Universidade do Minho
Escola de Engenharia

Bianca Cavedon Fontana

Information management workflow for the construction and operation phases on a BIM process

BIM A+ European Master in
Building Information Modelling

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Master Dissertation
European Master in Building Information Modelling

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Bianca Cavedon Fontana

RESUMO

Fluxo de trabalho para gestão da informação nas fases de construção e operações em processos BIM

Ao longo do processo de construção, um grande volume de informações precisa ser comunicado, coordenado e trocado. A Modelação da Informação da Construção (BIM) mostra-se como uma ferramenta eficiente para facilitar o gerenciamento e a centralização das informações do ciclo de vida do edifício. No entanto, as informações geradas e solicitadas em cada fase são diferentes e, para serem gerenciadas de forma mais eficaz, requerem um melhor entendimento de seu fluxo de trabalho.

Por este motivo, o objetivo principal desta dissertação é obter um modelo de fluxo de trabalho e requisitos de informação que possa auxiliar todas as partes envolvidas na fase de construção até a fase de operações no controle da gestão da informação BIM junto com seus processos. Esses documentos de gestão da informação foram desenvolvidos a partir de revisão bibliográfica específica, da análise de trocas de informações, formatos e stakeholders envolvidos em cada processo e do modo como as atividades estão interligadas. Esta pesquisa identificou que o envolvimento precoce de todas as partes interessadas pode melhorar a usabilidade da informação em fases posteriores. Além disso, a definição antecipada de parâmetros de informação e especificações técnicas para construção e operação coopera para o uso e aplicabilidade do modelo em diferentes usos do BIM. Além disso, a relevância da verificação e controle da qualidade dos dados foi discutida neste estudo.

Através do desenvolvimento de um modelo de fluxo de trabalho e requisitos de informação, esta dissertação fornece uma visão ampla sobre os tipos de troca, dificuldades e formas de transferência de informações. Concluiu-se que não existe apenas uma solução possível, mas diferentes formas de gerenciar a informação. Para ter bons resultados, a informação precisa de ser planejada desde o início do processo, acordada entre as diferentes partes, testada e verificada. Além disso, as responsabilidades devem ser claramente definidas. Este estudo contribui para a compreensão do fluxo de informações nas fases de construção e operação bem como a maneira de o controlar adequadamente. As conclusões são de interesse para as partes envolvidas na visão estratégica do projeto, onde uma visão global de todas as variáveis do projeto é fundamental.

De maneira geral, os entregáveis deste trabalho poderiam ser utilizados por profissionais envolvidos nos processos BIM para aprimorar o controle da informação e a sua utilização em todo o processo.

Palavras chave: Building Information Modelling (BIM), Fase de Construção, Gestão da informação, Fase de Operação, Fluxo de Trabalho.

ABSTRACT

Throughout the building process, a high volume of information needs to be communicated, coordinated and exchanged. Building Information Modelling (BIM) shows up as an efficient tool to facilitate the management and concentration of the building lifecycle information. Nevertheless, information generated and required in each phase is different, and to be managed more effectively, it requires a better understanding of its workflow.

For this reason, the main objective of this dissertation is to achieve a workflow and information requirements template that could help all the stakeholders involved in the construction phase and operations phase, to control the BIM information management along with their processes. These information management documents are developed based on specific literature review, through the analysis of the type of information exchanges, formats, and stakeholders involved in each process, and the way how activities are linked. This research has identified that the early involvement of all stakeholders can improve the usability of information on further stages. Moreover, the early definition of information parameters and technical specifications for construction and operations cooperate for the use and applicability of the model in different BIM uses. Also, the relevance of data quality verification and control was discussed in this study.

Through the development of a workflow and information requirements template, this dissertation has provided extensive insight into the types of exchange, difficulties and ways for the handover of information. From that, it was concluded that there is not only one possible solution, but different manners of managing this information. However, for it to be successful, it needs to be planned from the beginning of the process, and agreed between different parties, tested, and verified. Furthermore, responsibilities should be clearly defined. This study contributes to the understanding of information flow on construction and operation phases and the way to control it properly. The findings are of interest to stakeholders involved in the project's strategic view, where a global examination of all variables of the project is fundamental.

Generally, the deliverables of this work could be used by professionals involved in the BIM processes in order to enhance information control and the utilisation of the produced information throughout the entire process.

Keywords: Building Information Modelling (BIM), Construction phase, Information management, Operations phase, Workflow.

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1. INTRODUCTION

With the development of the construction industry, projects are becoming more complex as technologies are continually transforming this field. Throughout the building process, from the design to operation phases, a high volume of information needs to be communicated, coordinated and exchanged. The traditional project approach, with the existing information management platforms becomes effortful and inefficient as information is spread and gets lost along the project lifecycle, sometimes without even reach its targeted stakeholders.

As being one of the main standards developed about this subject, Pas 1992-2:2013 defines information management as "*tasks and procedures applied to inputting, processing and generation activities to ensure accuracy and integrity of information*". All stakeholders involved in the project lifecycle require and produce information, which must be interchanged. Nevertheless, in order to be successfully managed, the delivery of information needs to be strategically planned. Each one of the involved parties has to clearly understand what it is needed to perform their tasks and what it is needed to be delivered. Lifecycle information management demands improvement and guidance; thus, it has gained focus by the construction industry. One of the leading publications in the past years on digital information management focusing on the building and civil engineering works is the ISO 19650 international series standard. ISO 19650 approaches information management using building information modelling as an effort to guide and standardise information exchange on building projects.

Building Information Modelling (BIM) appears as an efficient tool to help centralise and manage the information on the construction lifecycle (Xu et al., 2014). BIM is a digital process and an information management approach that can be applied to enhance projects quality and increase productivity in the construction sector (EFCA, 2019). Furthermore, BIM adoption is a crucial response to the challenges faced in the design and construction phases as the market seeks for cost reduction, sustainable projects and efficient development (Sacks et al., 2018). When BIM is used during different phases, it is preconised collaboration. Building models from the design phase are required to include the necessary information for being used and extracted on the other phases, namely during construction and operation stages (Sacks et al., 2018).

Despite BIM improvements in centralising information and efforts on standardising information management, some adversities regarding mainly interoperability, information accuracy, delivery format and poor information requirements were reported in different researches. For instance, difficulties such as lack of BIM experience to require information is mentioned by Cavka et al. (2017), and issues on importing and using information from design and construction phases for operations was reported by Pishdad-Bozorgi et al. (2018). These examples brought attention to the need for more profound studies on the field of information management using BIM.

Information generated and demanded in each phase is different. To be managed more effectively, it requires a better understanding of its workflow on the construction phase. EFCA (2019) states that a great part of significant projects in Europe are applying BIM, so it is not a matter of convincing the industry about its benefits, but instead on instruct it on how to manage information delivery processes. Therefore, to respond to these challenges, the analysis of the information process and exchanges that occur between different stakeholders from the construction to the operation phases, is essential in order to achieve some outputs and conclusions that could help the BIM community to enhance the information management on a BIM process. The final challenge of this subject is to try to frame how the information produced in the design phase could be used throughout construction and operation and adapt it to each different projects.

1.1. Objectives

In order to better understand the information workflow and then to efficiently manage it, it is keen to map how to control and systematically process information along the construction to the operation stages on BIM processes. The main objective of this dissertation is to achieve a workflow and information requirements template that could help all the stakeholders involved in the construction phase and the operation phase control the BIM information management along with their processes. This will be achieved through the partial objectives for the development of this research, like identifying current difficulties on information exchange on the construction, handover and operation processes, verifying existent information management studies on BIM processes, setting information requirements for these stages, developing a process map to systematise the information flow, and validating the applicability of the results through the feedback of BIM professionals.

1.2. Partnership for the dissertation

This work was developed with close connection with BIMMS - BIM Management Solutions Lda, an international BIM consulting company that works on BIM Modelling, and BIM Project Coordination on medium to large projects. Despite the difficulties inherent to the pandemic period limitations, there was provided the conditions to work side by side with the company trying to define the needs and identifying the problems related to this subject. The colleagues involved were an important asset to criticise, and validate this work, therefore improving its initial status.

Also, this research was produced in a close relationship with the work dissertation “Guidelines for BIM Information Management at Design stage” developed by Terrosi (2020). The purpose of this collaboration was to split the BIM process into two parts (i.e. the design stage on one side, and the construction and operations on the other) so a more in-depth investigation of information management processes could be executed, obtaining better results for the partner company.

1.3. Structure of dissertation

This dissertation is organised into six sections. In the first three chapters, the base for the work is established. The first chapter aims to introduce the topic, present work motivations and a general panorama of the current situation of information management in BIM processes. Also, it exposes the objectives and goals aimed at this work. The second chapter comprehends a literature review about the topics considered essential to support the development of the work, mainly involving BIM and Information Management. Within BIM, general concepts, contract methods, interoperability and exchange formats, BIM lifecycle and software were reviewed. On the information management review, concepts and standards on the field are presented, as well as a review on related researches on information management on BIM processes, and difficulties and problems reported for construction, handover and operation. The third chapter of this work focuses on explaining the methodology used for the development of the proposed workflow and information requirements template.

The last three chapters concern the development and validation of the work. Chapter four presents the development of the workflow and information requirements template for information management involving construction, handover and operation phases. Also, the considerations on the work are presented and explained. Chapter five displays the validation of the deliverables of work. Besides a parallel process along the whole dissertation production, the validation is ultimately executed through a questionnaire with the BIM specialist partner company, and the proposed work is evaluated and analysed, mentioning possible improvements to the research work. The last chapter presents the conclusions of the work and suggestions for future development.

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2. LITERATURE REVIEW

This chapter presents an in-depth view of the main subjects that comprise information management for construction and operation phases. Initially, some aspects of BIM are discussed, such as interoperability and construction lifecycles. Then, works carried out on information management are introduced, like standards, commonly used BIM tools, methods, and issues are presented.

2.1. Building Information Modelling

2.1.1. General Overview

As defined by the National Institute of Building Sciences (NIBS, 2008), BIM can be described as "*an improved planning, design, construction, operation, and maintenance process using a standardised machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle*". In addition to this definition, Sacks et al. (2018) describe BIM as "*a modelling technology and associated set of processes to produce, communicate, and analyse building models*."

The benefits that BIM has brought to projects add value to all construction project lifecycle. For instance, it enhances design quality, improves prefabrication, adds efficiency to the construction schedule as it enables simulations, and improves the delivery of valuable information to the facility operator (Messner et al., 2019). Also, it allows earlier visualisation of project design, an earlier collaboration between different stakeholders, it cooperates for design errors and omissions detection, and to the extraction of quantities for cost estimations in a precise way (Sacks et al., 2018).

On a survey presented on the "National BIM Report 2019" carried out by NBS (2019) with 988 construction industry professionals, it is shown that the major effect stated on BIM use by these professionals is that BIM adoption requires a change in workflow, practices, and procedures (nearly 90%). Also, it increases coordination on construction documents (nearly 80%). These two aspects are both relevant from the perspective of BIM users and non-users, as can be seen in Figure 1. On this circumstance, it sustains the topic explored in this dissertation, as changes in work practices require the improvement of control of information processes. Other effects of BIM adoption are that clients and contractors have the tendency of requesting the use of BIM (61% agree on that), and that it can bring cost efficiency to the work process.

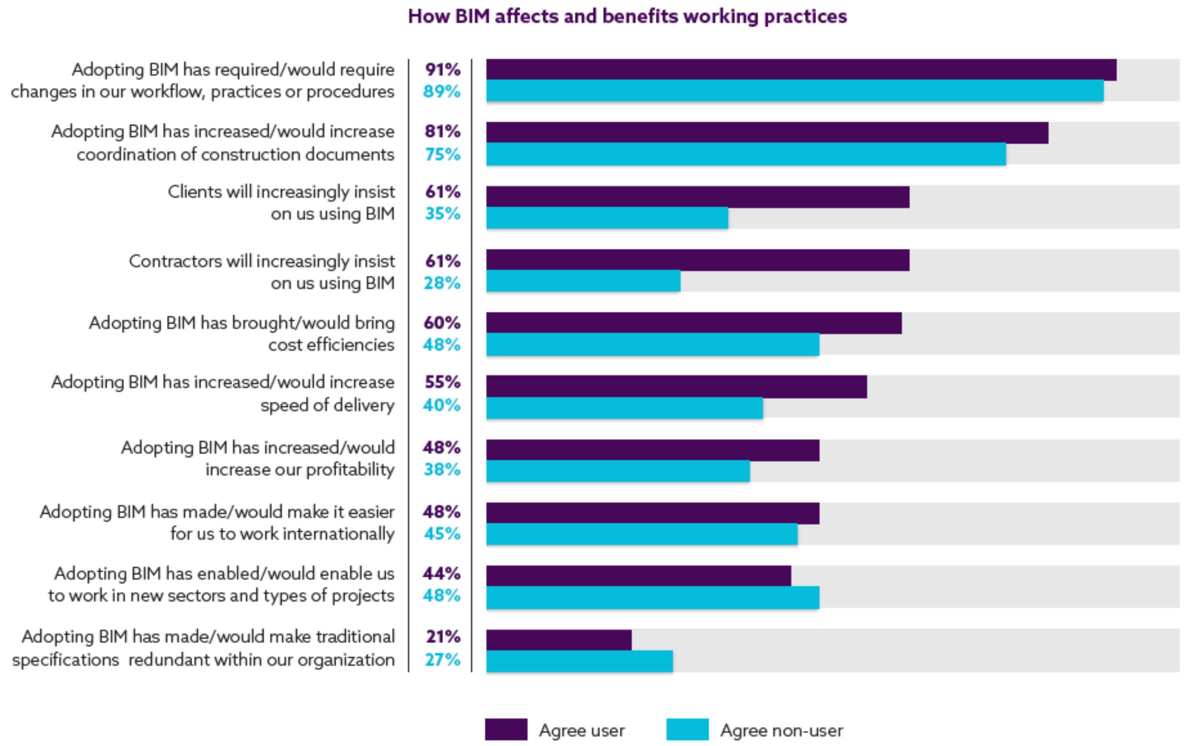


Figure 1 – Survey on How BIM affects and benefits working practices (NBS, 2019)

2.1.2. Contract Methods

The type of contractual method adopted on a project influences the exchange of information, on BIM development, and the participation and engagement of stakeholders (NIBS, 2017). The principal used types are: Design-Bid-Build (DBB), Design-Build (DB), Construction Management at Risk (CM@R) and Integrated Project Delivery (IPD) (Sacks et al., 2018).

In Design-Bid-Build (DBB), the owner contracts a designer to develop the project design under the owner's requirement. This design is put out for bid, and the owner chooses a constructor, and later goes for construction. In this sense, in DBB, during the design stage, the project gets limited or none contribution of the construction parties (AIA, 2007).

On the second type of contract mentioned, Design-Build (DB), the main feature is that the design and construction are responsibility of one single contract, which is typically with the general contractor. This method reduces the project risk for the owner and also the project schedule as the design and construction phases overlap (Kubba, 2017). The contractor develops the design and building program following the owner's needs, estimates total cost and schedule and the owner approves it or requests modifications early in the process. However, after this initial design approval, there is little flexibility for changes (Sacks et al., 2018).

Another type is Construction Management at Risk (CM@R), where a construction manager is hired at the beginning of the design phase, in addition to the constructor, to manage cost, schedule, and building techniques. CM@R. like in DBB, offers the benefit of the involvement of inputs about the construction and cost on an early stage, and differs from DB as the design is still responsibility of a different designer, contracted separately by the owner (AIA, 2007).

Finally, the Integrated Project Delivery (IPD) is a project delivery method that, differently from the fragmented and linear traditional methods, involves all the stakeholders (owner, designers, contractors, facility managers, operators) from the early stages of the project until handover. This collaborative approach on integrated projects aims to properly meet owner requirements with cost and time reduction (Sacks et al., 2018).

One of the IPD benefits mentioned by AIA (2007) is the early engagement of key participants. At this point, the contribution of all stakeholder's expertise improves decision making and aid as knowledge is included in the stage where it can cause more impact. Owners are capable of analysing project options that satisfy their business goals, constructors can share construction knowledge to enhance project quality, and designers benefit from these early inputs to achieve improved project solutions. As a result, projects are more likely to achieve the desired quality, cost, schedule, and goals. Other benefits raised by AIA (2007) are the open communication between all stakeholders, the incentive to innovation, and the savings and efficiency of the execution phase due to intense planning.

IPD is a project method that is not linked to any specific technology, but BIM is quoted as one of the appropriated processes to be used. In this aspect, BIM is a platform that allows the necessary integration and collaboration that an IPD contract needs (AIA, 2014). Sacks et al. (2018) also state that BIM has demonstrated to be one major enabling technology for IPD, as models created in the design phase include information of other phases and are used for fabrication, construction, and operation. For that, the used technologies and processes must allow interoperability and data exchanges.

2.1.3. Interoperability

Interoperability is defined by ISO 25964- 2:2013 as the "*ability of two or more systems or components to exchange information and to use the information that has been exchanged*". In the BIM context, interoperability is a key factor to allow collaboration and integration. The proper exchange of data between different applications facilitates information workflows and automation and helps the reduction of manual work on copying data from one application to another (Sacks et al., 2018).

In projects where different stakeholders and software are involved, it is vital to guarantee information interoperability, to enable outputs from one party to be opened, verified, and used by others involved in the process. Project deliverables have to be used throughout the entire project lifecycle, and interoperability ensures that information is useable and with no necessity of the rework of entering it again (EFCA, 2019). Figure 2 presents the loss of information that occurs among stakeholders between different project phases either on a traditional method either with BIM, demonstrating the importance of interoperability.

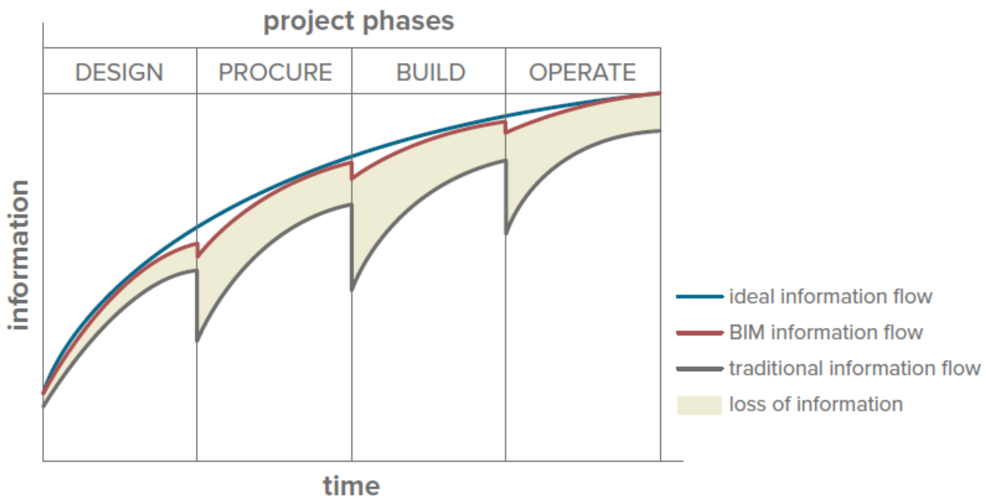


Figure 2 – Information flow throughout the project lifecycle (EFCA, 2019)

Interoperability should support baseline data (in this case, BIM models) and the analyses results of operations such as clash detection, cost simulations, and construction simulations. For that, the recommendation is to use open standardised formats, that allow exchanges independently of specific software companies (EFCA, 2019).

Within this concept, one of the most known and used is the IFC (Industry Foundation Classes). The IFC is an open, standardised data schema for the built environment. Initiated and maintained by buildingSMART, IFC is used to exchange information between different software and interfaces of different vendors (buildingSMART International, 2020). IFC data has the possibility of being presented in XML, JSON, and STEP formats and used in different ways, such as web services, files, and databases (buildingSMART International, 2020).

In terms of interoperability between earlier phases and the operations and maintenance phase, an international standard existent for non-geometric information exchanges in an open data format is COBie. COBie (Construction-Operations Building information exchange) is a data specification created for facility asset information delivery to provide a system information exchange of spacing and equipment. COBie idea is to allow the design team to organise building information necessary for facility management during design and construction phases and deliver this data to be imported and used in Computerized Maintenance Management System (CMMS) and Computer-Aided Facility Management (CAFM) (WBDG, 2016).

2.1.4. BIM throughout the building lifecycle

Worldwide, it exists numerous plans of work and manuals that help guiding stakeholders throughout the building lifecycle stages. Each of these documents deals differently with the building lifecycle and divides the project, construction, and operation phases on distinct stages (RIBA, 2020). In Figure 3, a comparison between the lifecycle phase division used in international plans of works is presented, based on the RIBA Plan of Work 2020. Notably, differences occur on the segmentation on design phase, on the nomenclature for phases after design, and the inclusion or not of handover and in-use phases.

Table 1 – Lifecycle phases comparison of international plans of work - adapted from (RIBA, 2020)

Generic Stages	Pre-Design		Design				Construction	Handover	In Use		Other
AIA (USA)											
			Schematic Design		Design Development	Construction Documents	Construction				
ACE (EU)	0	1	2.1	2.2	2.3	2.4	5				
	Initative	Initiation	Concept Design	Preliminary Design	Developed Design	Detailed Design	Construction		Building Use		End of Life
RIBA (UK)	0	1	2		3	4	5	6	7		
	Strategic Definition	Preparation and Brief	Concept Design		Developed Design	Technical Design	Construction	Handover & Close Out	In Use		
PAS 1992:2 (UK)		1	2	3		4	5	6	7		
		Brief	Concept	Definition		Design	Build & Comission	Handover & Closeout	Operation	In Use	
NATSPEC (AUS)											
		Establishment	Concept Design	Schematic Design	Design Development	Construction Documentation	Construction		Facility Management		
Penn State (USA)											
	Plan	Design					Construct		Operate		
BIMe Initiative	2000	3000				4000	5000		6000	7000	8000
	Capturing & representing	Planning & Designing				Simulating & Quantifying	Constructing & Fabricating		Operating & Maintaining	Monitoring &Controlling	Linking & Extending

When BIM is used, it is essential to have since the beginning of the project clear goals for the entire lifecycle use of the facility. Also, it is vital to tackle how all stakeholders will use BIM (Kreider and Messner, 2013). That being, the stakeholders involved in Construction and Operation phases can require the necessary data on BIM models for their phases (Rail Baltica, 2019). As can be seen in Figure 3, the initial strategy of the project should consider all the uses throughout other phases in the information requirements, such as Asset Information Requirements (AIR) and Employer's Information Requirements (EIR). Each new use intended for the model generally demands additional information to be added, in order to support the contractor activities for different construction work processes, as estimating, construction planning, and components fabrication (Sacks et al., 2018).

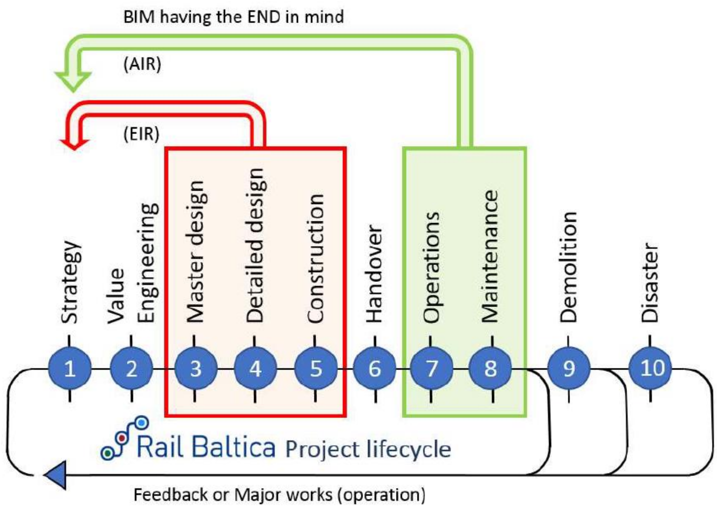


Figure 3 – Rail Balica Project lifecycle example (Rail Baltica, 2019)

In order to obtain good results when applying BIM in different phases, it is fundamental to have well defined the key goals in each phase, the BIM objectives, and necessary level of detail (RICS, 2014). Therefore, the following descriptions intend to bring up some of the possible uses and objectives in each one of the phases (pre-construction, construction, handover and operations and maintenance) that are the main focus of this dissertation.

2.1.4.1. Pre-construction / Construction planning and management

Some of the BIM-related activities in this phase involve cost, scheduling and risk management. In this stage, quantity surveyors can do a quantity take-off of the modelled items and calculate separately items that cannot be quantified, in order to develop the cost plan. (RICS, 2014).

Also, the link of the project schedule with BIM models allows creating simulations of construction sequencing, allowing the analysis of critical areas and critical path (Rail Baltica, 2019). This phase planning, also known as 4D model, can provide a better comprehension of the schedule by the owner and involved team and identify workspace conflicts before going to the construction (Penn State, 2019).

2.1.4.2. Construction

The construction phase depends on the design phase outputs (Rail Baltica, 2019). The model, in this phase, is referred sometimes as “construction model” or “field BIM”. One of the BIM-applications is to improve the design comprehension and the understating of items to be constructed and its sequencing. Some tools, such as information management platforms, with model visualisation, can help communicate the project for the construction teams. Furthermore, it is possible to design temporary works, plan site layout, fabrication drawings, and track construction progress (RICS, 2014). On Rail Baltica BIM Manual (2019), for instance, the model used in the construction had the functions of visualisations and construction progress report. In order to do the field progress tracking, construction updates are added on objects in the construction model according to the Work Breakdown Structure (WBS), through attributes created in the model for that purpose.

On the SmartMarket report of McGrawHill Construction (2014), the result of their survey shows that the main selected BIM activity during construction by the contractors is using a model-driven layout in the field (59%), as seen on Figure 4. The second activity most selected was model-driven prefabrication (43%). This process of premanufacturing offsite in a controlled environment is highly benefited by BIM uses as the constructability of elements can be foreseen in the models, guarantying more assertive elements. Others BIM uses considered for the construction phase were progress monitoring (40%), augmented reality for visualisation (32%), and the use of laser scanning to validate models (23%).

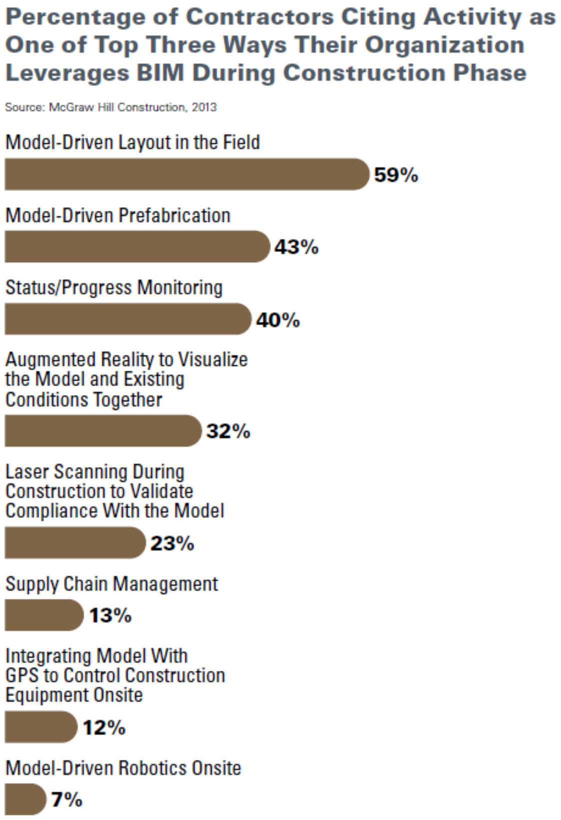


Figure 4 – Top BIM activities of contractors during construction (McGrawHill Construction, 2014)

2.1.4.3. Handover

The use of BIM in facility management depends on the information exchange process and the integration between them (RICS, 2014). Ideally, the BIM model detains information from different stakeholders collected throughout the design and construction phases, creating a database, and then transferred to facility managers (Pishdad-Bozorgi et al., 2018). However, one of the challenges in this phase is precisely how to transfer this information. Common file formats in BIM tools are not always supported by FM software, as the use of BIM in this stage is still in development. On account of this, owners and facility managers need to verify the formats accepted by current FM tools, in order to either find an intermediate solution to link information or to plan of transitioning to BIM-FM tools (Sacks et al., 2018).

Traditionally, as projects were developed in CAD, designs and documentations were handed over in paper or individual different computer files, leading to a manual task to input all data into the FM software. In the current scenario, COBie spreadsheets is the existent standard for this integration. However, as soon as BIM is applied with higher maturity levels, other types with higher integration take place, as seen in Figure 5 (RICS, 2014). On these scenarios, the aimed solution is the direct integration of the BIM model with the facility management system, avoiding the intermediate steps.

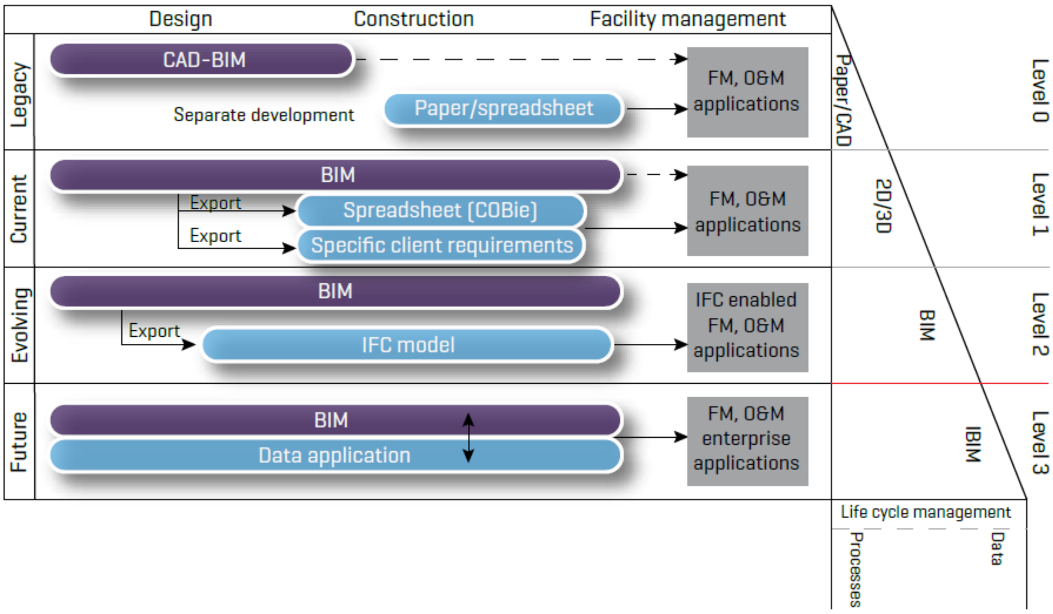


Figure 5 – FM and BIM Maturity Levels (RICS, 2014)

2.1.4.4. Operations and Maintenance

While the Design and Construction phases generally employ a file-based approach and utilise models that contain geometry and data information, stored in a Common Data Environment, the Operation and Maintenance phase is focused on a data-based approach stored in an Asset Register (Rail Baltica, 2019). During the operations and maintenance phase, BIM can be used to plan and perform the building maintenance, operate assets, manage and monitor energy efficiency. For facility managers, the BIM model serves as a source of information for facility management systems, such as CAFM (computer-aided facility management) (RICS, 2014).

When this link between model and FM system is bi-directional, it allows the use of model data to populate and maintain the database of the management system for FM operations and the visualisation of assets in the model (Penn State, 2019). Besides the visualisation, it provides information such as the precise location, relationship with other equipment and existing condition data, that can be accessed in the field (GSA, 2011).

2.1.5. BIM software for owner, contractors and facility managers

Throughout all building lifecycle, for BIM to be implemented and used efficiently, the process depends on adequate software and tools. For the phases explored in this dissertation, there are tools on the market that allow the use of information for the needed uses of owners, contractors, and facility managers. It is essential to know the available options, their functions, capabilities, accepted formats and interoperability with other software in the process, in pursuance of an optimised process. In a project, software should be chosen to assist the selected BIM uses. The number of existing BIM software on the market is continually increasing, and organisations should understand which needs the software has to support (CICRP, 2013).

A key concept when dealing with information management is the understanding of Common Data Environment (CDE). Defined in ISO 19650-1 (2018), CDE is an "*agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process*". According to ISO 19650-1 (2018), a CDE should be implemented so all the parties can access the information needed to perform their work. Furthermore, it mentions that there are different ways and technologies for doing that. In BIM processes, it becomes crucial establishing a CDE to centralise and systematically process communication and interchange of information throughout the project stages. In order to meet this demand, several platforms are available on the market, such as Asite, Trimble Connect, Bentley ProjectWise, Autodesk BIM 360, Conject, Acconex, Bimsync, Allplan Bimplus, just to mention some.

For the pre-construction phase, where the main focus is cost and planning, some of the available tools are: Navisworks Manage, Synchro Professional, Vico Office, CostX, Assemble Systems, DProfiler, ITwo, Bexel Manager, Navigator, Alice AI Simulation Platform, Primus. The main features of these tools are to allow contractors to simulate schedules, in order to check the phasing and schedule planning, to perform quantity take-offs and to make cost estimations linked with the model. Their difference consists of some of them being able to work with planning and costs, and others focusing on only one of these parts.

On the construction stage, BIM tools can provide the contractor access and visualisation of models, documents, and details necessary for construction. Also, it can allow communication between different stakeholders, requests for information, and register of changes on site. Some of the existing tools that enable visualisation and construction information management are Autodesk BIM 360 Field, StreamBIM, Tekla BIMsight, SiteVision, SYNCHRO Field, Dalux Field, Trimble Connect, BIM Track, BIMx, Finalcad. Furthermore, other technologies serve other purposes on the construction site rather than only visualisation. For instance, Verity compares point clouds with BIM models to check and analyse what was built over what was designed to identify construction mistakes easier.

The software used on operations and maintenance phase in BIM projects are mainly software that use BIM models and data to operate the facilities management. Most of these software have features that allow the facility manager to access asset location and information, execute asset maintenance and plan maintenance procedures. One aspect that needs to be researched when selecting and FM software is the accepted format as input. It is necessary to identify if the software reads open formats, like IFC, or if an integration step through spreadsheets or database format should be executed. Some of the software found for FM operations using BIM are Archibus, Ecodomus FM, Bexel Manager, FM:Systems, Maximo Asset Management, Planon, YouBIM, Spacewell, AssetWORKS.

The summary of the mentioned software and its related phases can be seen in Figure 6.

GENERAL	PRE CONSTRUCTION	CONSTRUCTION	OPERATIONS
• Acconex • Allplan Bimplus • Asite • Autodesk BIM 360 • Bentley ProjectWise • Bimsync • Conject • Trimble Connect	• Alice AI • Assemble Systems • Bexel Manager • CostX • DProfiler • ITwo • Navisworks Manage • Navigator • Primus • Synchro Professional • Vico Office	• Autodesk BIM 360 Field • BIM Track • BIMx • Dalux Field • Finalcad • SiteVision • StreamBIM • SYNCHRO Field • Tekla BIMsight • Trimble Connect • Verity	• Archibus • AssetWORKS • Bexel Manager • Ecodomus FM • FM:Systems • Maximo Asset Management • Planon • YouBIM • Spacewell

Figure 6 – Software list

2.2. Information Management

2.2.1. Information management overview

Information is generated at all stages of the project, and has to be well managed in order for a project to be successful. BIM appears as an innovative way for managing project information that is exchanged between all parties, for verifying the quality of it and increasing trust on the accuracy of what is being shared (EFCA, 2019). Information is defined by ISO 19650:1 as the "*representation of data in a formalised manner suitable for communication, interpretation or processing*". It can be classified as structured (geometrical models, schedules and databases or unstructured (documentation, sound recordings). Another essential concept is the definition of information management that PAS 1992-2 describes as methods and processes used to guarantee the accuracy and integrity of information on activities that occurs on the input, process and output of it.

In a general way, information management is a process to ensure that a specific information that was created for a pre-defined purpose is handed over to the correct place at the correct time (UK BIM Framework, 2020). According to the PMI (2017), the manner that information is stored, accessed and exchanged need to take into consideration some factors that can influence this process. For instance, it is necessary to understand who needs each information, who can have access to it, when this information is needed and where can it be found. Other important concerns are related to which is the information format, how to access it and any barriers that may appear, such as cross-cultural differences.

Turk (2006) presents that construction processes can be classified as information processes, where information is the main inputs and outputs. When analysing these processes, it is possible to break it up into processes that create, use and connect ("glue") the information. Information is created through the process phases of input, editing, recording and then is distributed as an output. The ideal situation is where the outputs of this process can be directly used as input on the next process. However, commonly it is necessary a "glue" process, as shown in Figure 7, that integrates the output of one process to the input of the next one. This process consists of finding the information output, retrieving it and, converting it to the necessary format for the next input.

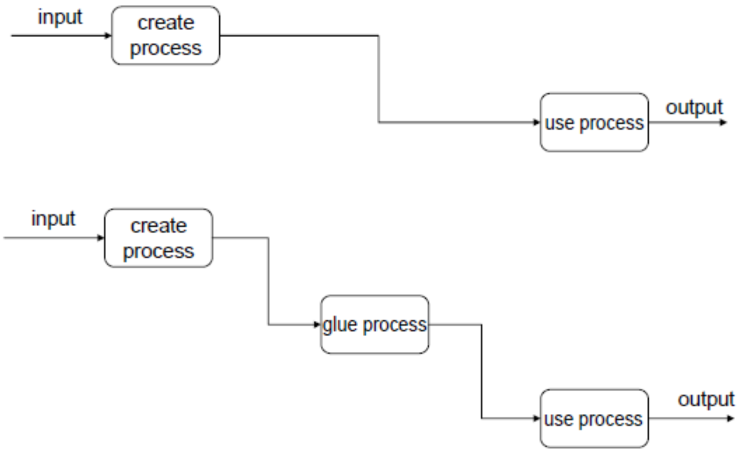


Figure 7 – Process – Process relations (Turk, 2006)

Succar and Poirier (2020) proposed an information management framework, the "Lifecycle Information Transformation and Exchange (LITE) framework", to facilitate the delivery of an information management platform for the whole project asset's lifecycle, that is digital and based on open-access. The LITE framework intends to represent the way information systems and information management function for physical and digital assets. It considers that information can be preserved on the transformation from digital format to a physical product if appropriately managed. Information can be comprehended in three states. The first one is the defined purposes, where the intentions and reason for delivering a new asset are concentrated. The second state is the deliverable, that is the definition of what it is aimed to be achieved. The third one is the state of methods and resource that are human and machine actors needed to deliver that asset. The framework, shown in Figure 8, presents eight milestones in which information pass over during an asset's lifecycle. They are divided between target status and actual status. The targeted status that is above the line consists of the ideas and goals for the asset. Differing from this is the actual status, below the line, that is related to the digital and physical asset.

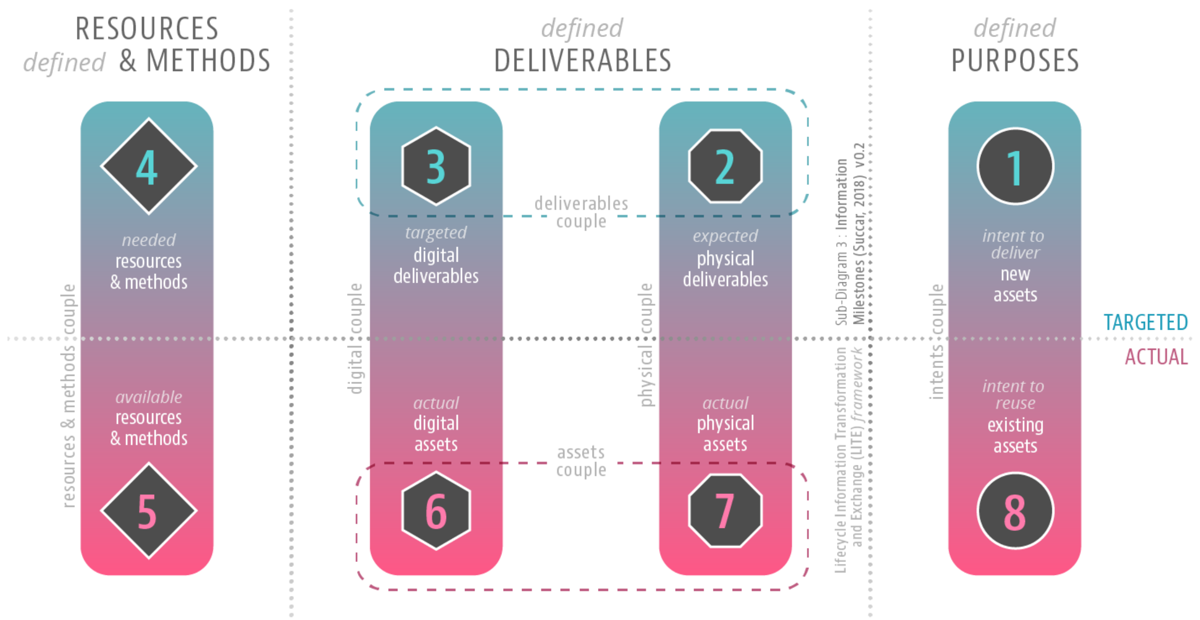


Figure 8 – Information milestones (Succar and Poirier, 2020)

For information to flow from being a new asset idea to an actual existing asset, it goes through the stages of (1) intention of delivering a new asset, to (2) expected physical deliverables, where attributes about the asset are defined. Then (3), where the information needed for the digital deliverable is defined, passing through (4), in which the needed resources and methods for delivering the asset are identified. On (5) occurs the evaluation of the availability of the necessary resources and methods, passing to (6) where information is expressed as an actual digital asset. Following, (7) refers to the information actually being achieved as a physical asset, going to the last stage where the reuse of the asset is analysed.

2.2.2. Standards

To understand information management processes, it is crucial to understand the existing standards in this area. In the field of information management on construction projects, many initiatives aim to standardise these processes. One of the most recent and relevant in this field is the ISO 19650, which was adapted from the PAS 1992 Series (Succar and Poirier, 2020). Following, both standards contribution to information management guidelines are examined, as well as the National BIM Standard of the United States.

2.2.2.1. ISO 19650 series

Published in 2018, ISO 19650-1 and ISO 19650-2 are international standards that present processes and principles for information management across the lifecycle of assets on built environment using BIM. This ISO series is oriented to the ones involved on built asset and asset management activities – that means everyone involved with the asset lifecycle – and suitable for construction projects of all sizes and levels of complexity (ISO, 2018a).

As stated on the ISO 19650 series, information needs to be created to answer to a specific objective requested by the receiver, as the receiver is the one who is going to work with it. The information receiver needs to specify the information requirements, based on the utilisation's purpose, so the information producer understands what needs to be created. ISO 19650-2 (2018) also states that information should not be excessively generated, for instance, with a higher level of information, or duplicated or superfluous information. Useless information consumes time for creation and management, and that leads to resource's waste (UK BIM Framework, 2020).

Dealing with information can be abstract, so in order to guarantee the quality of information produced, ISO 19650 mentions some features should be agreed between all parties. Firstly, the information and delivery formats to define how information is transported and communicated. Secondly, the properties content and necessary attributes for metadata. Moreover, the function of the information, that is its activities and uses (UK BIM Framework, 2020).

On the context of information requirements, the appointing party (organisation leading the project) should specify the information that is needed for the organisational and project goals so that the appointed party can provide it in their work. ISO 19650-1 presents the types of information requirements and how they are related through Figure 9.

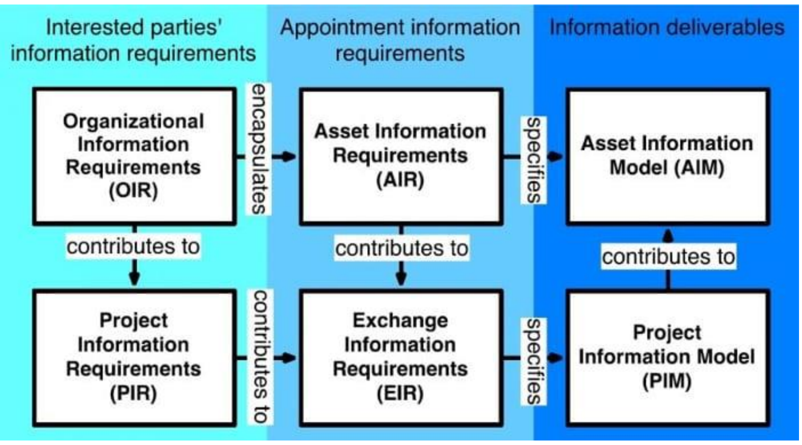


Figure 9 – Type of information requirements (ISO, 2018a)

Organisational information requirements (OIR) and project information requirements (PIR) correspond to "*high-level strategic objectives*" to achieve the organisational and project requirements. Meanwhile, the asset information requirements (AIR) and exchange information requirements (EIR) comprehend "managerial, commercial and technical aspects" on how to produce asset and project information. ISO19650-1 divides models in two types: the asset Information models (AIM) and project information models (PIM). Together, they are the information's repository that can be used throughout building lifecycles to serve as a base for different needs.

ISO 19650-1 presents the flow for information delivery to occur, as can be seen in Figure 10. Firstly, the appointing party should specify the information requirements. The appointed parties should prepare the response for these requirements and deliver it. After that, the one specifying the requirements should verify the information and approve it or not.

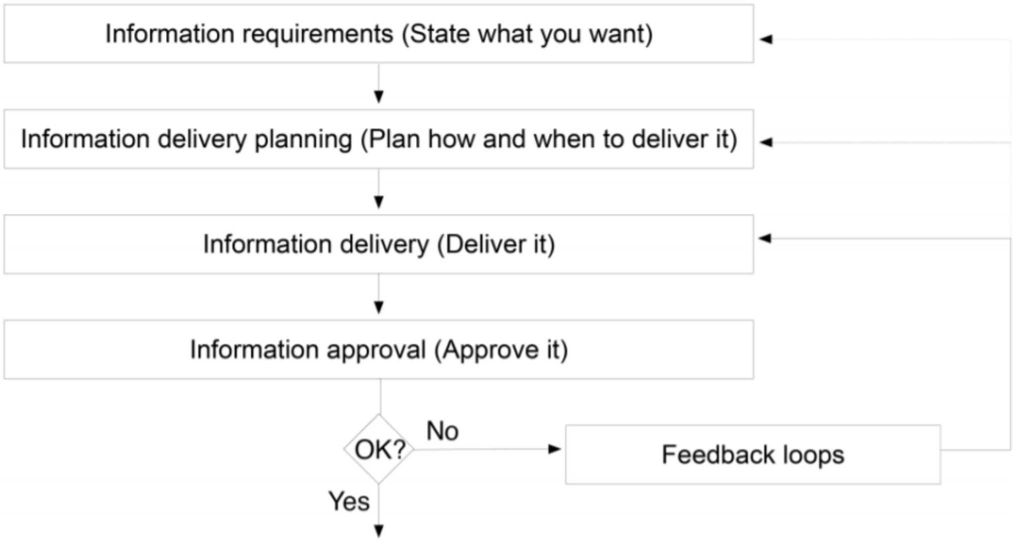


Figure 10 – Type of information requirements (ISO, 2018a)

About information verification and validation, ISO 19650-1 points out the importance of information's checks before going to the next project stage, especially when there is the change of the appointed party between these stages, in order to verify and guarantee the usability of the information. Also, it states that the methods for this verification should be agreed and defined in the begging of the process, before information exchanges start.

2.2.2.2. PAS 1992-2 and PAS 1992-3

Publicly Available Specifications (PAS) are "*rapidly-developed standards, specifications, codes of practice or guidelines*" as an answer to market needs, respecting guidelines of British Standards Institution (BSI) (NBS, 2017). The PAS 1992 series defines procedures for collaborative work and information management for the construction industry to reach BIM Level 2. While PAS 1192-2 approach information management focused on project delivery, PAS 1992-3 target the operational phase of assets.

PAS 1992-2 presents the information delivery cycle, where the path of information is detailed from the beginning of the project to the maintenance phase, as shown in Figure 11. Information management starts on the definition of the Employer's Information Requirement (EIR), and PAS goes through the minimum content this document should include. Following, it occurs the development of the BIM Execution Plan (BEP), with a more detailed project applied goals, strategies and milestones, to assist on the management of delivery on the project. Then, it is produced the Master Information Delivery Plan (MIDP) to control project deliverables.

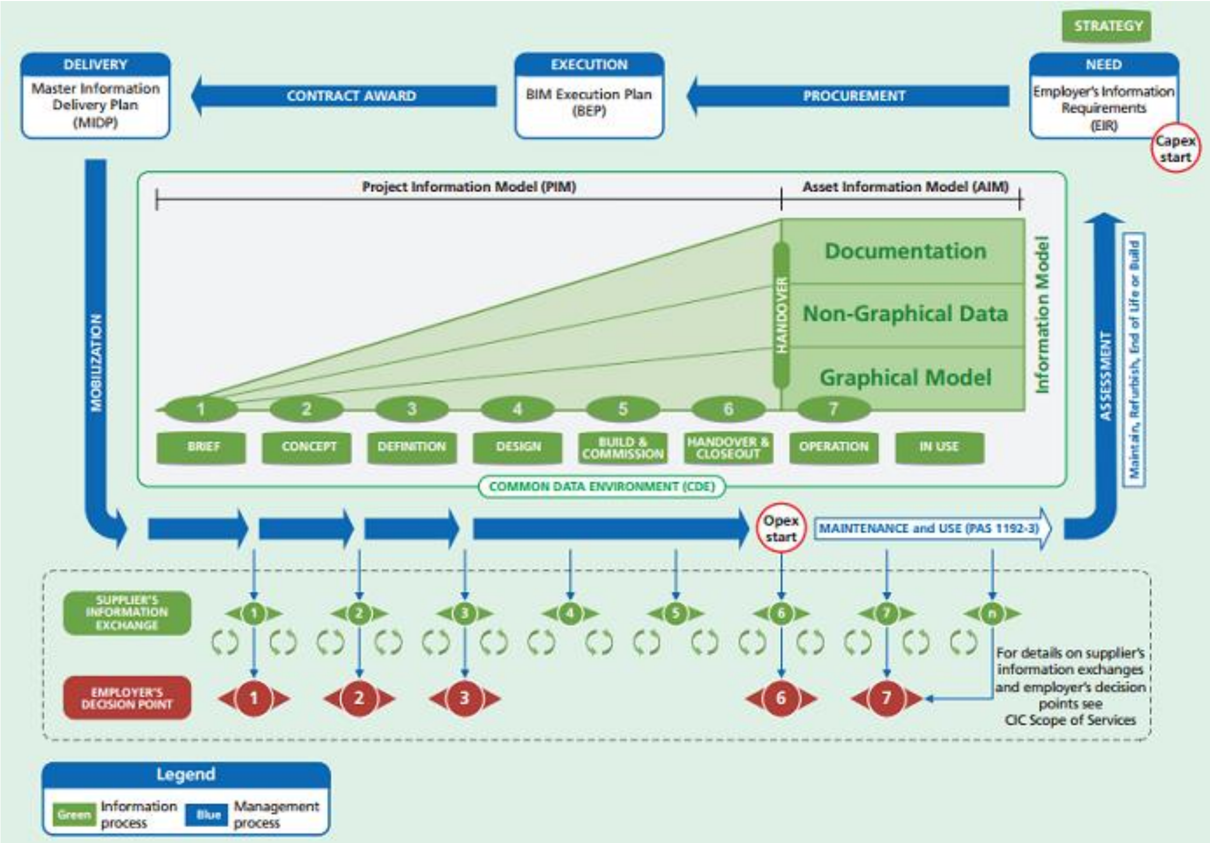


Figure 11 – Information delivery cycle (BSI, 2013)

From phases 1 to 6, as shown in Figure 11, the Project Information Model (PIM) evolves gradually, containing graphical data, non-graphical data and documents and probably consists of a group of federated building information models. PAS 1992-2 states that arrangements for the transfer of ownership of the PIM should be determined on contract. This consideration is made as the PIM is likely to "*start as a design intent model and then be developed into a virtual construction model as ownership passes from design suppliers to the construction supplier and their supply chain*".

PAS 1992-2 also defined the level of model detail and model information for each one of the lifecycle phases. Figure 12, adapted from PAS 1992-2, shows the information that the model provides for the phases of build and commission, handover and operations.

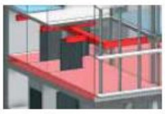
Stage number Model name	5 Build and commission	6 Handover and closeout	7 Operation
Systems to be covered	All	All	All
Graphical illustration (building project)			
What the model can be relied upon for	An accurate model of the asset before and during construction incorporating co-ordinated specialist sub-contract design models and associated model attributes. The model can be used for sequencing of installation and capture of as-installed information	An accurate record of the asset as a constructed at handover, including all information required for operation and maintenance	An updated record of the asset at a fixed point in time incorporating any major changes made since handover, including performance and condition data and all information required for operation and maintenance The full content will be available in the yet to be published PAS 1192-3

Figure 12 – Levels of model definition, adapted from (BSI, 2013)

Complementary to PAS 1992-2:2013, PAS 1192-3:2014 introduces information requirements and information model concept targeting the operational phase of an asset, focusing on the integrity, availability and exchange of information in this phase. Like the information requirements explained in ISO19650, the initial steps on the asset information management process requires the creation of an Organisational information requirements (OIR) that contain the "*policy, strategy and plan*" of the organisation for the asset management. Based on the OIR, an Asset information requirements (AIR) should be defined to achieve the requirements proposed and to guide the data and information creation and management on the Asset Information Model (AIM).

On the operations phase, instead of the Project Information Model (PIM), the single source of data and information of assets is contained on the AIM. The AIM is used as a repository to place information related to event works, also as a way to access links to the information about event works from other enterprise systems and as a way to obtain information from other parties. As mentioned on PAS 1992-3, the IM process shall have the connection between the AIM and existing enterprise systems, establishing a two-way connection where the enterprise systems can obtain data from the AIM, and vice-versa, as represented on Figure 13. As an example of the enterprise systems, it is mentioned document management systems, asset utilisation systems, work planning and scheduling systems, materials management and spares inventory systems, among others (BSI, 2014).

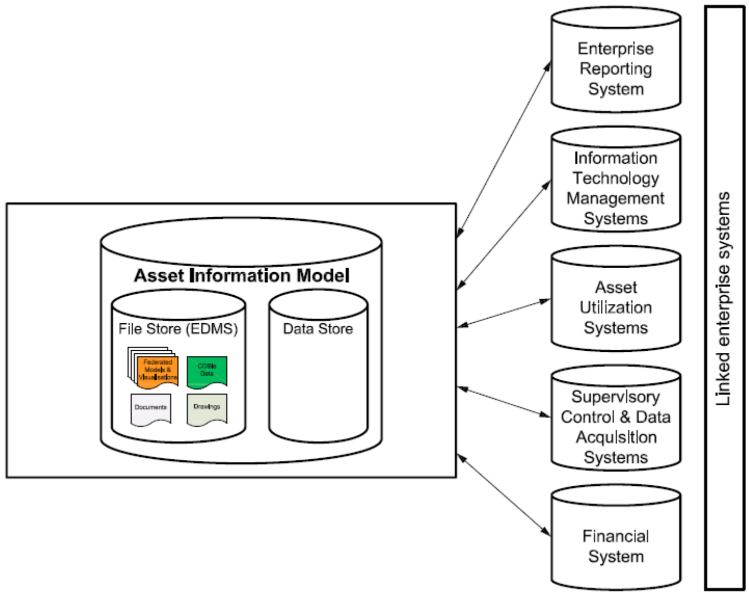


Figure 13 – Interface between existing enterprise systems and the AIM (BSI, 2014)

Another guideline outlined is the implementation of a CDE, where data and information can be stored and work shared for the whole team to access. On information exchange, PAS1992-3 points out that it should follow the requirements about structure, process and content established on the AIR. Also, it should be considered that the information exchange method should be interoperable with the operations systems, in order to guarantee that the organisation can execute everyday operations without problems.

2.2.2.3. National BIM Standard - United States Version 3

The National BIM Standard from the United States is a series of guidelines created by the National Institute of Building Sciences that comprehend the entire lifecycle of the built environment. Section number 5.6 “Planning, Executing and Managing Information Handover” of this standard specifies guidelines for defining organisation information strategies, information requirements, project information handover plans and implementation plans.

This guideline presents a road map for a successful information handover, as shown in Figure 14. The first process required is setting the information strategy for the organisation, according to business purpose and defining information packages. Information packages are identified according to facility-related processes, and need to have their business purpose defined, the phase where they are created, and the creator of this information (NBIMS-US, 2013).

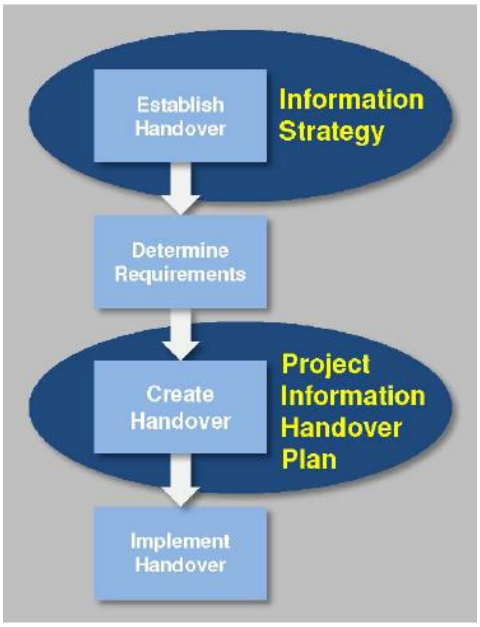


Figure 14 – Steps for information handover (NIBS, 2015)

After that, information requirements need to be established, considering contents, form and format for each one of the information packages. The third step indicated is the creation of the Project Information Handover Plan, where besides the requirements, the responsible and implementation methods should be pointed out. Each one of the information packages should have pointed out by whom and when information will be created and used. Also, information quality requirements should be addressed. The last step refers to the practical implementation, with the definition of contractual responsibilities and procedures.

2.2.3. BIM data quality

The quality of the data being exchanged in BIM processes should be a major concern. ISO 19650-2 (2018) specifies that each team should review the information being shared with others involved. For that, the review should be carried out to verify if it contains all the information requirements imposed by the lead appointed party, if the level of information is what is needed and if it presents the information required and necessary for other teams. Data quality control and assurance should be checked regularly, especially when moving through important milestones (Pishdad-Bozorgi et al., 2018).

It should be defined at the beginning of the project how model and information quality will be controlled. The procedures for quality assurance should be clarified in the BEP, and formal feedback should be provided at each validation step, before moving to another milestone (BIFM, 2017). Rail Baltica (2019) presents in their "BIM Manual" the type of quality checks that should be performed during the project lifecycle, as listed in Table 2. These quality checks comprehend geometrical verifications, clashes between elements, standards compliance and data check. All of these verifications help assure that information being exchanged has the properties and level of detailed requested.

Table 2 – Quality Control Verification, adapted from (Rail Baltica, 2019)

QUALITY CONTROL CHECK	
CHECKS	DEFINITION
Self-Check	General review on consistency, completeness and coherence of the design intent, graphic representation and inserted data. Verify if it attends the Employer's requirements.
Visual Check	Ensure there are no unintended model components, and the design intent has been followed. Verify if the level of detail complies with the requirements.
Clash Check	Detect problems in the model where two components are clashing. Perform it between elements in the same model, elements from different disciplines, and temporal clashes (clash with temporary equipment).
Model Data/ Integrity Check	Ensure that the project data has no-undefined, incorrectly defined or duplicated elements. Ensure properties are populated with requested data.
BIM Standards Check	Ensure that the BIM standard has been followed.
Technical Standards Check	Ensure that the applicable technical standards have been followed (not strictly BIM, but in certain cases verifiable with BIM models).

Data checks can be performed manually and visually. Nevertheless, due to the high number of components and data to review in BIM projects, it can be an ineffective and time-consuming task. There are available software tools in the market that can support BIM data validation. Rules can be created to verify parameters, check if requirements are covered, if properties have any data, and if this data respect a specific rule or range. Also, it is possible to create lists with non-compliant components and highlight them on the model. In this way, data validation can be executed more efficiently than manually doing (Pishdad-Bozorgi et al., 2018).

2.2.4. Case studies on information management on BIM processes

In order to support the development of the work in Chapter 4, the proposal of an exchange information framework, different case studies with examples of how information management was addressed in each studied phase were analysed and verified. This way, it was possible to understand the strategies applied to overcome the challenges found while using BIM from constructions to operations.

On the area of planning BIM processes, the "BIM Project Execution Planning Guide", from The Pennsylvania State University, explains two different process maps when talking about BIM implementation. The first one is the "Overview Map", used to show how different BIM uses in a project are connected. Moreover, the second one is the "Detailed BIM Use Process Map", that defines more precisely the sequence of tasks for each use. For these processes, it is necessary to define the BIM uses and their correlation, the information exchanges that need to happen between the project team, the responsible parties. Messner et al. (2019) explain that these maps allow all stakeholders to recognise how their work relates and interact with other's work and the information exchanges.

The "Saint Joseph Hospital" case study presented on the "BIM Handbook" provides a successful example of the use of BIM through design and construction (Sacks et al., 2018). One of the characteristics of the project was the use of integrated project delivery approach, where all the involved parties participated in the development of the BEP and contributed in early project stages. For the exchange of information, the team used the software Box to host field drawings available for all stakeholders, 3D models, and prefabrication information, such as status of prefab element and expected delivery on-site. The case study also mentions the main BIM uses applied during the project lifecycle and how they contribute to it. On planning, the schedule was developed, firstly, on Primavera P6 and imported to Synchro for continuing planning and visualise the construction sequencing. In this case, the 4D served to communicate the progress and needed decisions to the owner. Besides, it was used to get the evaluation of all team. About prefabrication, a key point mentioned was the importance of the early involvement of the contractors and subcontractors on the design phase. In this way, it was guaranteed that the prefabrication components met the design requirements. Another use of models mentioned was the use on the field, where it helped on-site coordination. Any deviations of the project on the construction site were informed, updated in the models, coordinated if necessary, and the revisions shared with all the team (Sacks et al., 2018).

On another case study of Sacks et al., (2018), the "Prince Mohammad Bin Abdulaziz International Airport" brings up BIM integration with facilities management and insights on this implementation. In order to manage communication and files exchanges, web-based platforms were used in a way to maintain all the team informed. For project management, Basecamp was adopted, and communication between stakeholders was centralised on it, to avoid using email exchanges. For project files, it is mentioned the use of a cloud file sharing platform from the company and also Aconex, a document management software. Aconex was used on the construction phase, as it abled to link documents with BIM elements from an IFC model optimising document's access. For the integration with facilities management, the BIM-FM platform Ecodomus-FM and the CMMS software IFS were used.

As stated in the airport case study, Sacks et al., (2018), it is crucial to maintain the BIM models with updated information to represent as-built conditions accurately. For that, modifications made on-site are entered on the mobile platform as photos or documents, and later used to update the models regularly, being this the contractor responsibility. Also, construction documentation is linked to the model on BIM-FM platform so it can be used to populate the CMMS database, and avoided to input all the information manually. One of the learnt lessons refers that BIM adoption for FM and the involvement of FM stakeholders from early phases helps to reduce the effort to populate the CMMS database, as it combines design and construction information (Sacks et al., 2018).

The study by Pishdad-Bozorgi et al. (2018) brings insights about the implementation of a FM-enabled BIM. About as-built BIM models, the responsibility of developing these models were from the subcontractors and the architectural team, the same authors from the design phase. To guarantee that the as-built BIM model could be used as data input for the FM team, it was developed a list with the necessary information for maintenance and the main assets, in order to monitor these items thorough project phase. During the construction phase, BIM 360 Field was used by the contractor to track equipment information. For managing and exchanging data from the models with FM systems, it was used COBie, considering it would facilitate the process. However, in reality, it occurred interoperability issues, and many errors in the COBie importing process happened. In the end, it was used "Pentaho", a program to use the data of excel spreadsheets to import into the FM systems. This study case also mentioned the importance of data validation, the topic discussed in this dissertation as well.

The U.S.General Services Administration executed pilot projects to explore the implementation of BIM for facility management. On the GSA (2011) BIM Guide Series for facility management, on the project of the Data Center Campus, the goal was to use BIM as a lifecycle tool. For that, it was set up a workflow where BIM metadata and the FM database could be merged regularly. For the model, Autodesk Revit tool was used, and for FM, Maximo Asset Management software was applied. The solution proposed was to model equipment with reasonable accurate geometry and with the necessary data fields required for operations as empty parameters in the model. From this, with the use of Autodesk Revit dbLink tool, the BIM model was exported from its native format into MS Access database format. From this created database, it was possible to merge the FM database from Maximo by linking elements ID from both databases. With this connection established, the BIM model parameters were populated with the information from the database connection. The workflow proposed can be seen in Figure 15.

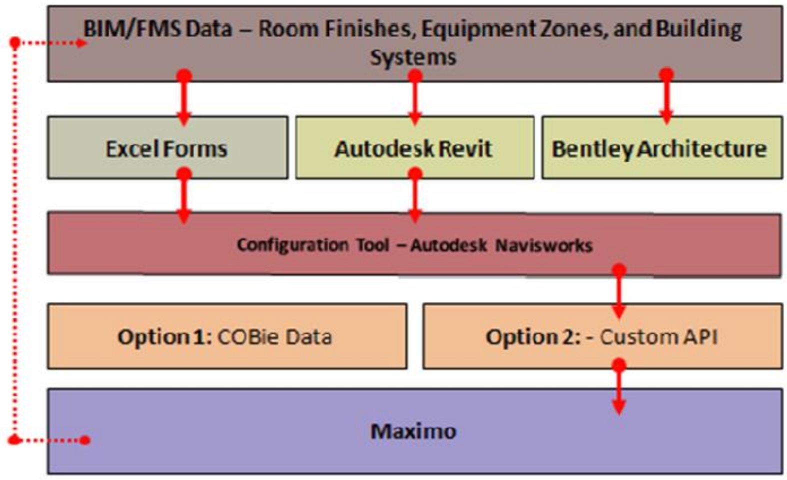


Figure 15 – Data transfer path for Data Center Campus pilot project (GSA, 2011)

As changes occurred, it was possible to repeat the process and keep the information updated both ways during the entire construction documentation phase. This was the proposed solution as the facility managers were familiar with database tools, but not with models. Another step set for the success of the process was to allocate one professional of the FM team in the design team to verify BIM modelling and data mitigation process, along the process (GSA, 2011).

Another approach in dealing with information management is managing BIM data through databases. BIM can be seen as a database that incorporates information from design and construction and data on geometries and spaces. Solihin et al. (2017) proposes the use of the concept of a data warehouse to obtain access to BIM data in a simple ad efficient way, not restricted to the pre-set functionalities of a currently available software. The idea is making BIM accessible through a relational database structure within the data warehouse concepts that can be linked to an analytical tool. The proposed approach uses a standard SQL allowed to access data, analyse data and also has the potential for rule-checking applications. However, in order to allow modifications to the data improvement is still needed (Solihin et al., 2017).

From the case studies cited on this subtopic, one common practice to improve the information management processes for construction and operation was the early involvement of different stakeholders. Contractors and facility managers, when involved since the requirements and design phase, can set the necessary information, test the interoperability between different platforms, and check the quality of what is being produced. In this way, when information arrives to these stakeholders, the benefit is that information can be used appropriately avoiding significant issues.

Different software was mentioned in the case studies. For the construction phase, to centralise information and visualise the model on-site, were mentioned tools such as Box, Acconex, BIM 360 Field. For operation, Ecodomus- FM and Maximo are brought up. From this aspect, it is possible to say that a wide range of different tools are available on the market. However, the solution for each project and the company needs to be tested to evaluate which fits the purposes better.

On operations and management use of information, it is possible to see different approaches for integrating BIM information with FM tools, such as COBie and a custom API linking databases. There are different solutions for linking this information. The necessary step noticed is running tests and quality checks on what is obtained. In this sense, it is possible to guarantee that information is not lost in the process and can be reused without rework or many manual steps.

2.2.5. Difficulties and problems found on information management

Although BIM facilitates information management on construction projects, some difficulties on interoperability, information relevance, the format of delivery and lack of specific requirements were mentioned in the literature. These adversities were reported appearing on different stages of the lifecycle. The following paragraphs intend to cite the main issues stated, in order to be used as a reference for the development of the workflow and information requirements.

- **Information Requirements**

The difficulty of establishing adequate BIM requirements for FM was mentioned by Cavka et al. (2017). The reasons for that discussed that owners are not entirely familiar with the necessary information required to operation, there is a lack of experience in BIM to evaluate the possible information exchanges and they are uncertain on how to demand this information (Cavka et al., 2017).

- **Accuracy and relevance**

Accuracy and relevance were cited as important points to use and manage information appropriately. Also, attention has to be paid on the quantity of information inserted because the overload of it can result in unused data (Cavka et al., 2017). Besides, errors such as human mistakes have to be considered when mentioning data accuracy. Pishdad-Bozorgi et al. (2018) points out that errors are inevitable when users input data in the model or the COBie spreadsheet.

- **Construction**

The lack of information management to centralise project lifecycle information in the same model is mentioned by Monteiro and Poças Martins, (2013). In BIM projects where there are not enough definitions on the model creation and uses, each involved party develops their model within their needs. Between designers and contractors, this deficiency of information management can result in the contractor remodelling the project from the beginning in order to contain its requirements for cost estimation and quantity takeoff. Also, there is a lack of standards for quantity takeoff as it is a task where commonly own rules of measurement are applied (Monteiro and Poças Martins, 2013).

- **Handover and O&M**

One issue on the handover phase pointed out by Cavka et al. (2017) is that, currently, the information from design and construction phases given to FM, in many cases, are not adequately organised, complete, present divergences, and unsuitable format. Frequently, the construction information is handed over in paper format or electronic documents (CICRP, 2013). Often building information from design and construction arrive incomplete on the O&M phase and containing errors and information loss (Lu et al., 2018). Also, in many cases, this information needs to be manually inserted in FM systems (Cavka et al., 2017). Pishdad-Bozorgi et al. (2018) points this out, and mention that a large amount of information is handed over to facility manager in paper or electronic documents, that needs to be processed into FM systems. This situation was also indicated by Kang and Choi (2015), where it was stated the facility management lost too much time looking for information. On that specific case study, it was pointed out that the facility manager had to deal with documents stored in Microsoft Word, Excel spreadsheets, PDFs and blueprints, which caused the work process to be inefficient and time-consuming. If this step where data is shifted from Construction to Operation phase is not performed correctly, results on data loss and necessity of recreating the database for the Operation phase (Rail Baltica, 2019).

Additionally, another issue reported was the lack of involvement of FM professional on design and construction phases, with their absence often leading to commissioning problems (Lu et al., 2018).

- **Interoperability**

A difficulty reported by Pishdad-Bozorgi et al. (2018) was with interoperability between the model and FM systems using COBie. In a case study, when exporting COBie spreadsheet from a Revit model and importing in the AIM system, it occurred errors on this process, even though the interoperability between systems was considered from the beginning of the project. This situation caused delays in the process (Pishdad-Bozorgi et al., 2018).

Although it exists the initiatives to use open formats, the full access to BIM data is still restricted to vendor-specifics tools, locking the data access to their specific software interfaces and purposes. Also, in many cases, a set of Application Programming Interfaces (APIs) is needed to have access beyond what each software allows, but one application written for one product may not be applicable for other (Solihin et al., 2017).

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3. METHODOLOGY

In this chapter, it is presented the process and considerations used for the development of the proposed work. First, a brief explanation of the area of focus of the thesis is explained. Then, the methodology of the dissertation is presented. Following, it is explained the factors involving the development of the workflow and information requirements template for information management on construction and operation phases.

In order to understand how to help stakeholders dominate the BIM information management on the construction and operation phases, a schema of the field of study was created. Figure 16 shows the structure of information levels that involves the field of study of this dissertation, going from a conceptual approach to the applications of it. Starting from the macro area of "BIM", the area of study here is the information management, focused on the construction and operation stages. The work developed in this dissertation approaches the 4th level of this pyramid (from the top), which is the "information exchanges". The development of the deliverables of this work comprehends the discussion on information requirements that can be contained in the EIR, AIR and BEP and the process map for the exchange of information in these phases. These deliverables of the work consider their application for new construction projects involving BIM, where collaborative practices are going to be applied. The level of specifications on the pyramid appears with different aspects necessary to manage the information exchanges properly. Along the work, some of these specifications are discussed as they are essential for the control of information.

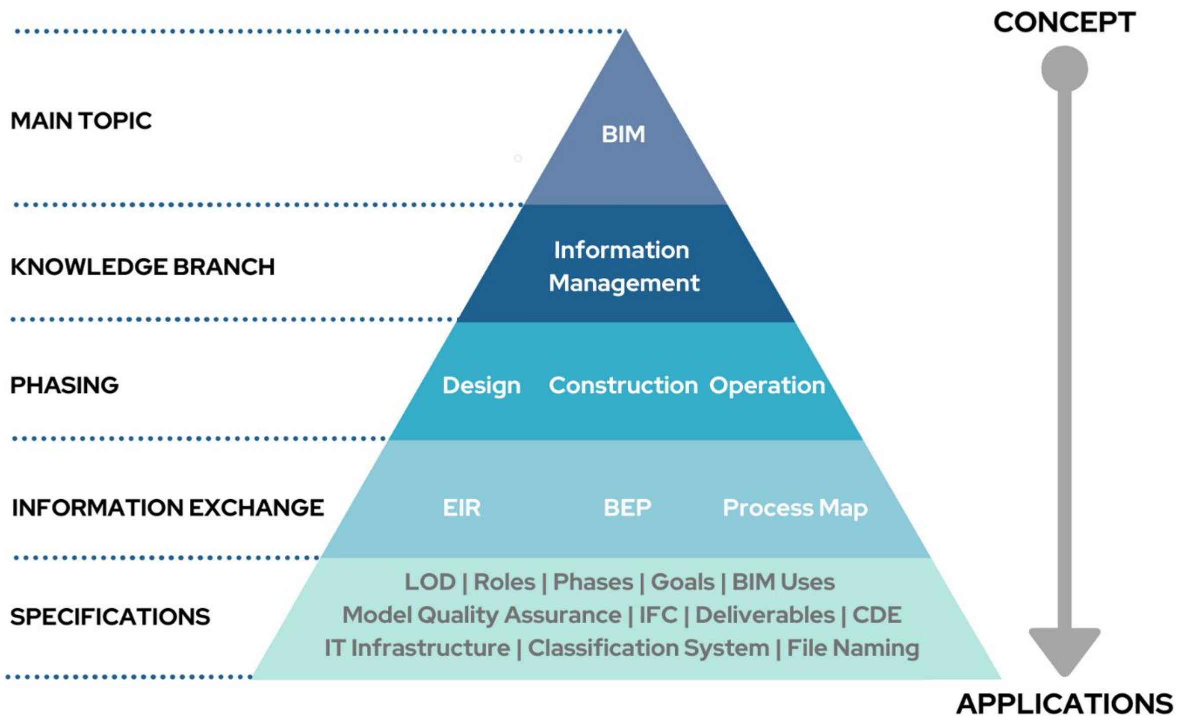

Figure 16 – Structure of Information

This research was carried out according to the following stages, that refers to different chapters of the dissertation.

- Literature review: This phase focused on gathering information from different sources to support the development of the dissertation. The main topics reviewed were involving BIM and information management. The covered topics are general concepts about BIM, contract methods, interoperability, CDE, and BIM uses in different lifecycle stages. Also, concepts on information management were presented, main standards, related researches on information management for construction and operation phases, and issues reported on this topic.

- Methodology: This part goes through the methods and considerations used for the development of the workflow and information requirements that are presented in chapter 4. The creation of requirements and process map variables will be defined.

- Development of information requirements and workflow: Based on the literature review and best practices of the partner company, the templates for information management documents will be developed. For that, it will be discussed and identified the information requirements and developed the information workflow process for the construction and operation phase. In order to develop this process map, it will be diagnosed with the type of information exchanges, formats, and stakeholders involved in each process, and linked with the activities.

- Validation of outputs and results: The proposed documents will be evaluated, and their applicability analysed through an interview with the involved company. Taken into consideration the outcomes of previous chapters, the workflow and information requirements will be reviewed and delivered the manual on BIM information management in construction and operation phases.

The steps mentioned are sequential, as presented in Figure 17:

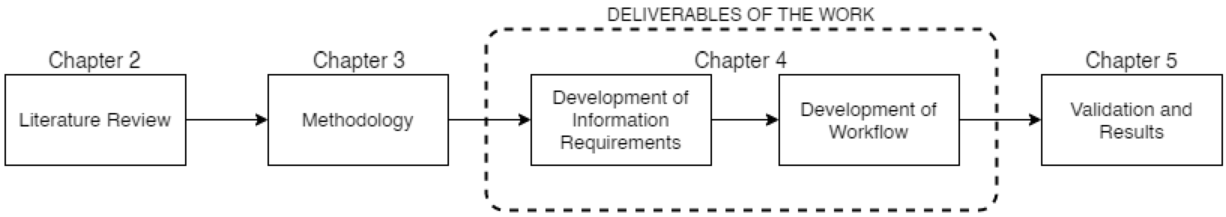

Figure 17 – Steps of the proposed work

3.1. Information Requirements' development

All information created in a project should serve a specific use so that the receiver can apply this information on its purpose (ISO, 2018a). That being so, the initial step is that the stakeholder that will receive this information (receiver) determine the requirements of this information to the stakeholder that will provide this information, as shown in Figure 16 (UK BIM Framework, 2020).

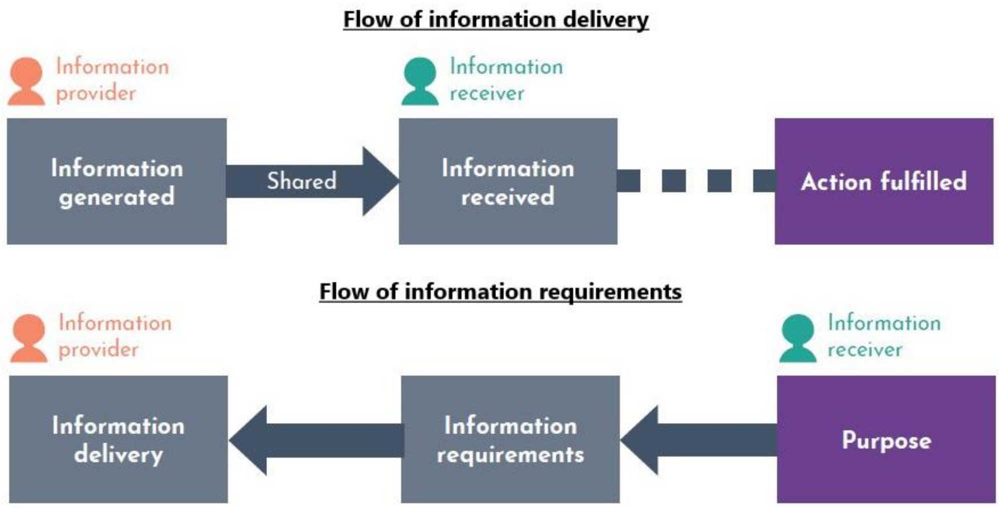

Figure 18 – Flow of information – Adapted from (UK BIM Framework, 2020)

To create the information requirements, the categories of requirements defined on PAS 1992-2 and PAS 1992-3 (BSI, 2013) segments the employer's information requirement and asset information requirement's. The contents are divided into technical information, management information, legal information, and commercial information. The requirements were developed based on these principles, on the issues reported on topic 2.1.3, based on guides and standards referenced on topic 2.2.2, and details raised during the development of the process map. As defined in standards of ISO 19650-1 (2018) and BSI, (2013), information requirements are specified on the EIR, AIR, and detailed on the BEP. The requirements developed on this dissertation are not segmented in these documents, as for each company, the level of detail in these documents can vary.

3.2. Workflow development steps

The development of a workflow is a crucial part of the process of managing information efficiently. In this dissertation, the workflow created was based on the best practices collected in state of the art and discussions with the partner's company. To start the development of the process map, the steps mentioned by Messner et al. (2019) were followed. To start, the BIM uses need to be decomposed on processes, and the dependency between these processes have to be established. Next, the information used as a reference and the information outputs should be identified, along with the responsible for each process. Subsequently, gateways are placed on milestones that need decisions, verifications, and quality checks. The last step mentioned by Messner et al. (2019) is the refinement of the process and periodical review.

To properly understand and control the exchange of information on construction and operation phases, mapping these interactions and activities was considered crucial. The creation of the workflow was based on the definition of the variables involved in the information exchange process, and the steps are shown in Figure 19. The analysed variables were the lifecycle phases, involved stakeholders, the information exchanged, and the activities that take place in these phases, regarding the main BIM uses of the model. These variables will be further detailed in the next subtopics.

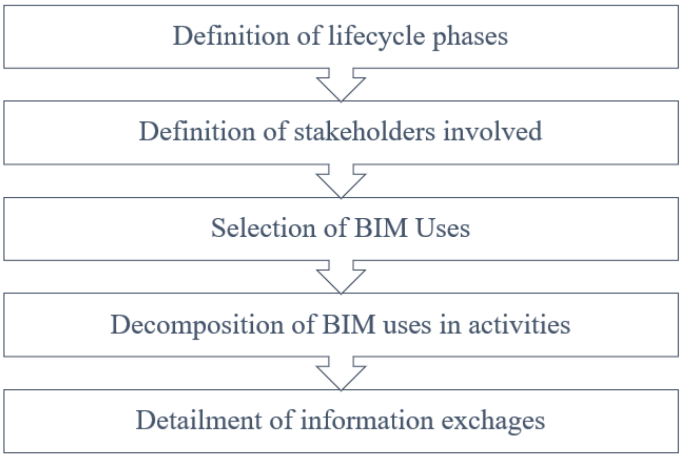

Figure 19 – Steps of the workflow development

3.2.1. Lifecycle phases

As presented in section "2.1.4 - BIM throughout the building lifecycle" of the literature review, the terminology for different phases in building lifecycle varies between guidelines, standards, and countries. Attending to this dispersion, for the proposed workflow, was used generic phases based on the found designations, but not being strict to a single standard, in order to facilitate the application of the workflow. Therefore, global designations that could encompass the most important divisions made within each standard were considered.

The creation of the workflow considered six different phases: (i) Preparation and brief, (ii) Design, (iii) Construction Planning and Management, (iv) Construction, (v) Handover, and (vi) Operations. Even though the focus of the dissertation is on construction and operation phases, the success of information management in these stages depends on requirements and stakeholder's contributions to the previous stages.

i. Preparation and Brief: Phase that precedes the design and project development, created based on RIBA (2020) and BSI (2013). This phase considers the client requirements in detail, to set information requirements that are crucial for other teams and influence the following stages, and to create and Execution Plan on how to generate information (RIBA, 2020).

ii. Design: Although the guides and standards analysed on item 2.1.4 consider several different phases for the design stage, for this workflow, it was considered only a generic and main one. This choice was made as on this process, the design is not explored, and it is not the focus of the process map. A more detailed workflow for the design stage can be seen in Terrosi, (2020).

iii. Construction Planning and Management: This stage did not appear on the standards and guides analysed, as they consider that the activities on this phase happen concurrently with the design. Nevertheless, this phase was considered to include tasks related to cost and schedule. In some guides, for instance, the BIM Uses guide of UCMC (2020), these tasks are considered under a "pre-construction" stage. Another consideration is from BIMe

Initiative (2020) that considers BIM uses related to cost estimation and planning as "Simulating and quantifying" series of uses. Although this stage appears on the workflow as a sequence to the design phase, it happens parallel with design, and may continue during construction.

iv. Construction: The construction phase appears in all references mentioned on the Phases comparison presented on topic 2.1.4, and the naming is almost a consensus. As stated on RIBA (2020), this stage comprehends the manufacturing and construction of the buildings.

v. Handover: Although many activities of the handover phase occur concurrently with the construction, the workflow developed considered it as a separate stage, based on RIBA (2020) and BSI (2013). This approach was taken as the delivery of all construction information to the client leads to discussions on information requirements.

vi. Operations: Phase considered for activities that occur in the building use, such as facility management and operations, after the end of construction and handover.

3.2.2. Stakeholders involved

The PMBOK (2017) defines stakeholders as individuals, groups, and organizations that are involved and affected in some way by a project. The type and intensity of involvement of these stakeholders might vary during the project's life cycle, and to properly manage the project, it is crucial to determine and evaluate their participation and expectations on the project (PMI, 2017).

The stakeholders adopted for this workflow were the traditional roles involved in the construction industry, but considering that, as they are involved in the BIM process, they should have professionals with proficiency in BIM. When exploring specific BIM roles, different countries and companies have different naming and responsibilities for the same role, so it was preferred to keep the stakeholders on the level of involved parties.

The roles considered are listed below, with a brief description of their functions.

i. Owner/Client: The owner is responsible for determining the goals for the project, such as function, schedule, and budget (AIA, 2007). Also, he is in charge of selecting the involved team, the type of contract, delivery processes and definition of general specifications and requirements. To obtain the maximum value working with BIM, selecting an adequate type of contract, providing BIM guidelines and selecting stakeholders with BIM experience is crucial (Sacks et al., 2018).

ii. Contractor: Responsible for performing and coordinating the construction of the project. Moreover, the contractor manages the time and cost of construction. With BIM and IPD process, contractors act in early phases anticipating cost estimation and construction schedule, and collaborating to guarantee the constructability of the project (AIA, 2007).

iii. Subcontractor: Party hired by the contractor to execute specialized services (Sacks et al., 2018). In this workflow, the subcontractor party was considered for prefabrication manufacturer.

iv. Design Team: Team composed by architects and engineers that are responsible for the project design, which is the activity where most information about the project is determined. On BIM processes, it occurs an improved collaboration between the project team and with other stakeholders (Sacks et al., 2018).

v. Facility Manager: Entity responsible for operating and maintaining the building, when the construction is finished (BIMe Initiative, 2019).

vi. Quantity Surveyors: Responsible for quantity take-offs and cost estimation. As it deals with costs, this stakeholder could also be considered under the contractor responsibility.

3.2.3. BIM uses and activities

In order to create the workflow activities, it was considered essential BIM uses for each one of the phases, based on the BIM uses list of BIMe Initiative (2020) and Penn State (2019). The BIM uses contemplated on the workflow are listed in Table 3.

Table 3 – BIM Uses considered in the workflow

Phase	BIM Use
Design	Design Authoring
Construction planning and management	Cost estimation, Quantity take-off, Phase planning
Construction	Digital Fabrication, Site utilisation planning, Record Modelling, Field BIM, Casework prefabrication
Handover	As-built Modelling
Operations	Asset Management, BIM/FM Integration

Each one of BIM uses was decomposed into activities, based on the researches and case studies mentioned on topics 2.1.4 and 2.2.4. With the result of it, the link between all activities was created, generating the sequence flow.

3.2.4. Information Exchanged

With the activities inserted in the workflow, the information exchangesbe exchanged in each process was added. The established exchanges were based on the researches and case studies mentioned on topic 2.2.4. It was not specified the format of the information exchange, as the idea of the workflow is not to be restricted to a specific software. Still, to avoid issues on the exchange of information, the formats should be agreed in the beginning between all parties, and open formats should be given preference.

4. DEVELOPMENT OF INFORMATION REQUIREMENTS AND WORKFLOW

This chapter addresses the development of documents to facilitate information management on the construction and operation phase. For this proposal, it was considered essential to develop two sections: the necessary information requirements, that needs to be mentioned inside the EIR, AIR, and BEP, and the process map of information. The understanding of these two parts at the beginning of a project can help and improve the management and request of information on the whole building process. Also, it gives a strategic view on how to require BIM and how to manage this information.

4.1. Development of information requirements

Information requirements are specified by the client in a BIM project, and as involves consequences to all involved team, it should consider the whole BIM process carefully. As BIM is based on collaboration, it is crucial to have the contribution of the stakeholders involved in the construction and operation phases on the information requirements stage. If well defined, it can help to avoid issues such as interoperability or information inaccuracy when beginning these later phases of the project. For this reason, the involved parties need a representative with adequate experience in BIM to determine and revise these requirements.

For this work, a template for information requirements was developed, focused on the important aspects of construction and operation. The template was created as an Excel file, as is a commonly used tool, in order to allow a company to use it in the future. Each one of the requirements is discussed, along with some examples. The goal is that the output of this work can support discussions on early phases of the project, in order to consider different aspects that can improve the quality of the information arriving in further stages. The information requirements created were based on literature review, insights from the development of a specific workflow further on considered on topic 4.2 of this dissertation, and best practices discussed with the partner company of this dissertation during the validation process. Moreover, the cells were filled with examples to illustrate how it could be used.

The information requirements in the template are divided into four categories: technical, management, commercial, and legal, as shown in Figure 20. This division is based on the segmentation which PAS 1192-3:2014 divides the “Asset Information requirements”.

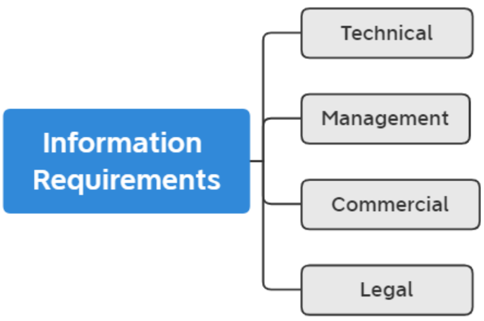

Figure 20 – Information requirements categories

4.1.1. Technical requirements

4.1.1.1. Software and data exchange format

Establish software and versions that will be used for each BIM use defined in the project. Also, it should contain the exchange formats between different parties. For the requirement's table, it was considered one field to be filled with the formats the software accept (such as rvt, IFC, COBie), and the format of the outputs. This information is necessary in order to avoid issues with interoperability, as most software used in these phases will have BIM models as inputs. Also, the output format is important for the stakeholders receiving the result of one activity. Some considerations for each one of the phases is presented below.

- Construction phase: Set out the software that will be used for construction, such as BIM to field, cost and simulations. One project can have many different software for each field. It is vital to list the software planned to be used for each BIM use to verify the acceptable formats (Sacks et al., 2018). If they accept open formats, such as IFC, it needs to be specified on the deliverables for the design team. Also, if a request for information during construction is made in a specific information management software, all parties should agree on using it for replies.
- Handover phase: Establish in which format the as-built model will be delivered.
- Operation phase: Define the system that will be used for operation in order to understand if it accepts data in COBie format. Otherwise, another way to transfer information and data from the BIM process to FM systems needs to be specified (BIFM, 2017). If that is the case, the responsible for testing solutions or this link of information should be defined, or if the software choice will be changed so the necessary training can be considered.

On the created template, it is shown how to require this information, as can be seen in Table 4. The table was filled with examples to illustrate its use.

Table 4 – Technical Requirements: Software and exchange formats

SOFTWARE AND DATA EXCHANGE FORMAT					
Phase	BIM Use	Software	Version	Formats accepted	Output Format
Construction	Quantity takeoff	Software 1	2020	IFC	.xls
	4D	Software 2	2020	IFC	Native format, .mp4
	5D	Software 1	2020	IFC	
	Field BIM	Software 3	2020	IFC	-
Handover	As-built model	Software 4	2020	Native format	Native format, IFC
Operations	Asset Management	Software 5	2020	COBie	

4.1.1.2. Data information exchange

Another information requirement that needs to be established at the beginning of the project is the definition of the common data environment (CDE). CDE is crucial for information management and to guarantee access to information by all stakeholders. Also, it is important to specify how data will be managed and stored during the project and after the handover. On the proposed template, it is considered a space to insert the platform chosen for the project, and the responsible for it. The data information exchange requirement is shown in Table 5.

Table 5 – Technical Requirements: Data information exchange

DATA INFORMATION EXCHANGE		
Common Data Environment	Platform	Responsible
	Platform X	Owner / Project Manager

4.1.1.3. Type of data

This field aims to specify how each type of data and information will be provided for contractors and facility managers. For instance, if they will be included as attributes inserted on the model or outside the model (e.g. manuals, documents, databases). Table 6 shows how this requirement is specified on the template and some examples of it. As construction, handover and operations deal with diverse type of data, gathering this information with the stakeholders involved and agreeing on it is essential to avoid losing the interoperability of information.

Table 6 – Technical Requirements: Type of data

TYPE OF DATA	
Data	Provided on
Quantities	.xls, integrated with software
Schedule	.mpp
As-built changes	Register on IM platform, Point cloud
Construction documents	PDF
Equipment's position	Model
Manuals	PDF, linked with model
Warranties	PDF, linked with model

4.1.1.4. Level of development and information needs

Each stakeholder should require the level of development and information needs according to its necessity. It should be considered which elements will be tracked, what information needs to be on the model, what information needs to be in spreadsheets and database, the level of development of each element, and what are the properties they should contain. For construction, the element's model segmentation could be specified according to a Work Breakdown Structure (WBS). For operations, facility data and properties should be specified for each facility element. One way to do it is by selecting the columns of COBie worksheets (CICRP, 2013). Also, it should be considered the responsible for adding and maintaining each information.

Table 7 shows a way on how to collect these parameters requirement. Each stakeholder could fill it in with parameters that, based on the experience in previous projects, are necessary.

Table 7 – Technical Requirements: Software and exchange formats

INFORMATION NEEDS			
Phase	BIM Use	Parameter	Description
Construction	Quantity takeoff	Classification system	The classification system X will be used to link with the bill of quantities
	4D	4D	4D parameter to insert sequencing on the model
	5D	5D	5D parameter to insert cost
	Field BIM	Field_Complete	Mark items that are executed in the field.
Operations	Asset Management	Manufacturer	Field to specify name of manufacter
	Asset Management	Installation Date	Field to specify the installation date
	Asset Management	Expected Life	Field to specify expected life of equipments

4.1.2. Management requirements

4.1.2.1. Standards

It is necessary to define the applicable standards and guides for the project. The objective is to define a coherent procedure for the collaboration of all parties, aligning the work with industry standards (BIFM, 2017). It should be verified the applicable standards and guides applicable to the country of work for information management and asset information management. For the template, it was created a list with examples of related standards, for it to be defined, which are the standards that are applicable and should be followed for the project. Also, a column was added to set the responsible for verifying the standards compliance. Table 8 shows how this requirement was inserted in the template.

Table 8 – Management Requirements: Standards

STANDARDS		
Standard	Applicable	Responsible
ISO 19650-1:2018	x	BIM Manager
ISO 19650-2:2018	x	BIM Manager
ISO 19650-3:2020	x	BIM Manager
Industry Foundation Classes (IFC)	x	Design Team
COBie (Construction Operations Building Information Exchange).	x	Facility Manager

4.1.2.2. Responsibilities

The responsible for each activity of the process map needs to be defined and agreed in the beginning. For instance, the responsibility of including necessary parameters for construction and operation phase, segmenting element's model according to cost and planning needs, developing the as-built model, linking construction data with operation systems, or accessing an information management platform to answer information requests needs to be pre-established.

For the template, a responsibility matrix was created, as shown in Table 9. It can be added to all activities mapped and defined the stakeholder responsible for the task. It is essential to have clear responsibilities agreed at the beginning of the project, to avoid tasks without ownership.

Table 9 – Management Requirements: Responsibility matrix

RESPONSIBILITIES					
Activity	Responsible				
	Owner	Contractor	FM	Design Team	Subcontractor 1
Model segmentatio according to WBS				X	
Insert 4D and 5D parameters to model		X			
Insert FM parameters to model		X			
Develop as-built model				X	
Link model data to O&M system		X			
Answer RFIs in platform Y	X	X	X	X	X

4.1.2.3. Quality control

A protocol for model and data coordination should be defined in order to guarantee the quality of the information being exchanged. For contractors and facility managers, it is crucial to receive the model and data with all the agreed and required information, to allow them to execute their tasks. Therefore, the procedures, the responsible and the milestones for quality control should be determined in the requirements to ensure that information can be used and operate and the success of work on construction and operation phases. In the template, a section was created to insert the type of verifications that will be performed, the responsible for doing it, the milestone it belongs to and the date, as shown in Table 10.

Table 10 – Management Requirements: Quality Control

QUALITY CONTROL			
Type of verification	Responsible	Milestone	Date
Data check	x	1	01/01/2020
BIM Standard Check	x	1	01/02/2020
Data check	x	2	01/03/2020
Data check	x	3	01/04/2020

4.1.3. Commercial requirements

4.1.3.1. BIM Uses

The BIM Uses for construction and operation need to be defined in order to establish all the other requirements. From the definition of how the BIM models are intended to be used, all the other discussions on needed software, formats, and responsible can be set. The template considers a column to list the main BIM uses possibilities, and another one to insert if it will apply to the project. As seen in Table 11, the BIM uses filled on the table are from Penn State (2019), as an example.

Table 11 – Commercial Requirements: BIM Uses

BIM USES FOR CONSTRUCTION AND OPERATION	
Uses	**Apply in project?**
Site Utilization Planning	x
Construction System Design	
Digital Fabrication	x
3D Control	x
Record Modelling	
Maintanance Schedulling	x
Asset Management	
Space Management	x

4.1.3.2. Deliverables

According to the uses, the deliverables should be listed for each activity, considering the technical aspects such as format of delivery, level of development, information needs, and type of data. Also, it should be stated in which stages they will be delivered. The way this requirement was considered on the template can be seen in Table 12.

Table 12 – Commercial Requirements: Deliverables

DELIVERABLES			
Activity	**Deliverable**	**Format**	**Responsible**
4D	Animation video	.mp4	Contractor
5D	Model linked with cost	x	Contractor
Model update to As-built	As-built model	.rvt	Design Team
Operations Database	Populated database with	.SQL	FM

4.1.4. Legal requirements

4.1.4.1. Ownership

The ownership of models, and the right and limits to use it need to be defined in the contract. It is necessary to be determined the owner of the information, the owner of BIM models, the ones that have the right to use the model, the ones that have the right to change the model, and who are the responsible for the information on models. The ownership should be clearly defined between all stakeholders to avoid conflicts during and after the project ends (Sacks et al., 2018). In this way, it should be defined in the contract if models can be used or altered for construction and operation and by whom.

The whole information requirements template produced can be seen in Appendix 1. These information requirements can cooperate with the stakeholders to define and discuss matters that are important to control information on the BIM process properly, at an early stage.

4.2. Workflow Proposal

Following the information requirements template, a workflow was produced to support the comprehension of information management on construction and operation phases. This workflow can be part of the contractual part, as it is a crucial tool to provide clearness on the contribution of each stakeholder, their interactions, and the information exchange that will occur in the BIM process. Also, it allows having a strategic view on the necessary collaboration of all involved parties.

Following the considerations on the variables explained on the topic 3.2, the process map was created using the Business Process Modeling Notation (BPMN). The workflow was divided in vertical lanes according to the lifecycle phases: (i) Preparation and brief, (ii) Design, (iii) Construction Planning and Management, (iv) Construction, (v) Handover, and (vi) Operations. The horizontal lanes are divided into processes and the information exchange, as it is shown in Figure 21. In the "Processes" section, all activities, their relationships, and the stakeholders involved are inserted. The "Information exchange" lane contains all the documents, files, and models that are exchanged within the process. Also, they contain how this information is related to the activities.

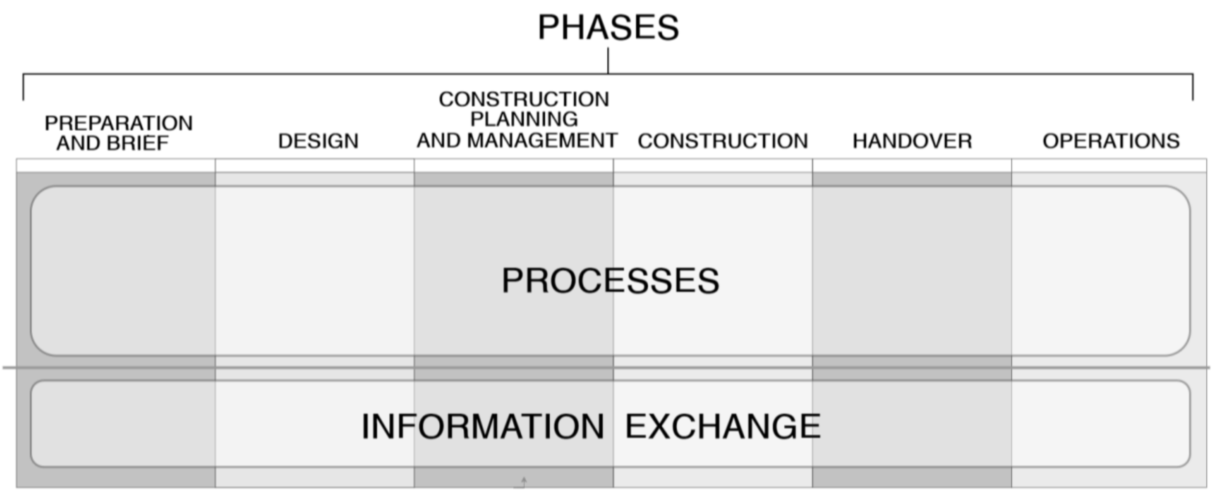

Figure 21 – Workflow schema

For the workflow relations, an arrow with a solid line is used to show the sequence flow of activities. For the files exchanges, a dashed line with arrow is used. For the events, activities, and gateways, the symbols are shown in the legend. A colour schema was used to identify and facilitate the understanding of the stakeholder involved in each activity. The legend can be seen in Figure 22.

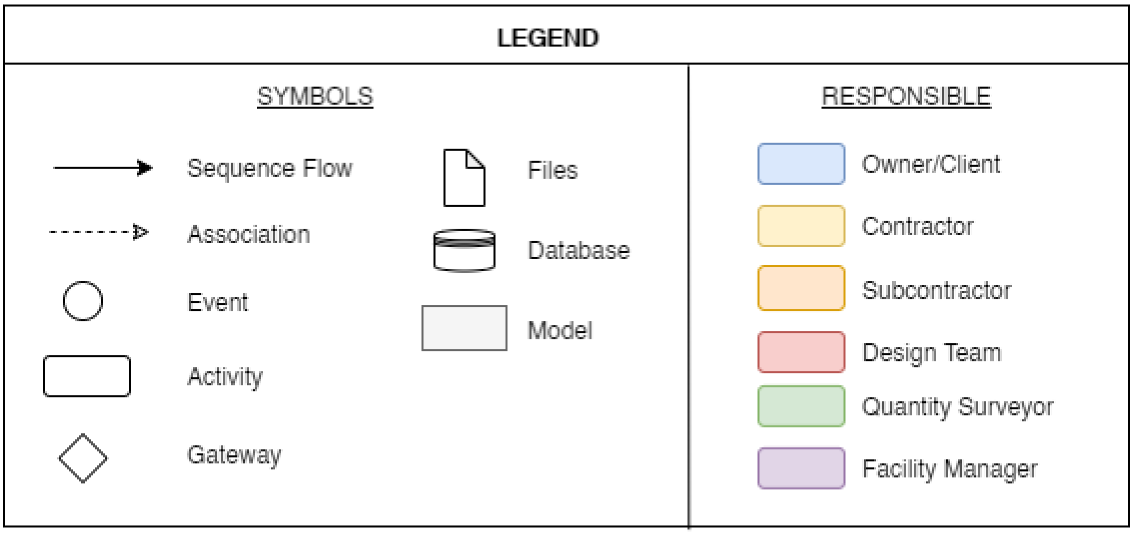

Figure 22 – Workflow legend

For the application and understanding of this workflow, some considerations must be taken:

i. Common data environment – It is necessary to have a well-established CDE for all information exchanges to occur properly and for all stakeholders to have access to the necessary information.

ii. Interoperability – The interoperability between different software has to be tested and agreed in the beginning of the process to guarantee the file exchange. Also, the use of open formats should be considered to enable the use of software from different vendors.

iii. Stakeholders – The responsible party of each one of the activities depends on the contract of each project and the agreements made. In different projects, some of the stakeholders might not necessarily be the one pointed out as responsible on the workflow.

iv. IPD contract – The workflow considers an integrated project delivery approach in order to have the contribution of all stakeholders since the beginning of the project. The choice was made based on the literature review made on project contracts and BIM processes, presented in chapter two.

v. Quality control – Milestones with quality controls are crucial to verify if the models contain the necessary information for the following phases and if it is according to standards. Without this verification and one party appointed as responsible for it, information use can be affected.

The workflow created is introduced in the following subtopics. In order to fully comprehend it, an explanation of each one of the phases, activities, information exchanges and considerations is presented.

4.2.1. Preparation and brief phase

The workflow initiates from the phase of "Preparation and brief". This phase comprehends the initial stage of the project where the owner sets the information requirements, and occurs the definition of the EIR, AIR, and BEP. When a new project starts, it is crucial to develop the information requirements considering the future uses of the model, and how the BIM processes will occur. The IPD approach leads to the involvement of all stakeholders since the beginning of the project. In this phase, the design team, quantity surveyors, contractor, and facility manager appear informing necessary specifications and considerations to include in the EIR, AIR, and BEP, as can be seen in Figure 23. The information needs of each one of the stakeholders is very different, highlighting the importance of defining the level of development and data properties need in the beginning (CICRP, 2013). The benefit is that when the following phases start, the information requirements and exchanges are already agreed and can occur smoothly. In this way, it reduces the chance of a stakeholder receiving a model or data that cannot be adequately used for its purpose.

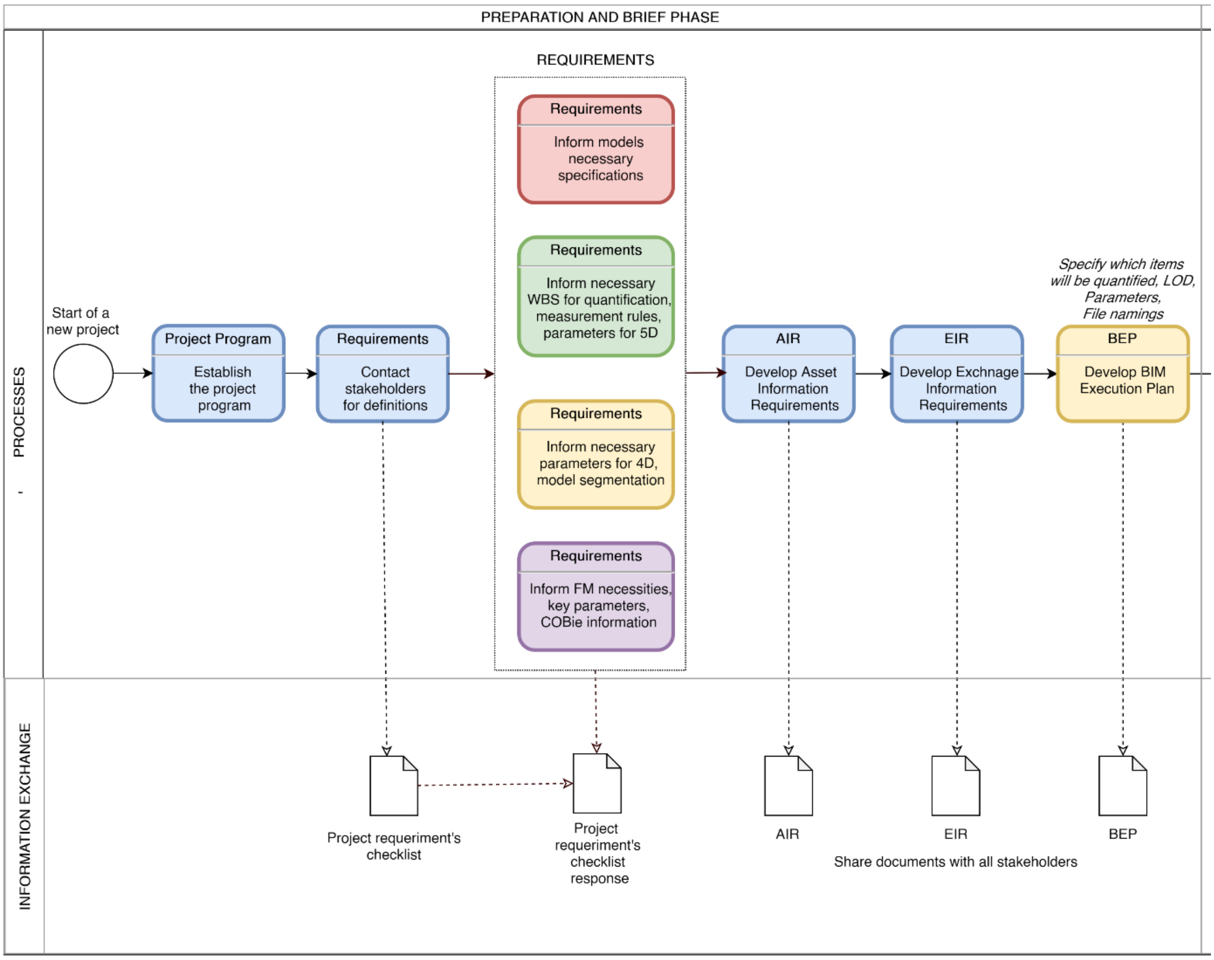

Figure 23 – Workflow proposal – Preparation and brief

As a means to collect the information requirements, a checklist distributed by the owner was considered, in order to guide the team on what to specify. This checklist could be elaborated based on previous projects and standards and contain topics that influence on the work of each stakeholder in the development of the project. For instance, it could cover the software and version each stakeholder is planning to work with, the formats the team can provide, and the model segregation used per discipline. For those involved in the construction, some aspects to consider are the WBS that the model should respect, the measurement rules followed, modelling requirements, what classification system will be used to correlate model and bill of quantities, necessary parameters for 4D and 5D. For the ones involves in operations and maintenance phase, it can be established what type of warranties it is wanted to track, the key parameters that the designer and contractor need to add and keep updated, the necessary facility management requirements, the COBie parameters that are necessary. After collecting these requirements, the EIR and AIR are developed by the owner. Based on these documents, the contractor details more these specifications and develops the BEP, that needs to be shared with the involved team.

4.2.2. Design Phase

In the "Design phase", which can be seen in Figure 24, although the main active stakeholders are the designers, all stakeholders should be actively providing inputs and participating in decisions that influence future stages. This early involvement facilitates the further use of BIM models and information and help incorporate valuable solutions to the design. The advantage of this contribution is arriving on the next phases with construction solutions validated, and the models with the necessary parameters for the determined BIM use. During this phase, information exchanges about design can happen in meetings, calls, and issues management platforms. Still, it was considered that the primary deliverable that will serve as input for the next stages are the BIM models.

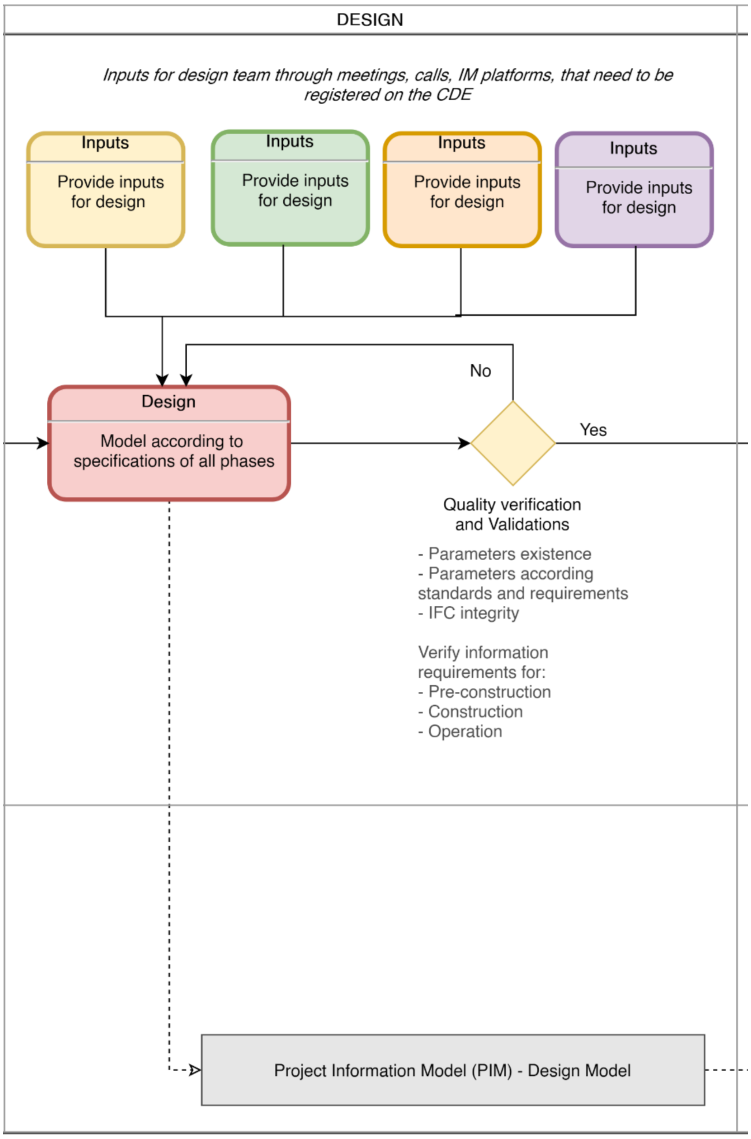

Figure 24 – Workflow proposal – Design phase

A gateway for quality verification and validation was added before the model continues evolving for other phases. Included as the responsibility of the contractor, this milestone's main objective is the visual verification (to check significant errors that may be present), model information verification (existence of parameters, standardised names, parameters agreed on BEP for other phases). The information verification can be programmed in a specific software to automatize and facilitate the process. In this stage, it is essential to guarantee that the design team added the previously agreed information that will be used by other stakeholders in the following stages.

4.2.3. Construction planning and management phase

The construction planning and management phase was created in this workflow to include the BIM uses of construction scheduling and cost estimation. This uses can be applied in different stages of the project, from discussing site logistic in the initial design phase to cost validation after completed work (Hardin and McCool, 2015). However, instead of making as a parallel activity to other phases, the representation chosen was a different phase because it was considered that it would not affect the comprehension.

The uses of construction scheduling and cost estimation have as one of the inputs the BIM model, as can be seen in Figure 25. The reliability of the outputs in this phase will depend on the accuracy and coherence of the model. The model should follow the rules of measurement, modelling requirements, and the way items need to be modelled, in order to be able to use it in this phase properly. For the quantities and cost activities, the main responsible for the tasks were considered the quantity surveyor. In order to perform the quantity take-offs, the necessary primary information considered was the WBS, specifications of units to be considered for each service, and rules of measurement. Also, the model's elements have to consider the segmentation of the WBS and the parameters listed at the beginning of the project so they can adequately be used in this phase. For example, if items need to be quantified per floor, elements have to be segmented per floor, or if items need to be quantified per façade, it would have to contain a specific parameter for this division. From that, the generated information is the bill of quantities, in a previously agreed format. This deliverable should be validated by the stakeholder that will make use of it. In this case, it was considered as the contractor. This validation is necessary to guarantee that the information delivered is organized correctly, and it will be able to be used. The gain on setting these information prerequisites is providing receiving quantity takeoffs that are useful and accurate.

Following the quantity take-offs, shown in Figure 25, a BIM-based cost estimation enters the workflow. The integration of the model with construction costs (5D) requires the software choice and model rules to be agreed previously in order to work smoothly. Also, each contractor may have its system of interconnecting the model with their Enterprise Resource Planning (ERP). The benefit of this step of integration is the creation of a direct link of information, decreasing the chances of losing information, as it reduces manual steps. Also, it allows the possibility of quick feedbacks, and cost analysis and simulations according to design options. From this step, the output will be the construction budget.

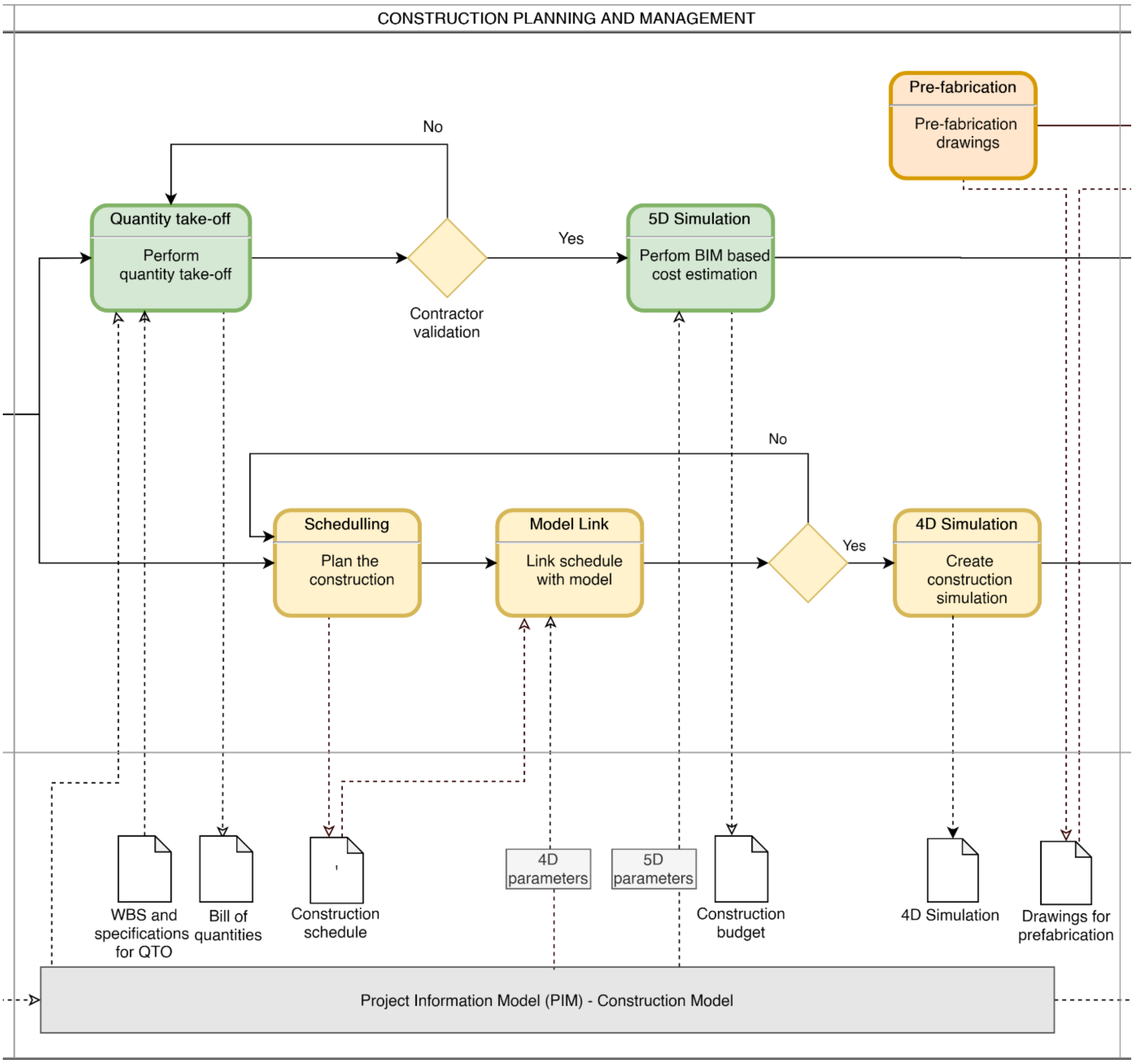

Figure 25 – Workflow proposal – Construction planning and management phase

Another use in this phase is the construction simulation, that was attributed to the contractor, as it is the stakeholder responsible for the construction. The first activity considered was the construction planning, delivering the construction schedule in the preferable and agreed format. Then, the link between the model and the schedule is executed. To avoid manual work and the chance of typing errors, the ideal situation is that the software for creating the simulation is interoperable with the schedule format. In this way, the planning schedule can be imported into the software and linked with the model. When linking the schedule with the model, mistakes on the schedule are easily targeted. A gateway of verification was considered in case of necessary review of the schedule. After this verification, the simulation is created and made available for the construction phase involved stakeholders.

On this stage, the main focus of the workflow is the application of BIM models to construction costs and planning, including getting quantities and simulating the construction. The deliverables generated are used to plan the construction phase, and to control this phase.

4.2.4. Construction phase

In the Construction phase, shown in Figure 26, the workflow deals with two components of activities: prefabrication using models and BIM to field. For prefabrication, the idea is to use models and model's information and details to serve. For that, in the design phase, all clashes and project issues should be solved, and pre-fabrication considerations should be taken into account when designing to facilitate the process. For this interaction between the design team and subcontractor to work, the format of the model delivery should be agreed previously, whether it is a native format or an open standard one, such as IFC.

During the prefabrication, the subcontractor has to inform the status of the components to the contractor and when they are going to be delivered. This information can be centralized in an information management platform, and informed to the contractor on site so he can consider that while coordinating the construction. This step can facilitate communication, improve the organisation of information, and enhance the coordination of the components on-site.

For the construction site, the primary use is for coordination of construction. For that, on the task of BIM to field, it is considered the BIM model as information input. The contractor should select a BIM Field application, that allows access to the model and support the coordination activity. To avoid interoperability problems, the BIM Field application should preferably read open formats, or the modelling software and application formats should be agreed at the beginning of the project. For the coordination of construction, besides the model, construction drawings are being considered. The idea is having details or any information in sheets if necessary, but ideally to be seen in screens on-site. In this way, it is easier to assure that the latest project version is being used and no version mistakes are made.

In the construction site, one of the mapped information exchanges that occur is the communication of issues and request for information (RFI) between all stakeholders. Among them, it occurs discussions about the project with designers, site communication between the contractor team, request for the subcontractor and validations with the owner. This RFI was proposed to be done through a cloud-based information management platform. In this way, all stakeholders can have access to this information in the time it is being requested, an contribute to the solution. Later, in case of doubts about a decision made in the past, the one involved in the choice can be tracked. The use of a proper platform for information management in the site can provide a more efficient and organised track of information exchange for later consultation.

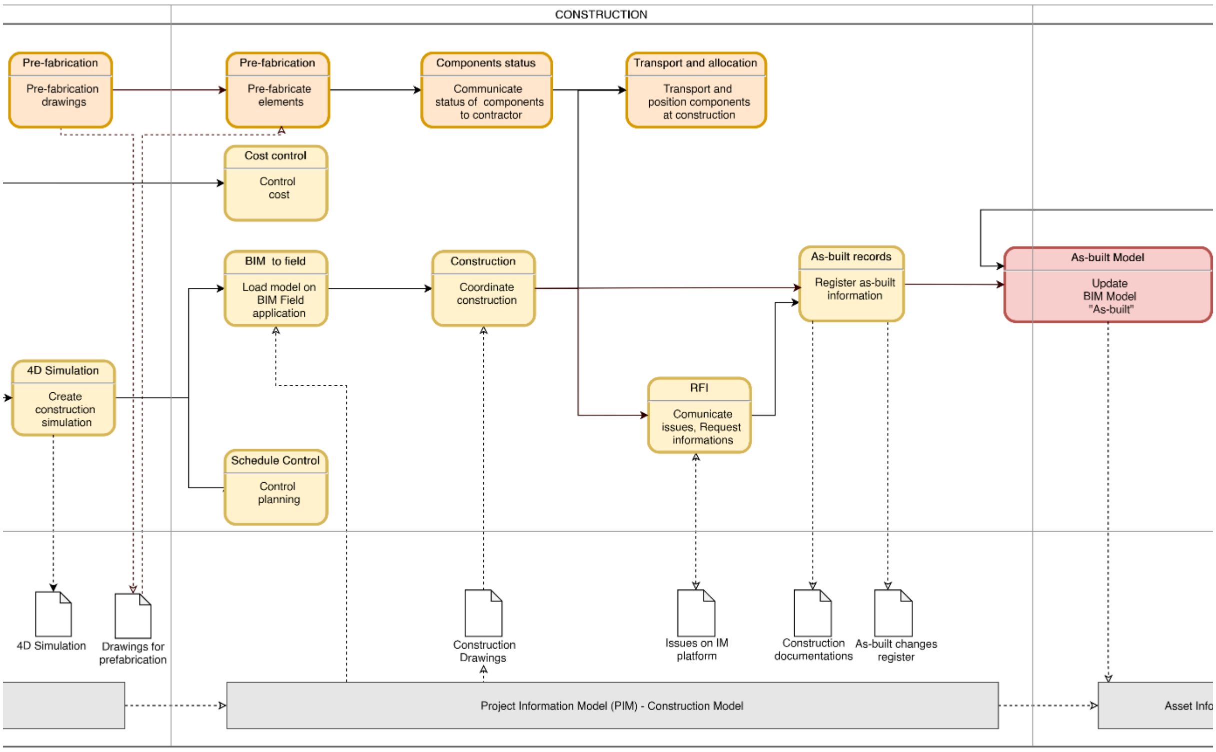

Figure 26 – Workflow proposal – Construction phase

Another activity that occurs during the construction is the register of as-built information. If the goal is to use the model for the next stages, such as operations, all changes from the original project and additional information that appears needs to be recorded. In the traditional process, the facility managers receive a lot of drawings, files, and documents, in an unorganized way, and they have to process all the information. To make this process more efficient, it is proposed to centralize all information in the model, and link documents and additional information when possible to the model, and the CDE. These changes could be done by list, pictures, and comments on the model. For this to work, the IM platform has to support and facilitate this registering process. With it, it helps assure the facility manager will receive the updated information in an organised way. This task was considered as the responsibility of the contractor, as it is the stakeholder responsible for handing over the information.

With the recorded information, the BIM model from previous phases needs to be updated. This task may start still during the construction, mainly if any changes on-site require an update of other parts of the design. On the workflow, it is considered that the process of the as-built model starts on the construction and finishes on the handover stage. The responsible for the task of updating the BIM model was assigned as the design team, but it will possibly be attributed to another stakeholder. The stakeholder in charge of this activity should be agreed on the contract because it could be the design team, the contractor, or any other third party that may be hired to do the activity. In case it is not the design team that executes it, it also needs to be agreed on the beginning who is responsible, which modelling tool it is going to be used, and if the design team will provide the model on the native format. In case only IFC is provided, it should be considered in the contract that the model will need to be developed from the beginning. This situation, if not well accorded, can cause frustration and loss to the parties involved.

From this process, the deliverable will be the as-built model, that turns into the Asset Information Model (AIM).

4.2.5. Handover phase

In the Handover phase, project and construction information needs to be handed over to the responsible for the operations. After the delivery of the update as-built model, a gateway with verification and validation was added to check if the model was updated entirely as the as-built conditions and to verify if it contains all the information that the facility manager will need. If yes, the model and the construction's documentation will be delivered.

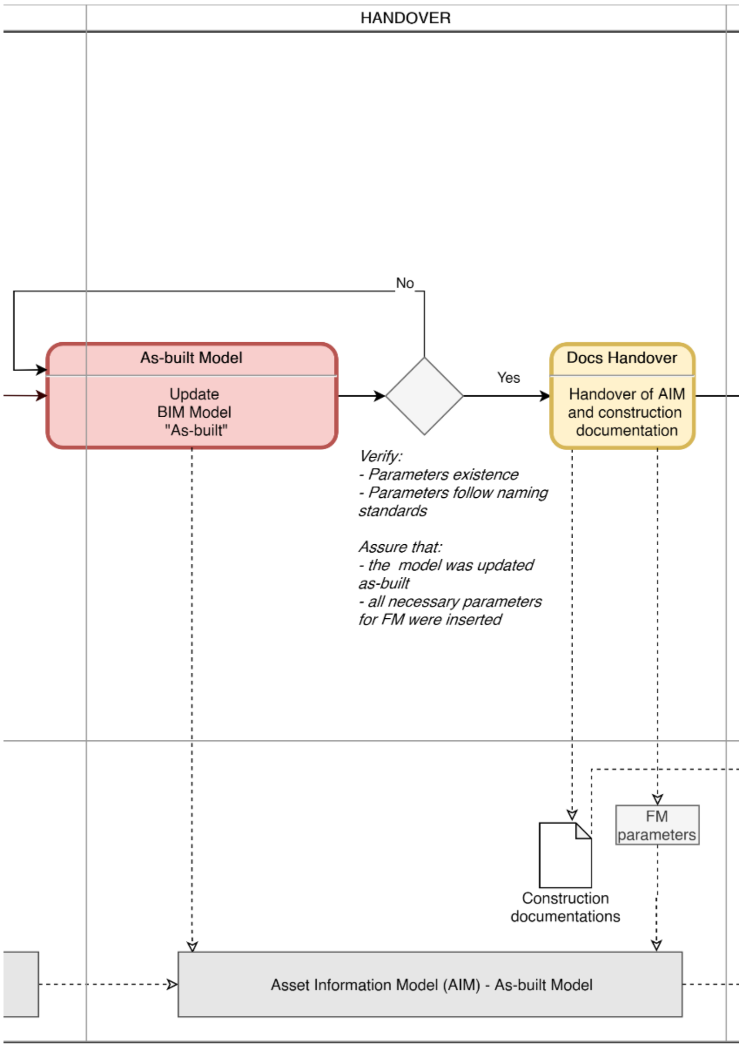

Figure 27 – Workflow proposal – Handover phase

4.2.6. Operations phase

In theory, a BIM model should achieve the delivery of design and construction's information to the facility manager, be a source of information for all parties involved during the building use, and enable supply the facility manager with accurate operations data organised in a database linked with the visualization of the model (Pishdad-Bozorgi et al., 2018). However, when arriving in the operations phase, one of the main issues on exchanging information is delivering the information gathered in the construction without much loss. The model contains information that can be used for facilities management, but in order to be useful, it has to be required accordingly. For that, it has to be established the delivery format and level of development so the facility manager can use this data in his software. Some options were discussed on 2.2.4., such as using COBie format, or creating a link from the model to an external database using a script. The definition of this format depends on the software used by the facility manager, and the type of database their software is able to read. If COBie is used, it can be generated from the AIM, and linked with the FM system, in order to populate the database with model's information. Another solution would be a link from the model to a database, so the FM can use the data in a database format, insert more information, and this database is linked bidirectionally. With the link of this information, the idea is to reduce the amount of manual work on adding to the operations and management (O&M) software. With this data, the facility manager could continue the operation of facilities using the O&M software. The workflow of the operations phase is presented in Figure 28.

Besides that, to have a successful transfer of data to the operations stakeholders, with information that has quality and accuracy, the BIM process should include the facility manager throughout the project lifecycle (BIFM, 2017).

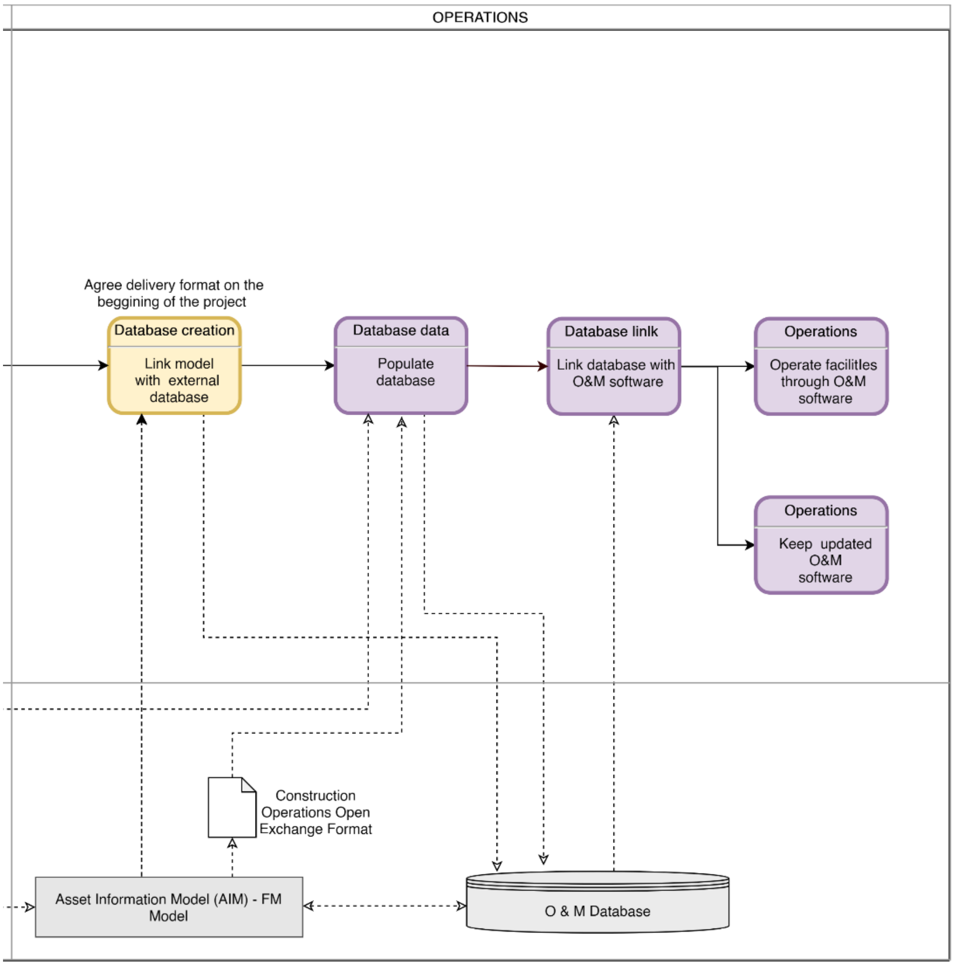

Figure 28 – Workflow proposal – Operations phase

After delivering the information of the project and construction to operations, the building will continue for years in these operations. It is aimed from the operations, the link of the model and building database is connected, and as the database is being populated, this bidirectional link continues.

With all these phases presented, the objective is that having a clear vision of the information exchanges that occur in all the process, stakeholders can discuss and agree on these matters at the beginning of the process and before issues start appearing.

4.2.7. Entire Workflow

The whole process map developed is displayed in Figure 29. On it, it is possible to comprehend better how information flows throughout the entire process until it arrives for the construction and operations phases. Moreover, it provides an understanding of how stakeholders interact, which are the information exchanges and how tasks are related. This workflow can be adapted and used by companies involved in BIM projects to have a strategic view on how to handle information, foresee possible issues, and plan on how to deal with its information in an efficient way. In order to adjust the workflow to apply in a different project, the company needs to identify the BIM uses objectives, the stakeholders, their responsibilities, and their deliverables. Also, using this workflow and having a clear view of interactions, it is possible to improve processes and consequently the productivity in the company.

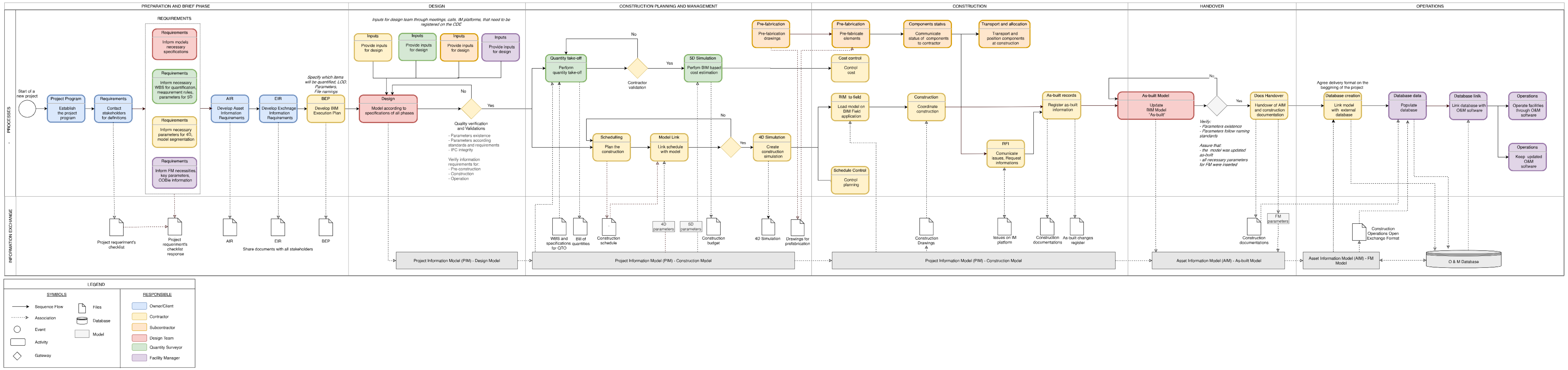

Figure 29 – Workflow proposal

5. VALIDATION AND ANALYSIS OF RESULTS

In this chapter, it is addressed the validation of the developed workflow and information requirements for construction and operations created in this dissertation. For that, firstly, it is explained how the validation was planned, the considerations made, and the way it was executed. Furthermore, the results of the validation of the deliverables of this work were analyzed and discussed. In order to validate the proposed information requirements and workflow qualitatively, this dissertation had the support of the BIM specialist company BIMMS – BIM Management Solutions. BIMMS is an architecture and engineering international organization located in Portugal, specialized in BIM consultancy and management solutions.

Besides a parallel process along the whole dissertation production, the validation of the developed work occurred in three major milestones. The first stage consisted of a meeting with BIMMS professionals, set at the beginning of the work, aiming to understand the case studies and to start the discussion on how information management is dealt with in practice. In the second milestone, a qualitative research method of in-depth interview was conducted with one of the company partners. This method consists of a guided interview in which the goal is to examine meticulously individual experiences and understanding about a subject (Yale University, 2015). The third phase was a presentation of the outputs of this work to the company board. This presentation was held at the end of the research process for a final validation. In this way, this research could also be validated not only in the academical, but also professional domain.

5.1. Case study presentation

At the first step of the validation process, it was set a meeting with two of the company's partner and two of their BIM Coordinators. This session's objective was to understand the case studies that were going to be used as examples and from where the company's experience would be based from. A questionnaire with project-related questions was prepared in order to comprehend the information processes in these case studies. Also, the questionnaire helped guide the conversation with the BIM coordinators. The discussions concerned the workflow of work, the actors involved, the level of information definition, the deliverables, issues with interoperability, quality checks, BIM uses and challenges found. All of these topics helped investigate better the case studies singularities.

It was provided by the company two different case studies of BIM projects that BIMMS was involved: an educational complex in the United Kingdom, and a data centre in the Netherlands. Due to confidentiality issues, in-depth information about the projects used as case studies cannot be published. The focus will be on the experience of the company on BIM processes and information exchanges obtained in these two projects.

One of the projects, considered as a case study, is an educational complex in the United Kingdom. The project started in 2014 and consists of four buildings. On the date of the interview, two blocks were in the construction phase, and the other two were already completed and being used. The project owner is an educational institution, but BIMMS was hired by the main Contractor. BIMMS's role in this project was the verification of design, coordination, and quality control of the mechanical, electrical, and plumbing (MEP) project. Furthermore, the company was responsible for information management on this process, controlling and verifying any missing or mistaken information. The educational building is a Desing-Build contract, and the information requirements were established by the client. In this project, there was a third-party entity responsible for the verification of the quality of the projects and deliverables, in order to make sure it was according to the client's requirements and standards.

The second project used as a case study was a datacentre in the Netherlands. Here, BIMMS's scope was modelling and adapting the design of MEP, design coordination, and shop drawings for the constructor. This project was a fast-track program, where the interval between design and construction was short, relying on the speed and collaboration of the BIM process. The level of information and deliverables of the project were defined in the beginning by the owner. In this project, besides being used in the design phase, BIM was used in the construction site.

5.2. Structured interview with professional

5.2.1. Planning and conducting the interview

For the second milestone, it was planned a semi-structured interview with a professional with knowledge and experience in BIM processes and information management, with the objective of gathering data that validates the proposed work. As this dissertation had a partnership with BIMMS, the idea was to select for the interview one of the company's professional with a strategic view of the company but who was also involved in practical aspects of BIM projects. On account of this, the interview was conducted with Bruno Caires, who is a civil engineer and one of the partners of the company.

On an in-depth interview, the interviewer may have a list of open and non-directive questions, and during the interview questions can be reorded, reorganized or abandoned, according to the flow of interview (Yale University, 2015). The questions were structured according to the related subjects and what needed to be validated. They were developed in collaboration with Terrosi (2020), as there were common topics that needed to be approached on this interview. The idea with these questions was to confirm the problems found in the literature review and validate the possible solutions proposed on the information requirements and workflow. The questionnaire used as a basis for the interview can be seen in Appendix 2.

The author and Terrosi (2020) conducted an interview with Eng. Bruno Caires. The interview lasted around three hours, and it was recorded to be analysed later. Firstly, it was explained about the procedure, confidentiality issues, and it was presented an overview of the study development and goals. The questionnaire created was used as a guide for the interview, but according to the answers given, some additional questions were raised.

The validation of the proposed items is analysed in the next subchapters by project phases and topics. Eng. Bruno Caires based his answers mainly in the case studies of BIMMS presented in the first meeting. The focus of the validation is not in the details of the projects, but on the BIM processes and information exchanges mentioned by the interviewee.

5.2.2. Preparation and brief and Requirements

5.2.2.1. IPD Contract

The proposed workflow considers IPD type of contract, in order to have all stakeholder's participation throughout the whole project. About which type of contracts is used on BIM projects and how they affect the BIM process, it was commented that the IPD contract "in theory, it is obviously the best contractual methodology", but legally, it is a "type of contract challenging to implement". The refered reason for that, is the difficulty in determining the percentages each one can intervene in the project, or how much one can contribute in each stage. It was cleared claimed that a good contract and trust between companies is a must.

It was also commented that the contract generally used was the design-build (DB) contract. It was referred that, in the DB contract, it is possible to see the benefits of BIM, especially on fast track projects, such the one in the case study. The reason for this is that while the design progresses, the construction's documents and schedules are being given though. In the case of the datacentre, this type of contract enabled different work methodologies to co-occur, and helped taking decisions on the construction site more quickly and confidently. When asked if there was any interaction with the facility manager in DB projects, Caires said that if the facility manager is already defined and the project that involves much money, it is knowledgeable to involve the facility manager. In the educational building case, even being a DB contract, some IPD policies were applied. In such case, the facility manager contributed on FM requirements, and to the design and construction.

With this discussion held, the conclusion about the type of contract was that IPD is still the ideal contract for full interaction between stakeholders and to achieve full BIM benefits. However, in order to consider the IPD for this workflow, more instructions on the contractual aspect could be included. On this subject, the workflow and information requirements should call attention for this fact, and recommend that when implementing this type of contract, the contract could be made based on other projects with the same type of contract that was successful.

5.2.2.2. Contribution of all stakeholders on EIR and AIR

For the developed workflow, it was considered that all stakeholders of the project would contribute to the EIR and AIR. Nevertheless, it was mentioned that the contribution of the involved parties depends mainly on the type of contract. Ideally, all stakeholders should give inputs in this stage. However, what happens in practice is that someone from the Project Management Team sets these requirements. It was stated that it is a feasible option, as the PM is involved from the beginning of the project until the operations phase. It is one entity "that thinks on behalf of the employer, and knows what the client wants to monitor throughout the entire process of design of construction, and what he wants to optimize at operations and maintenance". This entity is able to set these requirements because the PM should have experience in the field. If not, he can have consulting companies assisting him on these requirements. As the workflow of this dissertation was elaborated considering the IPD contract, and based on the statements of Caires about this subject, the contribution of all stakeholders in the beginning was validated.

5.2.3. Design Phase

5.2.3.1. Involvement of all stakeholders on the design

The workflow considers the contribution of all parties during the design stage. On the Datacentre case study, the participation of the constructor on the design was very active, as the interval between design and construction was short. This interaction was pointed as crucially responsible for the success of the project. On the educational building, the participation of constructor and facility manager was also mentioned, as it was a project with significant value and this contribution of all stakeholders aided provide reductions in cost and improvements in quality. With these examples, the participation of all the stakeholders in the design phase in the workflow was validated.

5.2.4. Construction planning and management

5.2.4.1. Work Breakdown Structure defined at the beginning of the project

In the workflow developed, the WBS is considered as an input at the beginning of the project, so the designers consider it in the model. When asked if the WBS was defined in the initial stage as a requirement of the contractor, the interviewee mentioned that this would be the ideal situation, but it does not happen in practice. The reason for that is the WBS changes during the project, and it would need to be updated in the model if it is inserted as parameters. One suggested solution was to implement a visual programming script, like Dynamo, to apply the necessary parameters when there are changes. For that, on the workflow, the WBS could still be left as an input at the beginning of the project. Also, it could be considered in the step for quality validation of the design the verification of WBS model considerations in the design stage. The entity in charge of performing this validation could be responsible for guaranteeing that WBS alterations that reflect in the model were considered.

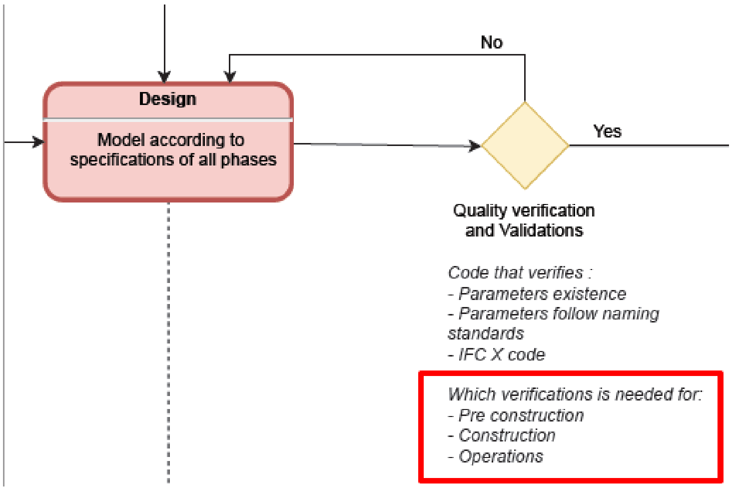

Figure 30 – Verification step for the Design phase

5.2.4.2. Quantity Take-off – Responsibility and validation

The responsible for the quantity take-off pointed out by the interviewee was the contractor. As mentioned, the contractor needs to control quantities and budget from the beginning of the project. The contractor should provide the designer in the BEP with the rules of measurement, modelling requirements, and the way items need to be modelled, in order to be able to make the quantity take-offs properly. Also, part of this scope is a validation milestone, as part of the task information delivery plan, the quantity take-off verification. The developed workflow made the same consideration for the responsible and the gateway with validation.

5.2.4.3. Responsible for 5D and software

About the stakeholder in charge of the 5D, it was mentioned that is the contractor's responsibility. On the proposed workflow, the quantity surveyor was chosen as responsible. Even though there is a divergence, the responsibility in the workflow can be maintained as in the role definition on 3.2.2 it was mentioned that the quantity surveyor could be under the contractor responsibility as well. Also, the workflow considerations are mentioning that the responsible party of each one of the activities may depend on the contract of each project and the agreements made.

5.2.4.4. 5D software

One aspect mentioned is about the software interoperability. As the 5D is on the interest of the contractor, in order to be able to use the connection of model and cost software, the contractor has to have a license and the intention to use the 5D software. It was mentioned that in the educational building case study, it was used the 5D software Crystal. Nevertheless, in other cases, where the contractor uses an ERP software, this link is made by understanding how the ERP software needs information, adding parameters to the models, exporting to an excel format and then add as an input in the ERP. Therefore, if the company does not use a 5D software, a solution of integration can be applied to work with the traditional software the contractor uses.

The workflow and information requirements mentioned about using open formats to allow the connection between model and cost software. Also, on the technical information requirements is pointed out to discuss this matter in an early stage to define and find the best solution for it. It could be the contractor acquiring a 5D software, or a way to link the model with the ERP with a programming application. The earlier this matter is discussed, more options can be considered and rework avoided. As this issue was considered in the information requirements, no necessary change on it is needed.

5.2.4.5. Interoperability between software – IFC data quality

In the interview, it was discussed that when using software for quantity takeoff or link with the bill of quantities that require IFC, the quality of the IFC model has to be verified. One main problem discussed was the loss of information when exporting to IFC. It was commented that it is easier to assure the IFC's quality when it is generated internally in the company. The reason for it is the existence of templates and standards used in the model, that helps to generate IFC correctly. However, when dealing with model from third parties, it is more difficult to control the integrity of information. On these cases, the interviewee mentioned that one solution adopted was exporting the data from the native software to an excel, or database format like SQL, and then linking with the bill of quantities. In this way, even though being a more traditional way, it avoided issues on the data use. Again, the case study showed that there is not a single fixed solution, but each case needs to be analysed and solved. The ideal solution is using an open format like IFC, but more practice and ability to controlling it needs to be acquired to function appropriately without significant issues. On the workflow, the validation and verification milestones consider that the IFC should be checked. For this reason, no changes are needed.

5.2.5. Construction

5.2.5.1. Uses of model on the field

On the workflow, the use considered for the model on-site was mainly construction coordination. Caires told that in the case studies, the main uses were for visualisation, design interpretation, health and safety issues, and coordination. Also, model phasing was used, to simulate cranes and installation of sky bridges, and to define exclusion zones. For that, the interviewee mentioned there were screen zones on-site to allow model checking. For Caires, one of the most significant gains of using technology on-site is always having the updated drawings and correct revisions. Under these circumstances, there were no changes made to the workflow, as it is considering the use for construction coordination and simulation.

5.2.5.2. Use drawings

When asked about the necessity of generating drawings when the team have access to the model on-site, it was answered that it exists this vision of not having drawings on-site. However, in his opinion, drawings are still fundamental for construction. The reason for that is that people constructing still need standard details to follow construct, instead of spending time measuring on the model every time. The proposed workflow is also considering the necessity of drawings, just as mentioned by the interviewee, so no changes were made.

5.2.5.3. Communication between site and others - RFI

On the process map, request for information were considered centralized in an information management platform. In the point of view of the interviewee, the problem is that “there is a lot of inefficiency with bad communication and misunderstanding of things”. The way to deal with it on the case study was by creating reports when there was a RFI from the site to a designer. These reports were added in a platform, so the designer could answer it. It was mentioned that these RFI processes could be improved using standard forms. In those, a picture can be taken with any mobile device, and a quick comment can be added, and avoid people being on the computer to launch these forms. On this dissertation outputs, although it already considers centralizing information in one platform, it could be highlighted the importance of selecting an information management platform that allows the quick interaction between site and other stakeholders and providing the infrastructure in the site that allows it.

5.2.5.4. As-built information records

The traditional way of doing the as-built record is taking pictures and updating drawings, as answered by the interviewee. In his view, the most effective way that this process could be improved is doing laser scanning of the site every time a delivery package is completed. The laser scan can be compared with the model, and the differences can be checked. This can be a quicker solution than registering all the changes. For that, it was mentioned that the contractor would have to agree on receiving the as-built information in this format. The proposed workflow considered the as-built information in a centralised platform. However, it could be included as one option the delivery of as-built information in laser scanning to update the models after.

5.2.5.5. Update BIM model – Responsible and consequences

The responsibility of the as-built model on the workflow was considered to the design team, but mentioned that this should be established on the contract previously, because it could also be the contractor. On the case studies, the responsible for the as-built model was the contractor. Caires explained that the ownership of the model needs to be well established in the contract, so after the design was completed, the contractor takes ownership of the model, copy it and start developing the construction model. Once changes are made on-site, the contractor starts incorporating to the model what happened on-site, and the designer validates it. The management requirements proposed addressed the necessity of clearly defining responsibilities, including the responsible for the as-built model. The responsible for each task needs to be well established on the contract, and the ownership of the model discussed, also, by doing that it is possible to foresee any incompatibility between different software used between different stakeholders. Although the responsible party used in the workflow and cited by Caires were not the same, no changes were added as it is made clear that the responsibility for this task should be defined in the beginning, and it is a matter of defining it in the contract.

5.2.6. Handover

5.2.6.1. How the information is handed over and verified

The workflow considered the delivery of the asset information model and construction documents on the handover by the contractor to the facility manager. It was mentioned that when working with BIM projects, the deliverables in the handover phase are the as-built model, the drawings, and the operation and maintenance guides. He mentioned that this information is generally delivered through the CDE, and it goes through an approval process by the client.

About the validation of the client, one matter raised by Caires is that in one of the case studies the client did a laser scan of the building and questioned differences between the laser scanning and the as-built model. In this case, the model had to be updated later by the contractors.

For the workflow, the validation of the updated as-built was considered as a verification gateway. For that, the verification consists of checking parameters and the compliance with the site changes. It could be added as an additional verification for the client or project manager the laser scanning.

5.2.6.2. Definition of format

The information requirements and workflow considered that the delivery format of handover information should be agreed at the beginning of the project. This consideration was made in order to allow the interoperability with the Operations and Management software. The interviewee pointed out that the issue of agreeing in the begging of the project is that, as a project can last around five years, the software used can be changed in this period. For this reason, it was said that the format could be agreed on the beginning. However, this requirement needs to be updated during the process. That being so, a note could be added on this matter to the process map or to the explanation about the necessity of updating the format agreement during the process.

5.2.7. Operations

5.2.7.1. Link with database

The responsibility of linking model information to an external database was attributed to the contractor on the workflow. The idea was that this database would be linked with the O&M software. When asked about it, Caires mentioned that if it is not on the contract, it will not be the contractor's responsibility. It was mentioned that it needs to be someone who understands deeply strategic matters, like the BIM manager of the client. The responsible for this need to "understand the strategy of how the building will be maintained, what is the best software to do that, the work process, what is needed to be collected from the assets, the network connection of model with the asset management software". For that, a change or consideration related to this task could be added to the workflow.

5.2.7.2. Interoperability

About the interoperability between the BIM model and O&M systems, it was mentioned that the format of exchange should be defined in the contract. The client will define how he wants to receive information within the information requirements. At the educational building, for example, it was defined that each object has a hyperlink connected to a PDF or a data sheet where warranties are located. So this information will not be on the model, but with a link for them to access the information. In this case, in Caires opinion, having this information on the model would allow to have access in the asset management software. The solution with the hyperlinks cut this information connection. If someone in the client-side wants to access this information on the management software, he will not be able, and will need to type again the same value that has already been typed.

On this work, the format definition is also considered to be specified in information requirements, so no changes were considered.

5.2.7.3. COBie format

Related to COBie, as it is an open standard for the exchange of information in the operations phase, it is indicated in the workflow as one option to be adopted. As stated on item 2.2.5, some researches point some issues found when dealing with Cobie. On account of this, Caires was asked about his experience using COBie. Also, if he had found issues while applying it, in his view, there will always be issues, especially when the team is not familiar with Cobie and using Cobie in big projects. However, it was mentioned that there are also a lot of successful cases with Cobie, and much work is done. For him, in order to have good outcomes, it is needed to be defined in the beginning how it is intended to capture information and run tests and pilots during the project to anticipate and overcome possible issues.

The workflow is considering the use of COBie. Nevertheless, with these considerations, the process map could include during the Construction phase, a task that occurs regardless of other activities to test this information exchanges with operations, as shown in Figure 31.

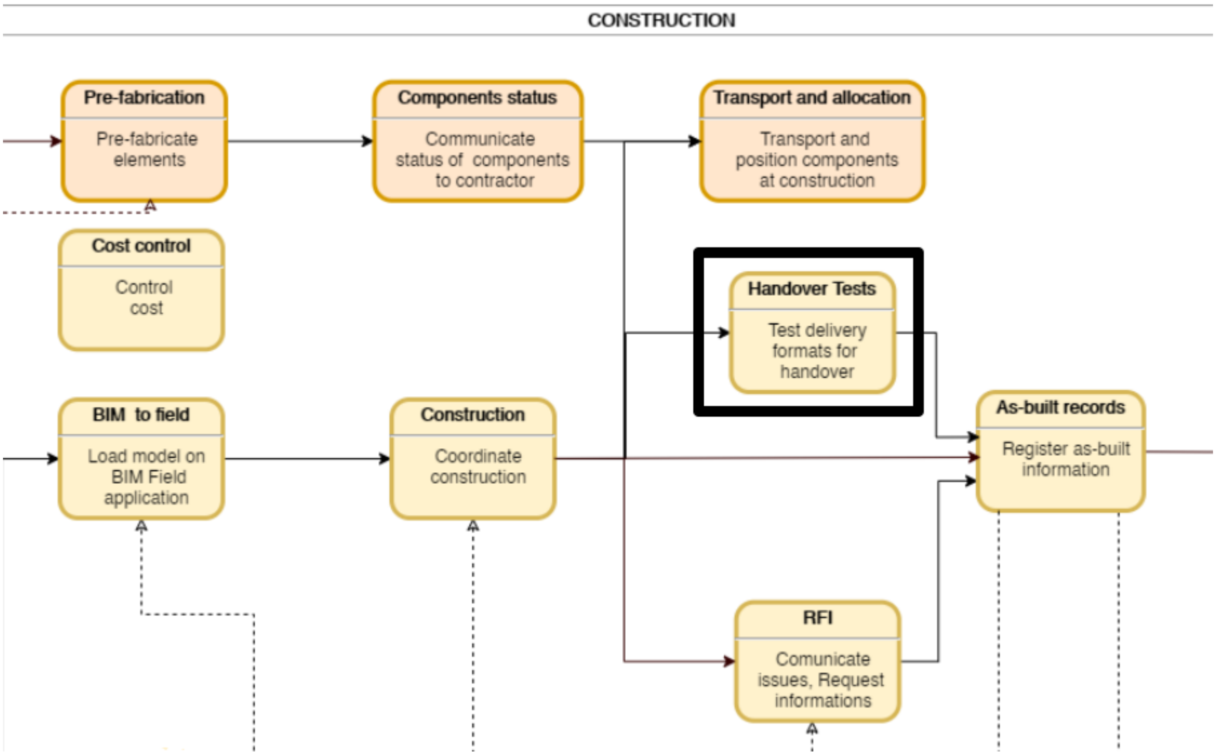

Figure 31 – Suggestion of how the handover tests could be added to the workflow

5.2.8. Compilation of validation

In order to summarize the content and comments of the validation process, the topics were compiled in Table 13. The table is divided according to each one of the discussed subjects. For each, it is pointed out if it was validated or not, a comment on the workflow or requirement proposed, and if any changes were necessary. The changes mentioned were suggestions on modifications or observations that could be added to the work in order for them to solve the specific found issue.

Table 13 – Validation results compilation

VALIDATION SUMMARY				
Stage	Topic	Valid?	Comment	Necessary changes
Preparation and brief	Type of contract - IPD	No	Difficulty in implementing IPD	Requirements should call attention for the best practices on IPD contract.
	Collaboration on EIR, AIR	Yes	Recomendable practice, although mentioned an experienced PM could also do it.	-
Design	Stakeholders participation	Yes	The collaboration of stakeholders on design was considered a positive practice.	-
Construction planning and management	WBS early defined	Yes	-	Add updated WBS verification to the validation milestone in the design phase.

	QTO responsability	Yes	Responsibility attributed to the contractor.	-
	5D responsibility	No	Responsibility attributed to the QS, instead of the contractor.	Not changed, as the responsible party may vary according to the project.
	5D software	Yes	Necessary discussion on the beginning of the project. Proposed technical requirements consider it.	-
	Interoperability - IFC data	Yes	Milestones validation considers IFC verification.	-
	Field's Model use	Yes	Workflow considers use for coordination and simulation.	-
	Use of drawings	Yes	Drawings can be still considered necessary, even with models.	-
	RFI	Yes	Centralize information in an IM platform	Highlight important considerations when selecting an IM platform
	As-built records	Yes	As-built register with pictures and model updates.	Add comment about the possibility of handing as-built information in a laser scan.
	As-built model responsibility	Yes	Responsibility attributed to the design team instead of the contractor.	Not changed, as the responsible party may vary according to the project. Necessary to define it in the contract.
Handover	Information handover	Yes	Handover of model and documents.	-
	Handover verification	Yes	Verification gateway of the client considered.	-
	Format definition	Yes	Format should be defined in the beginning.	Add a note to review this format during the process, in case it changes.
Operations	Database Link - Responsible	No	Responsibility attributed to the contractor, instead of the client's BIM Manager.	Add consideration that person in charge should understand the client's strategic matters deeply.
	Interoperability	Yes	Format should be defined in the beginning.	-
	COBie format	Yes	COBie format considered an option.	Add activity to run interoperability tests during construction.

5.3. Final presentation to the company

The third milestone of the validation consisted of a presentation of the developed work to a board of professionals from BIMMS. The meeting had the participation of five experienced people from the company, being three partners of the company and two BIM coordinators. The goal of this step was to show the final work to the partner company and to validate it in the professional environment. It was presented and explained the objectives of the research, the methods and developed work. After the presentation, each one of the involved professionals of BIMMS made comments, raised questions and suggested future developments to work.

Overall, the comments received on the developed workflow and information requirements were positive, with the board mentioning the work surpassed their expectations. It was commented that they were impressed by the work and stated that there was a "great balance between the scientific and professional world". Also, it was mentioned that the workflow provides a strong overview of the process and on how information is required and used throughout the construction and operations stages. In their opinion, the work can help people involved in BIM projects understand the process in a strategic view. Moreover, it can be adaptable to be used in the company.

There were remarks and ideas for further developments on how to detail more each one of the stages, especially the "Construction Phase". The suggestions involved the detailing of the construction quality control, and adding BIM uses related to procurement and commissioning stage. Also, it was mentioned that the interaction with the subcontractor could be explored. The procedures on ownership of the model with the subcontractors, on how to check models developed by third parties, and how to integrate were some of the suggestions pointed out.

The definition of requirements of contractors and facility managers at the beginning of the process was pointed out as an exemplary aspect of the workflow and information requirements. It was discussed the importance of defining parameters that will be needed in the end at the beginning of the process. Also, it was commented that this is an issue that appeared in some projects in the company, and having these clear instructions and template for requirments can provide help on it.

This presentation to the company validated the work in the professional environment, and enriched the work with comments from the practical and strategic point of view. BIMMS board members claimed to be satisfied with the work, and the relevance of the content of what it was presented. There was a unanimous approval of the work. The work developed will provide guidance to professionals in the company that want to comprehend the subject.

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6. CONCLUSIONS

This research aimed to identify a way to control and process information on Building Information Modelling (BIM) along the construction to the operation stages. As it can be confirmed by the developed work and raised discussions, BIM plays an important role in concentrating and transferring information. By all means, information management understanding can boost the use and exchange of information throughout the project process. In order to address the challenges of this work, information requirements and workflow were created comprehending the construction and operation phases. The outcomes indicate that information produced and required for each phase and stakeholder involved are distinctive and have to be managed according to its specific use and purpose.

This research has identified that the early involvement of all stakeholders can improve the usability of information on further stages. Having the owner, contractor and facility manager since the requirements are defined helps establish procedures for information exchanges. Moreover, the definition of information parameters and technical specifications for construction and operations cooperate for the use and applicability of the model in different BIM uses.

The relevance of data quality verification and control emerge from this study. Defining steps for validation of the data being created is critical throughout the entire process, especially when changing milestones. The work has also shown the importance of mastering the information exchange, especially when it occurs between different stakeholders. When performing the handover between design and construction, and later between construction and operation phases, attention should be put on the accuracy of information and interoperability of different systems used. This dissertation has provided extensive insight into the types of exchange, difficulties and ways for the handover of information. From that, it can be concluded that there is not only one possible solution, but different manners of managing it. Nevertheless, for it to be successful, it needs to be thought of at the beginning of the process, the solution needs to be agreed between different parties, tested, and verified. Also, the responsibilities should also be clearly defined in the contract to avoid misunderstanding later in the process.

The study contributes to the understanding of information flow on construction and operation phases and the way to control it properly. The findings will be of interest to stakeholders involved in a strategic view of the project, where a global examination of all variables of the project is fundamental. Overall, this work gathered knowledge of the scientific world and generated practical guidelines that can be adapted and used in companies involved in the BIM processes, in order to enhance information control and the utilization of produced information throughout the entire process.

Future research could continue to explore the information management, focusing on each one of the phases – construction, handover, and operations – in order to achieve a more in-depth investigation on the variables that involve each stage specifically. For instance, in the construction phase, more BIM uses could be considered, such as detailing the construction quality control, and uses related to procurement and commissioning stage. Also, it could be explored how the relation between model's elements classification systems are being related to the items in bills of quantities, in practical solutions. On the handover, the contents and necessities of the asset information model could be explored. For operations and maintenance phase, future researches could focus on investigating solutions for integrating the information generated in the BIM process, with FM systems, considering open formats possibilities.

In addition, studies on a practical approach on how to proceed with data quality and compliance verification might prove an important area for future research. Data quality has shown to be a critical issue on BIM processes, and guidelines on how to ensure that the model has the required level of development, information, and geometry would be useful to complement the present work.

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LIST OF ACRONYMS AND ABBREVIATIONS

4D	4 Dimensions
5D	5 Dimensions
API	Application Programming Interface
AIM	Asset Information Model
AIR	Asset Information Requirements
BEP	BIM Execution Plan
BS	British Standard
BSI	British Standard Institution
BIM	Building Information Modelling
CDE	Common Data Environment
CAD	Computer-aided Design
CAFM	Computer-Aided Facility Management
CMMS	Computerized Maintenance Management System
CM@R	Construction Management at Risk
COBie	Construction Operations Building Information Exchange
DBB	Design-Bid-Build
DB	Design-Build
ERP	Enterprise Resource Planning
EIR	Exchange Information Requirements
FM	Facility Management
FM	Facility Manager
IFC	Industry Foundation Class
IM	Information Management
IR	Information Requirements
IPD	Integrated Project Delivery
ISO	International Organization for Standardization
LOD	Level of Development
LITE	Lifecycle Information Transformation and Exchange
MEP	Mechanical, Electrical and Plumbing
NIBS	National Institute of Building Sciences
O&M	Operations and Maintenance
OIR	Organisational Information Requirements
PIM	Project Information Model
PIR	Project Information Requirements
PM	Project Manager
PAS	Publicly Available Specification
QS	Quantity Surveyor
QTO	Quantity takeoff
RFI	Request for information
RIBS	Royal Institute of British Architects
STEP	Standard for the Exchange of Product Data

SQL	Structure Query Language
WBS	Work Breakdown Structure
XML	Extended Markup Language

APPENDICES

APPENDIX 1: INFORMATION REQUIREMENTS TEMPLATE

TECHNICAL REQUIREMENTS

Project Name:	
Client:	

SOFTWARE AND DATA EXCHANGE FORMAT					
Phase	**BIM Use**	**Software**	**Version**	**Formats accepted**	**Output Format**
Construction	Quantity takeoff	Software 1	2020	IFC	.xls
	4D	Software 2	2020	IFC	Native format, .mp4
	5D	Software 1	2020	IFC	
	Field BIM	Software 3	2020	IFC	-
Handover	As-built model	Software 4	2020	Native format	Native format, IFC
Operations	Asset Management	Software 5	2020	COBie	

DATA INFORMATION EXCHANGE		
Common Data Environment	**Platform**	**Responsible**
	Platform X	Owner / Project Manager

TYPE OF DATA	
Data	**Provided on**
Quantities	.xls, integrated with software
Schedule	.mpp
As-built changes	Register on IM platform, Point cloud
Construction documents	PDF
Equipment's position	Model
Manuals	PDF, linked with model
Warranties	PDF, linked with model

INFORMATION NEEDS			
Phase	**BIM Use**	**Parameter**	**Description**
Construction	Quantity takeoff	Classification system	The classification system X will be used to link with the bill of quantities
	4D	4D	4D parameter to insert sequencing on the model
	5D	5D	5D parameter to insert cost
	Field BIM	Field_Complete	Mark items that are executed in the field.
Operations	Asset Management	Manufacturer	Field to specify name of manufacter
	Asset Management	Installation Date	Field to specify the installation date
	Asset Management	Expected Life	Field to specify expected life of equipments

MANAGEMENT REQUIREMENTS

Project Name:	
Client:	

STANDARDS		
Standard	Applicable	Responsible
ISO 19650-1:2018	x	BIM Manager
ISO 19650-2:2018	x	BIM Manager
ISO 19650-3:2020	x	BIM Manager
Industry Foundation Classes (IFC)	x	Design Team
COBie (Construction Operations Building Information Exchange).	x	Facility Manager

RESPONSIBILITIES					
Activity	Responsible				
	Owner	Contractor	FM	Design Team	Subcontractor 1
Model segmentatio according to WBS				X	
Insert 4D and 5D parameters to model		X			
Insert FM parameters to model		X			
Develop as-built model				X	
Link model data to O&M system		X			
Answer RFIs in platform Y	X	X	X	X	X

QUALITY CONTROL			
Type of verification	Responsible	Milestone	Date
Data check	x	1	01/01/2020
BIM Standard Check	x	1	01/02/2020
Data check	x	2	01/03/2020
Data check	x	3	01/04/2020

COMMERCIAL REQUIREMENTS

Project Name:	
Client:	

BIM USES FOR CONSTRUCTION AND OPERATION	
Uses	**Apply in project?**
Site Utilization Planning	X
Construction System Design	
Digital Fabrication	X
3D Control	X
Record Modelling	
Maintanance Schedulling	X
Asset Management	
Space Management	X

DELIVERABLES			
Activity	**Deliverable**	**Format**	**Responsible**
4D	Animation video	.mp4	Contractor
5D	Model linked with cost	x	Contractor
Model update to As-built	As-built model	.rvt	Design Team
Operations Database	Populated database	.SQL	FM

APPENDIX 2: VALIDATION INTERVIEW QUESTIONS

QUESTIONS FOR CASE STUDY		
INTRODUCTION		- Explain the confidentiality of the interview
		- Ask permission to record
		- Explain the focus of the dissertation
		- Explain what is expected from the interviewed, the number of questions and time planned
TEAM	1.1	What are the main challenges in your evaluation of the competences of the team members of your company? In your experience, is there someone evaluating the all teams competencies? If yes, how?
	1.2	Is anyone requesting specific competences? Certified ones or not?
	1.3	What do you think about this roles matrix proposal?
	1.4	Who is in charge to write down the EIR and the BEP? The BIM Manager? How is the BIM Manager role being attributed?
EIR	2.1	How have the BIM requirements been specified?
	2.2	In your opinion, who should contribute to the set up of these requirements? Are all the parties (designers, owners, contractors, subcontractors, facility managers) involved? Is that an imposed process, or is it a collaborative work?
	2.3	Should it be based on a specific guideline/rule, or is it project related?
	2.4	What type of contract is generally used? (DB, DBB, IPD) Do you think that affect the BIM processes?
	2.5	Do you think requirements should be more generic or more specific? Do you foresee this process as a machine to machine procedure in the future?
CDE	3.1	In your opinion, do you think it is feasible to have only one CDE during the whole process of information management? If yes, who should be responsible for it?
	3.2	How is it chosen the CDE for each project? Is it an employer requirements? If yes, do you have the chance to give your opinion about it?
AIR	4.1	Is it usual to require information that will be used in the operation phase since the beginning? Or when do you think that information should be required?
	4.2	Is the facility manager involved in this definition of this AIR?
BEP	5.1	During the development of the BEP, are all the parties (designers, owners, contractors, subcontractors, facility managers) involved?
	5.2	How is the LOD established? By whom?

	5.3	Is it agreed on software to avoid interoperability issues? Software and version?
	5.4	Does the company generally use IFC as exchange formats? What do you think are its benefits?
	5.5	How is the data segregation managed?
	5.6	Does the company generally use Cobie as exchange formats? In your opinion, what are its benefits?
	5.7	Once you define Cobie as exchange format, how do you manage the information (Excel, XML)?
	5.8	How is data security dealt with on BIM projects?
	5.9	How do you define the intellectual property of the model?
	5.10	Do you set out a protocol for issues? (clash detection, lack of information, quality assurance)
TIDP	6.1	Do you have a Task information delivery plan? Who controls it and verifies its fulfilment?
	6.2	Do you have a master information delivery plan? How do they collect and decide for information delivery?
MODEL	7.1	Does each team delivers one model?
	7.2	How to check model quality? What is verified? Who is responsible for it?
	7.3	Who runs the clash detection? How are the results of the clash detection transferred to the other team members?
DESIGN PHASE	8.1	Are all stakeholders involved here? (designers, owners, contractors, subcontractors, facility managers)
	8.2	How is the communication of issues? Is there a predefined hierarchy?
	8.3	What are the main problems in this phase working with BIM?
PLAN AND COST	9.1	Who is responsible for the quantity take-off? Does someone validate the quantity take-offs?
	9.2	Is the WBS defined at the beginning of the project? Is a requirement from the contractor at the beginning of the project (defined in the BEP?)?
	9.3	Are the quantity take-offs according to the WBS?
	9.4	Who is responsible for the 5D (cost)?
	9.5	Are the parameters in the model used for planning and cost added in the design phase? Or is it changed by someone else in the "construction planning" phase?
	9.6	What software is used on BIM cost and planning? How is the interoperability between them and the models from the design phase?
CONSTRUCTION	10.1	What software is used on BIM to Field? How do you visualize the model on-site?

	10.2	What is the use of the model on-site?
	10.3	Do you think other uses of the model could be applied on-site?
	10.4	How do you communicate from the construction site when there are issues or request of information?
	10.5	How do you think it could be improved? Is it centralized in an IM platform?
	10.6	How are the as-built information recorded? In a model? In paper? Through pictures?
	10.7	Who is the responsible for the as-built model in the study case?
	10.8	If the responsible for the as-built model is not the design team, do you think other stakeholders should start the model from zero?
HANDOVER	11.1	How is the handover to the facility managers? A CDE? Is all information contained on the model?
OPERATIONS	12.1	Does the facility manager requires, in the beginning, the format he needs the data so he can use in his O&M software?
	12.2	Is the model exported to an external database to be used by the FM?
	12.3	Do you think the contractor should make the link of the model whit a database or should the FM receive and deal with models and documentation?
	12.4	How is the interoperability between the model (data from previous phases) and O&M systems?
	12.5	In your experience, did you find any issues while using COBie?
MODEL	13.1	How does the model evolve from one phase to another? Who is responsible for exchanging the model information from one phase to another?
	13.2	How and where the model is stored after the project ends?