200	Struct	200	Struct	200	Struct
1234 Beams																																
1235 Intermediate floors																																
1236 Roofing decks	Yes	Yes	Yes	Database			100	Arch	200	Arch	300	Struct			100	Arch			300	Struct			200	Struct			200	Struct	200	Struct	200	Struct
1237 Structural frame stairs and landings																																
1239 Other structural elements																																

Modeling Standard: COBIM 2012 V1.0	Model Design Features				Info. Requir		Info. Requir		Info. Requir				Info. Requir						Info. Requir		Info. Requir				Info. Requir				Info. Requir			
Model Builiding Element Structure - Talo 2000 Classification	Element Included (Yes/No)	Arch Elements (Yes/No)	Struct Element (Yes/No)	Source	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party
124 Facades																																
1241 External wall (bearing wall)																																
1242 Windows																																
1242 External doors	Yes	Yes		Database					200	Arch											200	Arch			200	Arch			200	Arch		
1244 Facade attachments																																
1245 Other facade structures including curtain wall structures																																
125 External decks																																
1251 Balconies																																
1253 External shelters and pergolas																																
1253 Special external decks																																
126 Roofs																																
1261 Roof substructure																																
1262 Eaves																																
1263 Roofing																																
1264 Roof safety products																																
1265 Glass roof structures																																
1265 Wall-like root strcture of glass roof																																
1266 Skylights and hatches	Yes	Yes		Created					200	Arch					100	Arch					200	Arch			200	Arch			200	Arch		
1266 Wall-like root structure of skylights and hatches																																
1266 Others (roof openings)*																																
131 Internal dividers																																
1311 Partitions (non-bearing walls)	Yes	Yes		Created			100	Arch	200	Arch					100	Arch					200	Arch			200	Arch			200	Arch		
1312 Glass partitions																																
1313 Special Partitions																																
1315 Internal doors	Yes	Yes		Database					200	Arch											200	Arch			200	Arch			200	Arch		
1317 Space stairs and landings																																
132 Space surfaces																																
1321 Floor surface elements	Yes		Yes	Created																												
1322 Floorings	Yes	Yes		Database					200	Arch											200	Arch			200	Arch			200	Arch		
1322 Base layer treatment	Yes			Database																												
1232 Ceiling surface elements																																
1324 Ceiling finishings	Yes	Yes		Database					200	Arch											200	Arch			200	Arch			200	Arch		
1325 Wall surface elements																																
1326 Wall finishings	Yes	Yes		Database					200	Arch											200	Arch			200	Arch			200	Arch		
133 Internal fixtures																																
1331 Standard Fiitings	Yes	Yes		Database					200	Arch											200	Arch			200	Arch			200	Arch		
1332 Special fittings																																
1333 Acessories																																
1334 Standard appliances	Yes	Yes		Database					200	Arch											200	Arch			200	Arch			200	Arch		
1335 Internal signage																																
1336 Sanitary fixtures	Yes	Yes		Database					200	Arch											200	Arch			200	Arch			200	Arch		

BIM INFORMATION EXCHANGE REQUIREMENTS - Worksheet																						
Case Study - Project Balneary																						
BIM USE Title					Design Authoring				Structural Analysis		Cost Estimation				Design Coordination				Design Review			
Tipe of Information Exchange (Output/Input)					OUTPUT				INPUT		INPUT				INPUT				INPUT			
Time of Exchange (SD; D.Development; Detailed. D)					D.Development				D.Development		D.Development				D.Development				D.Development			
Disciplinary BIM Models Involved					Arch Model		Struct Model		Struct Model		Arch Model		Struct Model		Arch Model		Struct Model		Arch Model		Struct Model	
Model Reciever					RVT 2014		RVT 2013		RVT 2013		RVT 2014		RVT 2013		RVT 2014		RVT 2013		RVT 2014		RVT 2013	
Recieve File Format					IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3	
Modeling Standard: COBIM 2012 V1.0	Model Design Features				Info. Requir				Info. Requir		Info. Requir				Info. Requir				Info. Requir			
Model Builiding Element Structure - Talo 2000 Classification	Element Included (Yes/No)	Arch Elements (Yes/No)	Struct Element (Yes/No)	Source	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party
11 Site Elements (Site BIM)																						
Topography	Yes	Yes		Database	100	Arch													100	Arch		
111 Ground Elements																						
1112 Trenches	Yes		Yes	Created																		
1113 Channels																						
1114 Filling on site	Yes		Yes	Database			200	Struct					200	Struct							200	Struct
1115 Embankments																						
1119 Other ground elements																						
12 Building Elements																						
121 Foundations																						
1211 Column Footings	Yes		Yes	Database			300	Struct	300	Struct			300	Struct			300	Struct			300	Struct
1211 Pile Footings																						
1211 Wall Footings	Yes		Yes	Database			300	Struct	300	Struct			300	Struct			300	Struct			300	Struct
1212 Enclosure walls																						
1212 Foundation columns																						
1212 Foundation beams	Yes		Yes	Database			300	Struct	300	Struct			300	Struct			300	Struct			300	Struct
1219 Special foundations																						
122 Ground Floors																						
1221 Ground floor slabs	Yes	Yes	Yes	Database	300	Struct	300	Struct	300	Struct			300	Struct			300	Struct	300	Struct	300	Struct
1222 Ground floor ducts																						
1222 Ground floor ducts, grates, covers, hatches, etc.																						
123 Structural Frame																						
1231 Civil Defence Shelter floor																						
1231 Civil Defence Shelter walls																						
1231 Civil Defence Shelter roof structure																						
1231 Civil Defence Shelter closed space, emergency exit corridors and openings																						
1231 Civil Defence Shelter protective doors and hatches																						
1232 Bearing walls	Yes	Yes	Yes	Database	300	Struct	300	Struct	300	Struct			300	Struct			300	Struct	300	Struct	300	Struct
1233 Columns	Yes	Yes	Yes	Database	300	Struct	300	Struct	300	Struct			300	Struct			300	Struct	300	Struct	300	Struct
1234 Beams																						
1235 Intermediate floors																						
1236 Roofing decks	Yes	Yes	Yes	Database	300	Struct	300	Struct	300	Struct			300	Struct			300	Struct	300	Struct	300	Struct
1237 Structural frame stairs and landings																						
1239 Other structural elements																						

Modeling Standard: COBIM 2012 V1.0	Model Design Features				Info. Requir				Info. Requir		Info. Requir				Info. Requir				Info. Requir			
Model Builiding Element Structure - Talo 2000 Classification	Element Included (Yes/No)	Arch Elements (Yes/No)	Struct Element (Yes/No)	Source	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party
124 Facades																						
1241 External wall (bearing wall)																						
1242 Windows																						
1242 External doors	Yes	Yes		Database	300	Arch					300	Arch			300	Arch			300	Arch		
1244 Facade attachments																						
1245 Other facade structures including curtain wall structures																						
125 External decks																						
1251 Balconies																						
1253 External shelters and pergolas																						
1253 Special external decks																						
126 Roofs																						
1261 Roof substructure																						
1262 Eaves																						
1263 Roofing																						
1264 Roof safety products																						
1265 Glass roof structures																						
1265 Wall-like root strcture of glass roof																						
1266 Skylights and hatches	Yes	Yes		Created	200	Arch					200	Arch			200	Arch			200	Arch		
1266 Wall-like root structure of skylights and hatches																						
1266 Others (roof openings)*																						
131 Internal dividers																						
1311 Partitions (non-bearing walls)	Yes	Yes		Created	300	Arch					300	Arch			300	Arch			300	Arch		
1312 Glass partitions																						
1313 Special Partitions																						
1315 Internal doors	Yes	Yes		Database	300	Arch					300	Arch			300	Arch			300	Arch		
1317 Space stairs and landings																						
132 Space surfaces																						
1321 Floor surface elements	Yes		Yes	Created																		
1322 Floorings	Yes	Yes		Database	300	Arch					300	Arch			300	Arch			300	Arch		
1322 Base layer treatment	Yes		Yes	Database			200	Struct					200	Struct							200	Struct
1232 Ceiling surface elements																						
1324 Ceiling finishings	Yes	Yes		Database	300	Arch					300	Arch			300	Arch			300	Arch		
1325 Wall surface elements																						
1326 Wall finishings	Yes	Yes		Database	300	Arch					300	Arch			300	Arch			300	Arch		
133 Internal fixtures																						
1331 Standard Fiitings	Yes	Yes		Database	300	Arch					300	Arch			300	Arch			300	Arch		
1332 Special fittings																						
1333 Acessories																						
1334 Standard appliances	Yes	Yes		Database	300	Arch					300	Arch			300	Arch			300	Arch		
1335 Internal signage																						
1336 Sanitary fixtures	Yes	Yes		Database	300	Arch					300	Arch			300	Arch			300	Arch		

BIM INFORMATION EXCHANGE REQUIREMENTS - Worksheet																								
Case Study - Project Balneary																								
BIM USE Title					Design Authoring				Structural Analysis		Erection Sequence		Cost Estimation				Design Coordination				Design Review			
Tipe of Information Exchange (Output/Input)					**OUTPUT**				**INPUT**		**INPUT**		**INPUT**				**INPUT**				**INPUT**			
Time of Exchange (SD; D.Development; Detailed. D)					Detailed. D				Detailed. D		Detailed. D		Detailed. D				Detailed. D				Detailed. D			
Disciplinary BIM Models Involved					Arch Model		Struct Model		Struct Model		Struct Model		Arch Model		Struct Model		Arch Model		Struct Model		Arch Model		Struct Model	
Model Reciever					RVT 2014		RVT 2013		RVT 2013		RVT 2013		RVT 2014		RVT 2013		RVT 2014		RVT 2013		RVT 2014		RVT 2013	
Recieve File Format					IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3		IFC 2x3	
Modeling Standard: COBIM 2012 V1.0	Model Design Features				Info. Requir				Info. Requir		Info. Requir		Info. Requir				Info. Requir				Info. Requir			
Model Builiding Element Structure - Talo 2000 Classification	Element Included (Yes/No)	Arch Elements (Yes/No)	Struct Element (Yes/No)	Source	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party
11 Site Elements (Site BIM)																								
Topography	Yes	Yes		Database	100	Arch															100	Arch		
111 Ground Elements																								
1112 Trenches	Yes		Yes	Created																				
1113 Channels																								
1114 Filling on site	Yes		Yes	Database			200	Struct							200	Struct							200	Struct
1115 Embankments																								
1119 Other ground elements																								
12 Building Elements																								
121 Foundations																								
1211 Column Footings	Yes		Yes	Database			400	Struct	400	Struct	300	Struct			400	Struct			400	Struct			400	Struct
1211 Pile Footings																								
1211 Wall Footings	Yes		Yes	Database			400	Struct	400	Struct	300	Struct			400	Struct			400	Struct			400	Struct
1212 Enclosure walls																								
1212 Foundation columns																								
1212 Foundation beams	Yes		Yes	Database			400	Struct	400	Struct	300	Struct			400	Struct			400	Struct			400	Struct
1219 Special foundations																								
122 Ground Floors																								
1221 Ground floor slabs	Yes	Yes	Yes	Database	400	Struct	400	Struct	400	Struct	300	Struct			400	Struct			400	Struct	350	Struct	400	Struct
1222 Ground floor ducts																								
1222 Ground floor ducts, grates, covers, hatches, etc.																								
123 Structural Frame																								
1231 Civil Defence Shelter floor																								
1231 Civil Defence Shelter walls																								
1231 Civil Defence Shelter roof structure																								
1231 Civil Defence Shelter closed space, emergency exit corridors and openings																								
1231 Civil Defence Shelter protective doors and hatches																								
1232 Bearing walls	Yes	Yes	Yes	Database	400	Struct	400	Struct	400	Struct	300	Struct			400	Struct			400	Struct	300	Struct	400	Struct
1233 Columns	Yes	Yes	Yes	Database	400	Struct	400	Struct	400	Struct	300	Struct			400	Struct			400	Struct	350	Struct	400	Struct
1234 Beams																								
1235 Intermediate floors																								
1236 Roofing decks	Yes	Yes	Yes	Database	350	Struct	400	Struct	400	Struct	300	Struct			400	Struct			400	Struct	350	Struct	400	Struct
1237 Structural frame stairs and landings																								
1239 Other structural elements																								

Modeling Standard: COBIM 2012 V1.0	Model Design Features				Info. Requir				Info. Requir		Info. Requir		Info. Requir				Info. Requir				Info. Requir			
Model Builiding Element Structure - Talo 2000 Classification	Element Included (Yes/No)	Arch Elements (Yes/No)	Struct Element (Yes/No)	Source	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party	LOD	Resp Party
124 Facades																								
1241 External wall (bearing wall)																								
1242 Windows																								
1242 External doors	Yes	Yes		Database	300	Arch							300	Arch			300	Arch			300	Arch		
1244 Facade attachments																								
1245 Other facade structures including curtain wall structures																								
125 External decks																								
1251 Balconies																								
1253 External shelters and pergolas																								
1253 Special external decks																								
126 Roofs																								
1261 Roof substructure																								
1262 Eaves																								
1263 Roofing																								
1264 Roof safety products																								
1265 Glass roof structures																								
1265 Wall-like root strcture of glass roof																								
1266 Skylights and hatches	Yes	Yes		Created	200	Arch							200	Arch			200	Arch			300	Arch		
1266 Wall-like root structure of skylights and hatches																								
1266 Others (roof openings)*																								
131 Internal dividers																								
1311 Partitions (non-bearing walls)	Yes	Yes		Created	300	Arch							300	Arch			300	Arch			300	Arch		
1312 Glass partitions																								
1313 Special Partitions																								
1315 Internal doors	Yes	Yes		Database	300	Arch							300	Arch			300	Arch			300	Arch		
1317 Space stairs and landings																								
132 Space surfaces																								
1321 Floor surface elements	Yes		Yes	Created																				
1322 Floorings	Yes	Yes		Database	300	Arch							300	Arch			300	Arch			300	Arch		
1322 Base layer treatment	Yes		Yes	Database																				
1232 Ceiling surface elements																								
1324 Ceiling finishings	Yes	Yes		Database	300	Arch							300	Arch			300	Arch			300	Arch		
1325 Wall surface elements																								
1326 Wall finishings	Yes	Yes		Database	300	Arch							300	Arch			300	Arch			300	Arch		
133 Internal fixtures																								
1331 Standard Fiitings	Yes	Yes		Database	300	Arch							300	Arch			300	Arch			300	Arch		
1332 Special fittings																								
1333 Acessories																								
1334 Standard appliances	Yes	Yes		Database	300	Arch							300	Arch			300	Arch			300	Arch		
1335 Internal signage																								
1336 Sanitary fixtures	Yes	Yes		Database	300	Arch							300	Arch			300	Arch			300	Arch		