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Development of the Ontology-Based Framework and Tool for Employer Information Requirements (OntEIR)

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Declaration

This work has not been submitted in substance for any other degree or award at this or any other university or place of learning, nor is being submitted concurrently in candidature for any other degree or other award.

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Abstract

The identification of proper requirements is a key factor for a successful construction project. Many attempts in the form of frameworks, models, and tools have been put forward to assist in identifying those requirements. In projects using Building Information Modelling (BIM), the Employer Information Requirements (EIR) is a fundamental ingredient in achieving a successful BIM project.

As of April 2016, Building Information Modelling (BIM) was mandated for all UK government projects, as part of the Government Construction Strategy. This means that all central Government departments must only tender with suppliers that demonstrate their capability on working with the Level-2 BIM.

One of the fundamental ingredients of achieving the BIM Level-2 is the provision of full and clear Employer Information Requirements (EIR). As defined by PAS 1192-2, EIR is a "pre-tender document that sets out the information to be delivered and the standards and processes to be adopted by the supplier as part of the project delivery process". it also notes that "EIR should be incorporated into tender documentation to enable suppliers to produce an initial BIM Execution Plan (BEP)".

Effective definition of EIRs can contribute to better productivity (in terms of budget and time limit) and to improving the quality of the built facility. Also, EIR contribute to the information clients get at the end of the project, which will enable the effective management and operation of the asset at less cost, in an industry, where typically 60% of the cost go towards maintenance and operation.

The aim of this research is to develop a better approach, for producing a full and complete set of EIRs, which ensures that the clients information needs for the final model delivered by BIM be clearly defined from the very beginning of the BIM process. It also manages the collaboration between the different stakeholders of the project, which allows them to communicate and deliver to the client's requirements. In other words, an EIR that manages the whole BIM process and the information delivered throughout its lifecycle, and the standards to be adopted by the suppliers as an essential ingredient for the success of a BIM project. For the research to be able to achieve the aims set and the formulated objectives, firstly a detailed and critical review on related work and issues was conducted. Then the initial design of the OntEIR Framework, which introduced the new categorisation system of the information requirements and the elicitation of requirements from high-level needs using ontology was presented. A research prototype of an online tool was developed as a proof-of-concept to implement and operationalise the research framework.

The evaluation of the framework and prototype tool via interviews and questionnaires was conducted with both industry experts and inexperienced stakeholders. The findings indicate that the adoption of the framework and tool, in addition to the new categorisation system, could contribute towards effective and efficient development of EIRs that provide a better understanding of the information requirements as requested by BIM, and support the production of a complete BIM Execution Plan (BEP) and a Master Information Delivery Plan (MIDP).

Key words:

Requirements, Information Requirements, EIR, BIM, BEP, MIDP, Framework, Categorisation of requirements, Construction, ontology, Employer Information Requirements, Building Information Modelling, BIM Execution Plan, Master Information Delivery Plan, web-based tool

List of Publications

Thesis author’s publications related to research subject or cited in this thesis report

Journal Papers:

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Conference Proceedings

Dwairi, S., Mahjoubi, L., Odeh, M. and Kossmann, M., 2017. Ont-EIR framework to deliver sustainable heritage projects. In *Advanced Technologies for Sustainable Systems* (pp. 19-30). Springer International Publishing

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Conference Proceedings

Alzoubi, H.H. and **Dwairi, S.,** 2013, Re-Assessment of National Energy Codes in Jordan in terms of Energy Consumption and solar right in Residential Buildings. GCREEDER 2013, Amman-Jordan, September 10th– 12th 2013 1

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List of Abbreviations

AEC	Architecture, Engineering and Construction
AIA	American Institute of Architects
BEP	BIM Execution Plan
BIM	Building Information Modelling
BIM IDL	BIM Information Delivery Lifecycle
BSI	British Standards Institute
CAD	Computer Added Design
CIB	Council for Research and Innovation in Building and Construction
CIC	Construction Industry Council
CIOB	Chartered Institute for Buildings
COBie	Construction Operations Building Information Exchange
EIR	Employer Information Requirements
HTML	Hypertext Mark-up Language
GUI	Graphical User Interface
IFC	The Industry Foundation Classes
IPD	Integrated Project Delivery
MEP	Mechanical, Electrical and Plumbing
MIDP	Master Information Delivery Plan
NBS	National Building Specifications
NIBS	National Institute for Building Science
OntEIR	Ontology Based (Framework/Tool) for defining Employer Information Requirements
OWL	Web Ontology Language
PAS	Publicly Available Specification
PIM	Project Information Model

RII	Relative Importance Index
UK	The United Kingdom
UniClass	Unified Classification
XML	eXtensible Mark-up Language

Chapter 1 Introduction

1.1 Background

The definition of requirements it practiced in almost all disciplines as a first attempt to ensure that the final product is delivered according certain needs and desires, this is usually done before work on the project even starts. In construction, this is also the case, Employer Information Requirements is a document that sets out the information to be delivered, and the standards and processes which are to be adopted by the supplier as part of the project delivery process.

It is very important for the success of a BIM project that an EIR is in place from the beginning. By doing so, it is ensured that the project team are aware and fully understand the levels of services they are expected to offer during the execution of the project. Consequences of a team not working with an EIR result in the team not being able to formulate the appropriate BIM Execution Plan (BEP), which is the main means to ensure that the right information is issued at the right time during the project. With the right EIR in place, the production of a right BEP will be possible, that will comprise of a plan that will explain how the BIM aspects of the project will be carried out, who will be involved, when will the information will be delivered and how it will be delivered.

This chapter introduces the context of the research within the construction industry, and in particular with projects using BIM, and will demonstrate the importance of this study in the industry (Section 1.2), related previous studies that conducted in the field of requirements in the construction industry will be presented in (Section 1.3), associated with the gaps in knowledge (Section 1.4). The research aim, which is to develop an ontology-based framework for EIR, and the objectives set to achieve it will be described in (Section 1.5). The research methodology set to achieve the previous aim and objectives is explained in (Section 1.6), followed by the description of the process this study follows to achieve the aim and objectives (Section 1.7), finally, an overview of the research and the chapter contents will be discussed in detail in (Section 1.7).

1.2 Context

This research concerns creating an ontology-based Employer Information Requirements (OntEIR) framework, to enable clients in defining and specifying the information requirements for a BIM project, which leads to enhancing project quality and increasing client integration in the project.

Defining requirements has always been an important first step in the construction project, it is considered one of the critical success factors of the project (Sanvido *et al.*, 1992), in fact, poor requirement identification during the first stages of the project is a major source for problems in buildings, an example is the Pruitt Igoe project that was demolished in 1976 because it did not respond to the social and behavioural needs of the users (Newman, 1966; Shen *et al.*, 2004). Other projects such as Terminal 5 in Heathrow Airport was more employer-oriented, and had a more systematic and clear way in identifying the employer needs in the project, which was also expressed in the contracts and agreements in the participating parties in the project, this clear and adequate expression of requirements was one of the main reasons that enabled the project to be delivered on budget and ahead of schedule (Potts and Ankrah, 2014).

The importance of good identification of requirements arises from them being a way to define the end product in terms of the clients and stakeholders needs, meeting the clients' satisfaction, and improve the projects performance, which is the basis of every project (Walker, 2015). The lack of skills in defining the requirements in the beginning of the project often leads to incompatibility of client requirements, cost, and time for completion, which will eventually lead to overrun in cost and time (Sebastian, 2011).

Although Employer Information Requirements (EIR) has appeared alongside the appearance of the Building Information Modelling (BIM) to specify the information requirements associated with the BIM project, Employer Requirements (ER) or client requirements have existed in the construction industry long before and defining them was considered one of the most important part of the construction process. As the construction industry evolved, and BIM becoming an important process, the requirements for the projects have evolved as well, incorporating the information requirements, making EIR an important success factor of the BIM project.

It is necessary at this point to make it clear that despite the distinction between the terms client and employer, this thesis refers to both the client and the employer as the same entity, which according to e CIOB Code of practice for project management, defines a client as the 'Entity, individual or organisation commissioning and funding the project, directly or indirectly.' (CIOB, 2015) The client is also sometimes referred to as the:

- Employer;
- Promoter;
- Owner;
- Purchaser;
- Principal.

Employer requirements, or Client requirements have been in the industry for so long, and have been considered one of the critical success factors in the project(Sanvido *et al.*, 1992), studies conducted (Kamara, Anumba and Evbuomwan, 2002) refer to these requirements as "the voice of the client", because it includes the collective wishes, perspectives and expectations of the various components of the client body (Kamara, Anumba and Evbuomwan, 2002). Thus, client requirements, or the employer requirements constitute the primary source of information for a construction project and is considered vital to the successful planning and the implementation of a project.

Client Requirements are considered one of the two essential inputs which are considered vital for the EIR; requirements for the physical aspect of the building (client requirements or brief) and requirements for the information content and flow the project; the Information Requirements (IR) (Saxon, 2016). The project brief defines the client's requirements for the project, sets out the performance criteria in the terminology of the building, and continues to evaluate the project after it has been finished and occupied (Blyth and Worthington, 2010) and is the main contributor to the Organisational Information Requirements (OIR). On the other hand, IR require a great deal of attention in order to be able to achieve the full potential of BIM across the whole lifecycle due to the fact that they cover requirements that control the delivery of the Asset Information during the project stages (AIR), which contribute to the vital role in making strategic and operational decisions during the project's lifecycle until the project is complete at the end of the process (Saxon, 2016). The requirements discussed above; the client requirements, the brief, the Information Requirements, and the Asset Information Requirements, collectively contribute to the EIR, which is an all-inclusive set of requirements for the BIM project. One of the key pillars of BIM (PAS 1192-2:2013, 2013) produced by the BIM Task Group proposed setting out the EIR, as part of the Employer's Requirements document, which is incorporated into tender documents. Such documents provide information that is mandatory for suppliers to be able to produce the BIM Execution Plan (BEP), in which the proposed approach, capability and capacity can be evaluated. This information includes requirements required by the client in addition to key decision points and project stages.

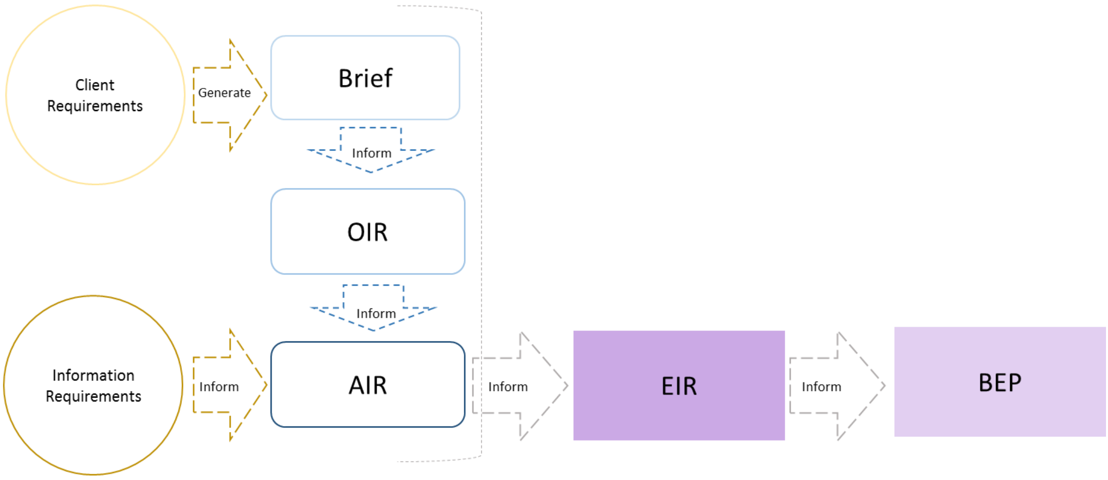


Figure 1.1 Organisational Information Requirements (OIR) and Asset Information Requirements (AIR) as Inputs to Employer Information Requirements (EIR)

According to PAS 1192-2013 (BSi, 2013), EIR should be specified at the very beginning of the project, it is considered an essential first step of the success of the project because they are specify the information that should be delivered by the project team during the project lifecycle, in creating the Project Information Model (PIM), which is developed into an Asset Information Model (AIM) that holds all the information needed for the management of the asset, from handover and until the end of life of the asset, as shown in figure 1.2.

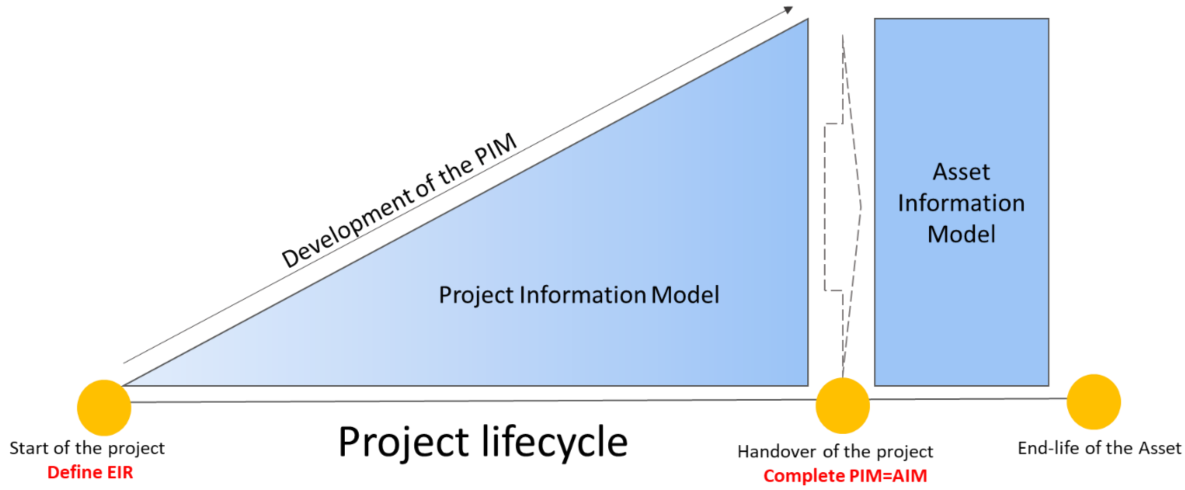


Figure 1.2: Development of PIM and AIM during the project according to the EIR-PAS 1192-2 (bsi, 2013)

Unfortunately, current practices for EIR specifications are ambiguous for experienced clients as well as inexperienced clients in BIM. “EIR Needs” are discussed in PAS 1192 and not requirements, there is still a need to elicit and specify those requirements to eliminate all ambiguity about it, and assist clients in creating a clear and comprehensive EIR.

Clear definition of requirements is considered a crucial factor in the improvement of construction projects (Lam el at, 2008). However, the preparation of the requirements depends largely on the employer’s experience; experienced employers are more capable of producing more detailed and meticulous requirements while unexperienced employers tend to ignore them completely (Murray, 1995). That is why it is of significant importance to pinpoint the problems with managing requirements in construction projects and searching potential solutions that will assist employers in defining their requirements in a more clear and comprehensive manner, specific to current practice in the construction industry, this gives rise to the need for a new manner to assist the inexperienced clients in identifying their needs completely and correctly, which is the aim of this research.

1.3 Previous Studies

Several studies attempted to identify client requirements, but a shortage of studies concerning the EIR is noticed, and many of the studies concerning requirements in construction is not BIM related (Hafeez *et al.*, 2015)

Research work is in the field of requirements postulated by Kamara et al. (2000), which advocated construction briefing as "client requirements process" within the discipline of concurrent engineering for life cycle design and construction. Bruce and Cooper (2000) highlighted the importance of understanding both hard and soft processes when developing requirements for clients. The document that contains the written instructions/requirements of the client is referred to as the "brief" which should include the following information:

• The background, purpose, scope, content and desired outcomes of the project;

• The functions of the intended facility and the relationships between them;

• Cost and time targets, instructions on the procurement and organization of the project;

• Site and environmental conditions, safety, interested third parties, and other factors that are likely to influence the design and construction of a facility (Kamara and Anumba, 2001).

Other studies assume the role of developing requirements through the practice of architectural programming. Pena and Parshall (2001) describe programming as the pre-design activity that develops the considerations or design determinants that define a comprehensive architectural problem. The information gathered and processed from the five-step iterative phase, which are: 1) Establish goals; 2) Collect and analyse facts; 3) Uncover and test concepts; 4) Determine needs; and 5) State the problem; culminates in an information index that adequately defines the problem and solution for design and construction development. These considerations are: function, form, economy and time. Pena and Parshall (2001) developed various programming methods to establish client and project values to allow designers to respond with alternative solutions to defined problems.

Other models that have been implemented in this area is the Client Requirements Processing Model (CRPM), which adopts structured methods in translating the "voice of the client" into the "voice of the designer" (Kamara *et al*., 2000). The model has three main stages: define client requirements, analyse client requirements, and translate client requirements. These stages sub-divide further into activities and utilise appropriate information gathering tools, decision support tools and quality assessment tools (e.g. Quality Function Deployment) to develop solution neutral specifications. CRPM is computerised within a software system called ClientPro and has been received as generally satisfactory in effectiveness. Test feedback reports that requirements generation, prioritization, clarity and visibility were adequately supported within the formal process. Kamara and Anumba maintain that client requirements be:

- Precisely defined, with as little ambiguity as possible, and reflective of all the perspectives and priorities represented by the client body;
- Stated in a format that is solution-neutral (i.e. not based on any design concept that could serve as a solution to the client's problem) and which makes it easy to trace and correlate design decisions to the original intentions of the client.

ClientPro was evaluated by four industry practitioners and rated relatively low in areas such as the facilitation of communication among members of the processing team, the usefulness of the software to the overall construction process, and the ease to use the system (Kamara et al., 2002).

Other tools introduced for processing clients' requirements is the Quality Function Deployment, which can be used for understanding and tracking requirements, and improving communication among product development team members (Kamara et al., 1999). This method is based on representing the requirements through matrixes as well as documenting. However, the use of QFD has been very modest in construction (Dikmen et al., 2005). Limitations of the use of QFD in construction as pointed out by Lima et al. (2008) is being time consuming to process this information, particularly if the proportions of the matrix become very large, it is not easy to involve product development team members in the processing stages that are necessary to produce the matrix.

Furthermore, in the field of EIR, not many studies were found. One of the attempts put forward to manage and define the EIR, is the Publicly Available Standards (PAS 1192-2, 2013). PAS 1192-3:2013 deals with the construction (CAPEX) phase and sets out to specify the requirements for achieving BIM Level 2 by setting out: the framework, roles and responsibilities for collaboration, the Common Data Environment (CDE) (Mcpartland, 2017).

It provides specific guidance for the information management requirements and the information exchanges during the project (The B1M, 2015). To do so, PAS 1192-2 explains the EIR as being the corner-stone of the BIM project and should contain all the information for the management and delivery of the information throughout the project lifecycle (BSi, 2013). Only that the way the EIR is explained in the PAS holds a lot of ambiguity, and needs further explanation especially for novice clients. In fact, in an article published in Shelidon (2017), under the title "PAS 1192-2 is under revision", it is clear that there are a lot of ambiguities and misconceptions that lead to lack of understanding the BIM process that starts with the EIR. Ashworth (2017) argues that users of PAS 1192-2 are overwhelmed by the amount of information that they don't know where to start when preparing their EIR. One of the confusions in PAS 1192-2 that will be talked about in detail in chapter 3, is between "needs" and "requirements" when discussing EIR. PAS 1192-2 makes the mistake of referring to the needs of EIR by requirements. The items discussed when explaining EIR are in fact high level needs, that should be further broken down to reach the end requirements. The needs mentioned in PAS are not enough for the definition of a full EIR, but they can act as a starting point for eliciting the final requirements and as check list when revising the EIR. The confusion this creates for new clients should be dealt with, and explained, and a distinction should be made between the high-level information needs and the information requirements.

One of the popular tools developed is the publicly shared BIM Toolkit developed by the NBS, the project is delivered on behalf of the Department of Business Innovation and Skills, the UK BIM Task Group and Innovate UK. The BIM toolkit comprises a digital plan of work, a unified classification system, thousands of definition templates and a verification tool.

The BIM toolkit offers Classification and Definition guides – a single unified classification system that will work across the industry and a Digital Plan of Work tool – to define responsibility for information within a project and clarity as to who is responsible for each part and when. Despite the great benefits this toolkit has to offer, it wouldn't be appropriate to identify it as an EIR toolkit, because in fact it only covers a very small fraction of the EIR needs as described in PAS 1192-2. Tina Pringle NBS Head of Technical Content, has noted on the NBS technical support page, in April 2015 that: "The NBS BIM Toolkit can be used to generate the content for sub-section 1.1.4 (Level of Detail) of an EIR. This defines the specific information requirements that are aligned to the project stages. This will be the information that the bidders and then project team subsequently build on through the digital plan of work.” On other words, the main if not the only job the NBS toolkit has to offer is identifying “some” information related to the project stages.

There is still a need for a more comprehensive EIR framework that is able to cover all “Needs” of the EIR and the “Requirements” that satisfy them, which will be the outcome of the Ontology-based framework for defining Employer Information Requirements (OntEIR) framework as will be discussed in detail in Chapter 4.

Additionally, the National Building Specifications (NBS) has also issued a set of Plain Language Questions (PLQs) that are intended for the client to answer at the end of each phase of the construction process to decide whether to proceed to the next phase or not. PLQs were initially set out by PAS 1192-2 (BSi, 2013) support the EIR in defining requirements for the phases of the process, the initial PLQ should respond to the aims and objectives of each phase of the construction process, answering them should demonstrate how successful the collaboration process between the team members was in achieving the aims of each phase, and how pleased the client is with the process and information provided, the PLQs should be able to cover the needs of the EIR as introduced by PAS 1192-2. Although the previous questions are written in plain language and are easy to interpret and answer, but still they have not been able to fully capture the client’s requirements. Clearly there are many other important aspects that should be covered in order for the client to be able to deliver a complete and comprehensive requirement document for the construction team. According to PAS 1192-2:2013 (2013), the EIR should include information regarding 3 main aspects: Information Management, Commercial Management, and Competence Assessment, in addition to employer’s requirements and the vision the client has for the project

1.4 Gaps in knowledge

The need for a comprehensive EIR framework arises from the fact that many issues should be covered completely in the EIR to assure delivery of a full package of requirements for the construction project team, which in turn will allow them to produce a complete and correct BEP, that will be the basis upon which the whole construction process will be based, and what the project team will rely on in taking decisions (Kumar, 2015) .

The success of EIR is measured, in terms of the degree to which it meets its purpose, therefore, the identification of this purpose should be done from the beginning of the development of the EIR. As studies have shown, inadequate, incomplete and ambiguous or inconsistent requirements have a significant negative impact on the quality of the project delivered (Assaf and Al-Hejji, 2006; Potts and Ankrah, 2014).

The process of elicitation, analysis, documentation, validation, and management of Employer Information Requirements and communicating them to the various stakeholders is an important process in reaching a more comprehensive, correct and clear set of EIRs, which in turn will enable stakeholders involved in producing a more successful project with less additional cost and overrun. The process is called Requirements Engineering, and has proven its ability in delivering a better quality sets of requirements in product development industries, this discipline can influence how well it is targeted to user needs, the accuracy of the design and specification, the ultimate cost and quality of the final product (Cysneiros, 2002).

However, the lack of fully understanding BIM and its benefits, which include the requirements needed to gain these benefits, have prevented from accepting and practicing this on a wide scale (Succar, 2010). In order to address these challenges, the client's role will have to be more of a team member that fully understands the BIM process, its requirements, and benefits (AIA, 2010). One of the main reasons for this lack of understandability of requirements is because the specifications and guidelines do not clearly specify these requirements. There is still some kind of confusion between EIR "Needs", and "Requirements", where Need refers to the informal expression of something that has to be provided, ensured, or avoided by a system or the development project of this system; from the viewpoint of one or several stakeholders (Kossmann, 2016). Kossmann (2016) also describes needs as being derived from the specified problem space of a given domain or project, i.e. they are based on specific problem areas or aspects. This problem space of a given domain or project has to be specified with the help of the identified relevant stakeholders and domain experts.'

On the other hand, Kossmann (2016) also argues that requirements are detailed expressions of specific aspects of a less detailed stakeholder need… It formalizes a relationship between one or several stakeholders and the developer of a system. Requirements are most frequently expressed as textual requirements, but in some areas, such as safety critical software requirements, formal requirements or models may be used.

Requirements are descriptions of how a system should behave (functional requirements), or of an overall system property or attribute (non-functional requirements). They may be a constraint on the development process, and on the program or project by which the system in question will be developed or modified.' (Kossmann, 2016)

Also, there should be more attention paid to novice clients, who still don't fully understand the BIM benefits and the requirements to achieve it. This research addresses these issues and aims at developing an EIR framework that will be clear, complete, and detailed in a way that all kinds of clients will be able to understand and use.

Despite the various research efforts, the specification of EIR is still underdeveloped, and a more client focused template for EIR is needed (Liu and Issa, 2013; Al Ahbabi and Alshawi, 2015). In order to improve the specification of requirements, Kiviniemi and Fischer (2005), suggested that is essential to develop IT tools to provide some degree of automation for requirements managements. However, the use of IT in that task poses important challenges, such as the difficulty of capturing both implicit and explicit requirements, maintaining information up to date, and storing different requirements from distinct stakeholders throughout the product development process (Leinonen and Huovila, 2001). This was the main reason for choosing an ontological approach for OntEIR, which is due to the potential it has to offer in improving both requirements elicitation and management (Castañeda *et al.*, 2010) and defining a common vocabulary for researchers who need to share information in a domain. It includes machine-interpretable definitions of basic concepts in the domain and relations among them (Noy and McGuinness, 2001). Ontology as defined by (Gruber, 1995) is a specification of a conceptualization; that is that ontology is a description of the concepts and relationships that can exist in the domain, this definition is consistent with the usage of ontology as set-of-concept-definitions, but more general. The relationships of the concepts existing in the domain is seen through the hierarchy of these concepts, where a domain is fragmented into classes and each class into sub classes until the instances are reached which are at the lowest rank of the hierarchy in the system.

EIR is the cornerstone for a successful BIM project. The importance of OntEIR is derived from the fact, that defining adequate EIR is an important step in the forming of the BEP, which will have the most influence on the project outcome. Another key reason for considering this framework to be critical, is in its novelty in being addressed to main key players of the different disciplines involved in the BIM project, it seeks to provide answers and address questions and issues that will be of great importance for the formulating of the project programme for all disciplines.

1.5 Aim and Objectives

The aim of this research is to develop an ontology-based framework for specifying Employer Information Requirements (OntEIR) for construction projects using BIM, this framework should address the complexity of multidisciplinary BIM projects in specifying the information requirements for it. The framework should meet four criteria, It should be:

Complete – i.e. Able to cover all the information requirements needed to produce a successful EIR;

Correct – i.e. the framework will be validated with many stakeholders in the industry, and evaluated to produce the final prototype, to ensure the correctness of the requirements specifies by OntEIR;

Consistent – with the underlying industry standards on BIM (PAS 1192-2, 1192-3, 1192-4, 1192-5)

User-friendly and understandable by all types of clients and stakeholders.

In order to reach the aim of this research, a number of objectives have to be met. Each chapter of this thesis will cover one or more of these objectives:

Objective 1: Review client requirements and their importance in a successful project delivery

Objective 2: Review of EIR and the contents of a full and complete set of requirements.

Objective 3: Develop the initial EIR framework based on the literature review conducted and validating it with key experts in the field

Objective 4: Build the OntEIR online tool based on the validated OntEIR framework and validate it with experienced and inexperienced clients and stakeholders in the industry

Objective 5: Provide conclusions and recommendations for the industry and the framework, as well as further studies to be conducted.

1.5.1 Contribution to Knowledge

This research is expected to contribute to knowledge in the following aspects:

- The identification of an elicitation system that allows the definition of more requirements than current studies and standards, up to 3 more times of more requirements;
- The contribution to Ontology, through utilising it defining Employer Information Requirements, through the hierarchy of needs, and the new categorisation system proposed in this research;
- Contribution to the industry through providing a state-of-the-art tool on defining EIR that is able to solve problems identified in the gaps of knowledge in the current practices.

1.6 Research Methodology

The purpose of this section is to provide an explanation of the research design dimensions adopted by this study. It examines the theoretical perspective that lies behind the methodology selected for this study. It also discusses the implications of the adopted methodology on the appropriate research methods.

The first stage of the research is to develop a conceptual framework. The proposed conceptual framework identifies the predominant research issues, which have significant implications on EIR. It seeks to draw together existing research and to provide a foundation for future work in this field. To provide a theoretical foundation that sheds light on EIR, a synthesis of existing literature and models is undertaken to develop a conceptual framework. Based on the analysis of state of the art in this field, the key attributes and their potential interactions are identified. Within each of these categories, a series of attributes are examined.

The validation of this conceptual framework is undertaken by a representative sample of relevant experts in the industry. Semi-structured interviews and surveys are carried out to generate information in response to validation criteria. The main characteristic of this methodology is that it does not need too many re-meetings and preparation by participants, the participants' contributions can be made in a single meeting which may last for about two hours, and the result of the meeting can be informed to participants as soon as the task has been completed (Twible, 1992).

Also, online questionnaires are distributed to the participants that are short and anonymous. The questionnaires also are designed to validate the framework according to the validation criteria that will be explained in detail in chapter 6.

The framework is then revisited and updated based on the results of the validation interviews and survey, to deliver the final OntEIR framework, upon which the tool will be developed.

The next stage of the research entails developing an ontology-driven EIR tool, which is based on the validated conceptual framework. This tool can potentially improve the specification of EIR by guiding users through the various aspects of the framework that need to be addressed and considered. According to (Kiviniemi and Fischer, 2005), a requirements management tool based on a framework can deliver the following:

- Create a formal structure for modelling requirements;
- Enable the creation of requirements templates, which may contain a large amount of information, being possible to define sub-sets of requirements of different types of projects;
- Store data that can be compared not only with design solutions but also with maintenance information throughout the building's life cycle.

Methods adopted to validate the tool include: focus groups and surveys. Focus groups were organised in two locations: The Airbus headquarters and KIER group. The aim was to demonstrate the tool to a group of experts and record their feedback and comments. A short questionnaire was also distributed that validates the tool according to certain criteria. Also, many relevant stakeholders and inexperienced and experienced clients were contacted through LinkedIn, and were asked to try the tool and fill in the questionnaire, which were both online.
Comments and feedback were recorded and will be discussed in the conclusion and recommendations chapter.

1.7 Research Process and Overview

This section provides and overview of the chapters in this thesis. Figure 1.3 illustrates the process and activities which were conducted during this research. The research consisted of four main activity clusters that led to specific deliverables and corresponding publications during the entire research process. The four activity clusters include: the literature review, the development and validation of the OntEIR framework, the development and validation of the OntEIR tool and conclusions and recommendations for future studies. Each of these clusters had an impact on a publication and/or a chapter, as seen in Figure 1.3.

This thesis consists of eight chapters, which are:

Chapter 2: Client Requirements

The main idea discussed in this chapter is client requirements. The chapter starts with discussing types of clients and their categorisation. Then it reviews the types of requirements and their categorisations in different disciplines. In this thesis, the terms client and employer refer to the same thing, which means that client requirements and employer requirements are the same also. Chapter 2 also defines the terms client requirements (or employer requirements) in the construction context, and will draw the map of the employer requirements in the construction industry sources of these requirements.

Chapter 3: Employer Information Requirements

This chapter discussed everything about EIR. It starts with describing the relation between EIR and BIM, and the importance of EIR in BIM projects, being the corner stone. It also discusses the term 'Needs' in EIR and points to the difference between needs and requirements. This chapter then examines the sources of information that are needed for a full and comprehensive EIR, and investigates in detail what should be covered by the EIR for it to be full and comprehensive. Chapter 2 also examines the challenges that face the definition of requirements in general and EIR in particular, it ends by a critical review current studies and state of the art in EIR.

Chapter 4: Research Methodology

Chapter 4 examines in detail the approach, methodology and the process in which this research designed and conducted, and the reasoning behind them. It also looks into the validation methodology for the framework and tool and the rational thinking behind it.

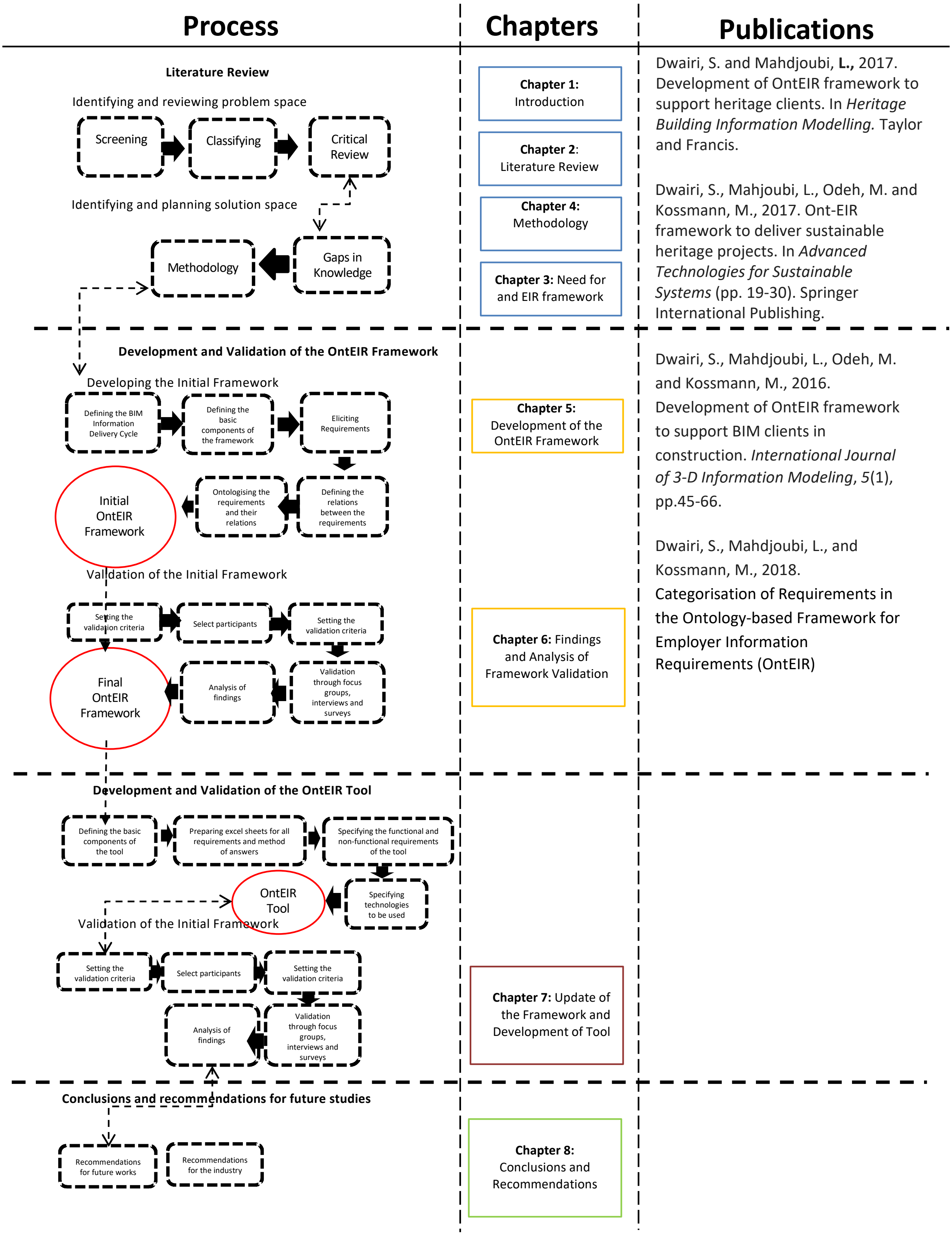


Figure 1.3: Research Activities and Publications

Chapter 5: Development of the OntEIR Framework

This chapter discusses the development of the framework in accordance to the BIM Information Delivery Cycle (BIM IDL). It examines the basic components and high-level needs of the framework. This chapter also discusses the elicitation process from needs to requirements and the categorisation system used in this framework to categorise those needs and requirements into static needs and dynamic needs, and the definition of each. it also talks about the role of Ontology in producing the OntEIR framework

Chapter 6: Findings and discussion of Framework Validation

In this chapter the initial framework is validated with key experts in the industry in terms of: the categorisation system used, the comprehensiveness of the framework and its ability to cover all the essential information needed for a full and complete EIR and the understandability of the framework. The validation is conducted through semi-structured interviews and surveys, and results are used to update the framework into its final form.

Chapter 7: Update of Framework and development of tool

This chapter reviews the update of the OntEIR framework, and presents the final framework. It then examines the steps taken to develop the online OntEIR tool in terms of: specifying the tool requirements, the technology and programming of the tool and uploading it. It then goes on to demonstrating the tool, on terms: of the general requirements (static), stage requirements (Dynamic) and the submission of the form. The tool is validated through focus groups and surveys. Participants are selected to have different and variable experiences. The validation criteria cover: The Graphical User Interface and ease of use, the understandability of the tool and the quality of the results. Results are analysed according to the amount of experience participants have (high, medium, low) to be able to update to tool to accommodate all types of users and experiences.

Chapter 8: Conclusions and Recommendations

The final chapter of this thesis is aimed at examining work done in this study and if it was able to achieve the objectives set. It also discusses the contribution this study has offered the construction industry and the innovative part of it, in addition to the limitations the study faced.

It ends with providing recommendations for both the industry and this study, in achieving higher standards and more aims.

Chapter 2 Client Requirements and Briefs

Identifying the Client Requirements (Employer Requirements) is the most important part of the construction project's initial phases. These requirements are the main ingredients of the project brief, which hold all the information needed regarding the built assets (physical requirements, performance requirements, feasibility, business objectives etc.).

This chapter will examine in more detail the client requirements that are used in Design & Build (D&B) projects as the initiator and the source of all information needed for the related built assets. The structure of this chapter starts with defining the term 'client' and the different categorisations of clients in the construction industry (Section 2.1). in Section 2.2 the term 'requirement' is defined and the differences between requirements and needs are discussed. Section 2.3 covers client requirements in D&B projects in terms of contents, and the process to achieve the full and clear set of requirements, which is called the 'briefing process' that includes the statement of need, strategic brief and the project brief.

2.1 Client Requirements

"Successful projects are characterised by meeting client requirements"

(ChinTian Lee and Egbu, 2008)

Being the initiators and the financers for the construction project, and having the driving force in the project, the ultimate goal of the project should be to satisfy to the full extent the requirements of the client(s). However, for the requirements to be satisfied, a clear definition of them should be reached first, in which the 'voice' of the client is captured and subsequently translated in the construction process.

But before establishing an understanding the term 'client requirements' it is important to be able to define the terms 'client' and 'requirement':

2.1.1 Who is the Client?

A client can be defined as the person or organisation responsible for commissioning and paying for the design and construction of a facility, and is usually, but not always, the owner of the facility being commissioned (Kamara, Anumba and Evbuomwan, 2002).

The establishment of a definition of the client is essential in order to avoid misunderstandings, and it is proposed that the following meaning will be used throughout this work: The organisation, or individual, who commissions the activities necessary to implement and complete a project in order to satisfy its/his needs and then enters into a contract with the commissioned parties (Masterman, 2003).

The client is the sponsor of the construction process, (Masterman, 2003), who provides the most important perspective on project performance and whose needs must be met by the project team (Latham, 1994).

According to Kamara et al. (Kamara, Anumba and Evbuomwan, 2002), the 'client', which is the buyer of the construction services, actually represents a body or an entity that incorporates other interest groups, including the owner(s), which may or may not be the client; the user(s) and the buyer(s) of the construction services.

Employer is another name that can be used to refer to the client as mentioned in Chapter 1.

Client organisations are undoubtedly diverse in terms of their construction-related expertise. Blackmore (Blackmore, 1990) suggests that there is no one definition of 'a client' as such, and quotes John Brandenburger, a founder member of Ove Arup, as saying "clients are simply an assorted collection of men and women seeking advice a member of one or more of a profession".

Clients of any industry are not a homogeneous group, and it follows that different clients, or categories of clients, will require different and probably discrete solutions to their problems and will present different opportunities (Masterman, 2003). The next section will address some of these categorisations in the construction industry.

2.1.2 Categorisation of Clients

Clients have been traditionally divided into the two basic and classic categories of public and private organizations but it has also now been universally acknowledged that subdivisions of these categories have existed with the two main divisions relating: 1. to the client's experience of implementing building projects; and 2. to whether or not they are 'primary' or 'secondary' constructors (Masterman, 2003).

However, when it comes to classifying clients, most literature concentrates on their prime business functions (Masterman and Gameson, 1994). In a survey conducted by Newman (Newman, 1981) a list of 18 client types was produced. This list included types such as: private commercial, industrial, developers, leisure, education, hospitals and public authorities; and some of these were further divided into more specific sub-groups.

Clients do not always refer to the 'owner' of the facility, the client can be the 'developer' who intends to sell it as soon as it is finished (Wilkinson, 2013).

Walker (Walker, 2015) argues that understanding the client organisation's structure is important to the construction project. According to Walker, the client does not have to be both the owner and the occupier of the building. Various types of clients can be identified accordingly (Masterman, 2003; Walker, 2015):

- According to origin: the individual client, the corporate client, and the public client.
- According to profile: primary clients; who are the primary source for income derived from constructing buildings for sale, lease, investment, etc.; and secondary clients; those who only require buildings to enable them to house and to undertake their own main business activities).
- According to the client's construction experience: experiences and sophisticated clients, and inexperienced clients.

Even though the client is not always the owner, and sometimes is just the developer of the project, nevertheless, the clear identification of requirements is important for both. For 'owner' clients of the asset, defining requirements and information to be delivered will allow them to maintain their assets responsibly (Wilkinson, 2013). For the 'developer' client, the need for defining the requirements and asset information to be delivered is still of great importance. According to Wilkinson (2013), offering good quality structured data for the buyer will have a beneficial effect upon running cost and better sustainability ratings. This will secure a sales advantage over those who do not.

This research is intended to serve all types of clients: public and private, developers and owners, and experienced and inexperienced clients. It is to assist any type of client in identifying their requirements in a complete, consistent, and user-friendly way.

2.2 Needs versus Requirements

It is worth mentioning that there is an important distinction between requirements and needs, and not being able to identify the difference between the two terms could cause confusions, as discussed in Section 1.2 previously. ‘Requirements are descriptions of how the system should behave, or of a system property or attribute. They may be a constraint on the development process of the system’ (Sommerville and Sawyer, 1997b). Another definition of a requirement, as proposed by the International Institute of Business (IIB), is ‘a condition or capability required by a stakeholder to solve a problem or achieve an objective’, while a need is a “high-level” representation of the requirements needed. The need is the answer to the question: why are we doing this? Needs could also be used like a check list at the end (Elgendy, 2016). Identifying the needs should be a first step before establishing the requirements (Blyth and Worthington, 2010). The first step in the process of identifying the need is to recognise that there may not be a single solution to satisfy the need, in other words recognising that there might be several different requirements that can satisfy one given need; just as there will be different possible solutions to satisfy a specific set of requirements, which in turn satisfies one need (if a solution satisfies this set of requirements entirely, it is considered that the need underlying the set of requirements is also satisfied).

2.2.1 The Definition of Requirements

For a certain condition to be achieved, or a product to be produced, the underlying need(s) should be defined. In most cases, these needs are often set by the client(s) who request the delivery of a certain service or product. These needs, once defined and further developed, will help to develop a set of corresponding, usually more detailed requirements.

According to the Office of Government Commerce, UK, ‘Requirements are capabilities and objectives to which any product or service must conform and are common to all development and other engineering activities.’ Requirements may also be defined as a ‘description of a set of testable conditions applicable to products or processes’ (Fiksel and Dunkle, 1992). Requirements are the more detailed statements of the employer’s needs which are transformed into an architectural design and subsequently into a finished facility.

According to Robertson and Robertson (Robertson and Robertson, 2012), requirements are ‘something that a product must have’. Oduguwa (2006), refers to requirements as ‘needs’ of

customers, that are documented as engineering specifications after being analysed, and before the product is designed and produced (Oduguwa, 2006).
Young (2004), describes a requirement as a statement that identifies a capability, characteristic, or quality factor of a product or system for it to have value and utility to an employer or user, which makes it an essential attribute to the product or system (Young, 2004). It is a statement of need, something that some classes of employers, users or other stakeholders want (Alexander and Stevens, 2002). 'Requirements' in the computer engineering world are defined during the early stages of a system development as a specification of what should be implemented (Sommerville and Sawyer, 1997a). They are descriptions of how the system should behave, application domain information, constraints on the system's operation, or specifications of a system property or attribute (Kotonya and Sommerville, 1998). Requirements are the foundations of any development project. Good requirements are complete, unambiguous, consistent, feasible, solution neutral, traceable, necessary, not used for wrong purpose, concise, correct and verifiable (Kamara and Anumba, 2000; Young, 2004; Zielczynski, 2008).

From a construction point-of-view, Kamara et al., (Kamara, Anumba and Evbuomwan, 2000), state that 'client (employer) requirements can be described in terms of the objectives, needs, wishes and expectations of the client (i.e. the person or firm responsible for commissioning the design and construction of a facility)'. Kamara et al. (Kamara, Anumba and Evbuomwan, 2002) further noted that 'The "voice of the employer" (employer requirements) includes the collective wishes, perspectives and expectations of the various components of the employer body. These requirements describe the facility that will satisfy the employer's objectives (or business needs)'. According to the Office of Government Commerce, UK, 'Requirements are capabilities and objectives, to which any product or service must conform, and are common to all development and other engineering activities.'

2.2.1.1 Categorisation of Requirements

Requirements were basically defined to enable the development of a functional product or a service, which are the basis on which these requirements were categorized into 'functional requirements', 'business requirements' and 'non-functional' requirements. According to Holt et al. (Holt, Perry and Brownswor, 2012), these requirements are defined as following:

- "Functional requirements, in their essence, yield some sort of observable result to someone, or something, which is using the system. By their very definition, functional requirements 'do' something and result in some sort of function being performed. Functional requirements are usually what are referred to when people misuse the term 'user requirements"

Examples of functional requirements include the following:

- 'Do X'. A functional requirement often looks like a direct instruction to do something.
- 'Provide service X'. A functional requirement may state that a service must be provided to a set of stakeholders.
- 'Deliver X'. A functional requirement may state that a product or artefact must be delivered to a set of stakeholders.

- The Business Requirement is used to state the needs or capabilities of a business. This includes business drivers that impact the entire organisation and all the projects within it. These requirements will be, by necessity, described at a very high-level. Examples of business requirements include the following:

- Make money.
- Keep customer happy.
- Provide service (X).

- Non-functional requirements decide whether the project is successful or not. Non-functional requirements are directly linked to functional requirements, which means that they must be considered as important as the functional requirements; it constrains or limits in some way, the way that a functional requirement may be realised. According to Summerville (2001), many non-functional requirements are related to the system which makes them more critical than individual functional requirements, where failure to meet a non-functional system requirement may make the whole system unusable.

Robertson and Robertson (2012) also discussed these types of requirements, stating that 'functional requirements' are those needed to specify what that product must 'do' and the actions it must carry out to support its function. While 'non-functional requirements' are the requirements that describe the properties and qualities of that product.

Other types of requirements categorisations include the categorisation proposed by Kamara *et al*. (2002), which is based on the decomposition of general requirements to reach more detailed client requirements. This categorisation (decomposition) included: primary, secondary, and tertiary requirements. Primary requirements are those that represent the more 'general' requirements of the client. Secondary requirements are a decomposition of the primary requirements, into a more detailed set of requirements. Another decomposition of the secondary requirements generates the tertiary requirements.

In another attempt to categorise requirements, specifically in the construction context, Kiviniemi *et al*. (2004) identified two types of requirements; direct and indirect requirements. Direct requirements are requirements related to the spaces and recorded in the building programme. On the other hand, indirect requirements are those related to the bounding elements and technical systems. These types of requirements are difficult to notice because the detailed design process related to them often takes place later and often by people who were not involved in the early stages of the briefing.

Saxon (Saxon, 2016) had a different perspective in requirements categorisation. He discussed that there are two types of requirements that need to be identified to be able to make up the employer information requirements (EIR). Those types of requirements are the 'product' requirements, and the 'process' requirements. Product requirements are those that cover the physical side and performance of the asset, including both functional and non-functional requirements; while process requirements are the ones related to the asset information; content and flow.

In this study, a new categorisation of the requirements will be introduced in Section 4.2. This categorisation of the requirements is based on the work in this field previously presented.

2.3 The Importance of Client Requirements

The need for a more client-oriented industry, which can incorporate the needs and requirements of the client (the voice of the client), represents a major change in the construction industry. Previously it has been rather more oriented towards the needs of the environment, aesthetics and posterity, but not the client (Latham, 1994). This change was the basis, on which many reports were published with a repeated call for the construction industry to be more client-oriented (Latham, 1994; Howie, 1996; Egan, 1998).

In the construction industry, there are many types of requirements that should be taken into considerations before beginning the actual work on the construction project. These requirements are all stated in what is called the Brief of the project. Kamara et al. (2002) suggest the following types of requirements:

- Client requirements: requirements of the client, which describes the facility that satisfies their business needs. These incorporate employer requirements, developer requirements, user requirements and the lifecycle requirements of operating, maintaining, and disposing of the facility.
- Site requirements: these describe the characteristics of the site, on which the facility is to be built.
- Environmental requirements: these describe the immediate environmental context (climatic factors, neighbourhood, environment conservation, etc.) surrounding the proposed site of the facility.
- Regulatory requirements: building planning, health and safety regulations, and other legal requirements that influence the acquisition, existence, and demolition of the facility.
- Design requirements: requirements for design, which are a translation of the employer needs, site and environmental requirements.
- Construction requirements: requirements for actual construction, which derive from the design activity.

The interrelations between these requirements are shown in Figure 2.1:

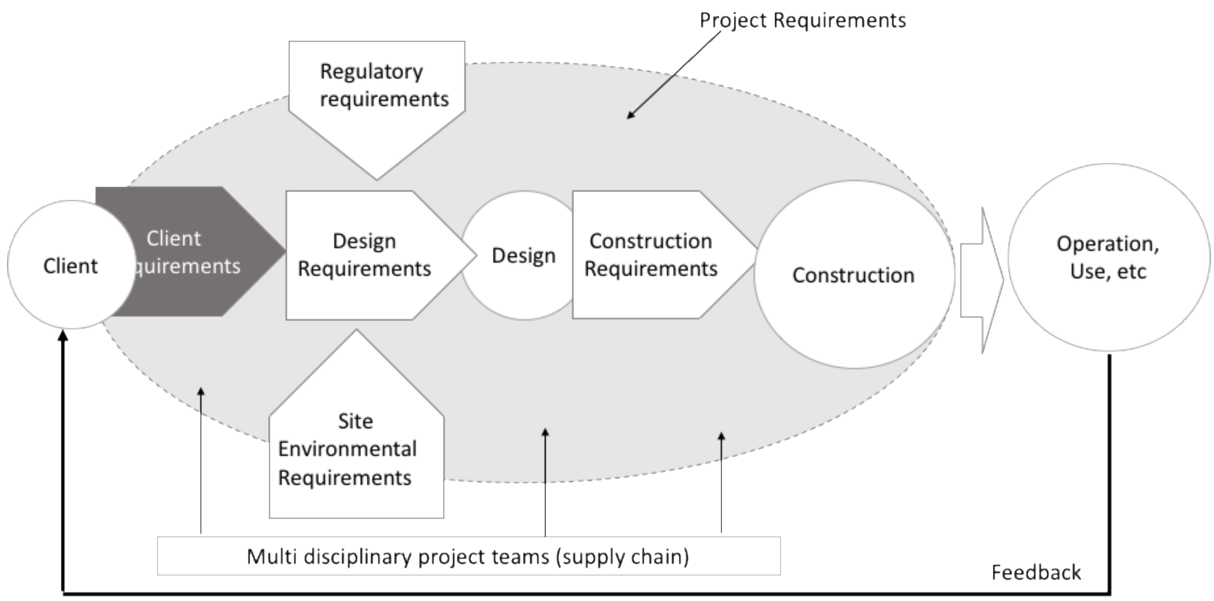


Figure 2.1: Interrelations between requirements of construction projects. Source Kamara et al.,(2000), reused with permission from © *Emerald Publishing Limited*

The importance of identifying requirements is that it provides the basis for all the development work that follows. Setting the requirements is the first step to be done before any other technical work can be initiated, such as design, tendering, construction, commissioning, and operation (Yu *et al.*, 2010). Failing to reach a clear and adequate understanding of the requirements results in failure to deliver projects within budget, late delivery of projects, failure to consider project decisions from a whole life cycle perspective, and poor customer satisfaction (Fernie et al., 2003).

Rawlinson (2007) argued that the client requirements must clearly communicate performance standards, aesthetic intent, and functional requirements. The requirements must also describe the process of delivery, so they may need to go beyond a typical 'preliminaries' document.

But before addressing the technical, managerial and aesthetic aspects of the project—the identity, nature and characteristics of the client are comprehensively and accurately identified and that the project team is fully aware of, and understands, the client's needs (Masterman, 2003).

Many studies have shown that the clear identification of the client requirements and thus producing a clear brief is considered one of the critical success factors for a construction project (Songer and Molenaar, 1997; Takim, 2005; Chan, Scott and Lam, 2002; Mahamadu, 2017).

The identification, elicitation, clarification, articulation, and representation of the client requirements during the early stages of the construction project is called 'Briefing' (Yu and Shen, 2013; Blyth and Worthington, 2010). The Construction Industry Board (CIB) notes that the briefing is the process in which other members of the team are informed of the client's needs and aspiration for the project, either formally or informally. A 'brief' is a formal document that sets out the client requirements in detail (Yu and Shen, 2013).

Yu and Chen (2013) have also concluded the importance of clear requirements in the brief as being a critical success factor. They defined 6 critical success factors of the project which are: Factor 1: Client's Business, Organization, and Project Requirements; Factor 2: Requirements of Stakeholders; Factor 3: Knowledge, Experience, and Cultural Background of the Stakeholders; Factor 4: Decision Making and Management Skills of the Senior Project Managers; Factor 5: Competence of the Design Team; Factor 6: Balanced Interest of the Stakeholders.

The gathering and analysing of the client requirements (the briefing process), is a critical step in the successful delivery of a construction project (O'reilly, 1987; McGeorge and Zou, 2012). The briefing process is what informs the decision making and decision implementation. It is in fact the most important task in the project planning process (Yu and Shen, 2013; Gibson Jr, Kaczmarowski and Lore Jr, 1995; Hamilton and Gibson Jr, 1996; Dumont, Gibson Jr and Fish, 1997). This initiation phase could be considered the most important and influential phase of the whole lifecycle (Yu and Shen, 2013). The reason for that as discussed by Dvir *et al*., (2003) has to do with how it influences the project success. In this phase, major decisions are made that decide the project objectives and planning the project execution (Dvir, Raz and Shenhar, 2003). In BIM projects, this phase is important because it is the basis, on which the BIM Execution Plan (BEP) is developed (BSi, 2013). Richard McParland, editor of the NBS.com, argues that the success of a BIM project relies on developing an effective BEP (McPartland, 2017), which is based on the clients' requirements of the project.

For the client requirements to be legally recognised and binding in a construction project, they have to be incorporated in a contract/document called the Employer's Requirements.

2.4 The Employers' Requirements (ER)

In design and build projects, the 'Employer's Requirements' (ER) is the contract that holds all the essential information for the success of the project, which include the client requirements, the specification for the building, the scope of services required from the team and an allocation of risk for unknown items (Klee, 2015). Being crucial to the success or failure of the project, ER should provide precise requirements for the completed works, and cross-refer to the conditions of the contract, which means that defining, using and maintaining a consistent terminology is of the upmost importance (Poulsen and Zahonyi, 2013).

ER is a very important document that defines the success of the outcome. If the Employer's Requirements are not properly developed; the employer can incur significant additional costs, as any requirements which are not properly specified.

Rawlson (2007) argued that ER must clearly communicate performance standards, aesthetic intent, and functional requirements. The requirements must also describe the process of delivery, so they may need to go beyond a typical 'preliminaries' document. ER should also include the definitions and purposes of the work, the definition of the site, quality and performance criteria, and special obligations such as training, spare parts and warranties (Klee, 2015).

Detailed ER gives the employer full control over design, under this approach, more typically associated with complex, one-off projects, the design is completed to a high level of detail by the employer before the tender.

According to the Designing Buildings Wiki (designingbuildings.co.uk) the ER might include:

- A project overview;
- The scope of services required, including identification of elements requiring contractor design;
- The form of contractors' proposals required;
- The format required for the contract sum analysis;
- The procedures that will be adopted upon award of the contract;
- Parts of the strategic brief (or project brief if this has been developed);
- Prescriptive or performance specifications (or a combination);

- Site information;
- Existing design drawings (if they exist), or perhaps an existing BIM model;
- Programme and delivery process (including phasing);
- Proposed form of contract, perhaps including a model enabling amendment making a BIM protocol part of the contract documents;
- Procedures for inspection, testing, commissioning and handover;
- Responsibility for statutory approvals (such as planning permission and building regulations approvals) and information about any existing approvals or consultations;
- Design liability;
- Requirements for warranties,
- Professional indemnity and other insurance requirements;
- Allocation of risk;
- Requirements for samples and items for comment or approval;
- Tender pricing document (or form for contract sum analysis);
- Pre-construction Information;
- Client policies (such as environmental or health and safety policies);
- Collaborative practices;
- Employer's information requirements for building information modelling;
- Request for details of named or nominated sub-contractors;
- Any requirement for consultants to be novated or switched to the contractor once the contract has been executed;
- Targets for post-occupancy evaluation.

To reach a full and complete ER, briefs are developed. Briefs describe the requirements defined in the ER for which the project will provide solutions.

According to Rezgui *et al*. (2003), the briefing process is ‘a process running throughout a construction project by which the requirements of the employer and other relevant stakeholders are progressively captured, interpreted, confirmed, and then communicated to the design and construction team’.

Markus (1997) defines the brief as a ‘process of analysis, research, ordering of concepts, specification, definition and problem clarification which precedes and often continues alongside and accompanies the process of developing a design solution in terms of spatial and material proposition'.

This description broadens the customer perspective emphasizes cyclic aspects and clarifies the briefing activities (Barrett and Stanley, 1999).

However, there always needs to be an avenue for stakeholders to identify, clarify, analyse, formulate, and confirm their perspectives (Rechtin and Maier, 2000; Spencer and Winch, 2002) a process with the overall aim of continually and jointly coordinating the employer's business and facility planning.

Blyth and Worthington (2010) state that a project cannot begin without a brief. Briefing is the process that starts before the beginning of the project, runs throughout the project implementation and even deals with post project issues, which must be part of the activities at the end of the project life cycle.

The briefing process goes through three stages: preparing the statement of need, the strategic brief and the project brief.

2.4.1 Preparing the Statement of Need

The statement of need is the first step in developing the ER. In it, the client describes the possible requirements necessary to achieve the objectives of the project. According to the Commission of Architecture and the Built Environment (CABE) guide for clients (Eley, 2003), the statement of need should incorporate the aims and the high-level requirements. It is a simple document before any work on the project happens, or before looking for funding or even a client advisor. It provides a central reference against which to measure how well the project meets its aims. It may include the following information (designingbuildings.co.uk):

- A description of the business need that may result in a project.
- An assessment of how it will contribute to the corporate strategy.
- An analysis of the high-level options (such as do something, do nothing, new build, extend, refurbish, relocate, change the way the organisation works, etc.).
- A description of the nature of the client, and its history.
- A description of the nature of client's operations.
- Information about existing premises and likely future requirements.
- The assumed budget (and the basis for the budget).

- The assumed programme.
- An assessment of the potential for future changes.

The statement of need starts as a simple document, that then evolves to the initial description of the client goals and requirements, which forms the basis for feasibility studies and decisions about the project, and is called the strategic brief.

2.4.2 The Strategic Brief

CABE (2003) defines the strategic brief as ‘a description of what a client wants to include in the project and how the finished building is to perform’. Blyth and Worthington (2010) regard the aim of the strategic brief as setting out the objectives of the project based on the organisational needs. The main task of this is to ensure that the developed design will correspond to the business objectives of the organisation (client).

At the strategic briefing stage, two key issues should be addressed:

1. What is the nature of the organisation in respect to its speed and type of change?
2. What will be the impact of change on the building, fit-out and facilities management provided?

The strategic brief is a document prepared by the client. It should describe the requirements by using clear wording and describe what the project needs to achieve.

Contents of the strategic brief should include (Eley, 2003):

- The organisation’s overall vision and the project’s role in meeting it;
- Key aims and objectives for the project to act as measures for its success or failure;
- The organisation’s structure and decision-making processes;
- The project’s contexts: physical, historical, economic, ecological, social and political, with discussion of any potential conflicts;
- The urban design and town planning context: listed building issues, the building’s role in its setting and its contribution to urban spaces or landscape;
- The project parameters covering quality, time and cost (including assumptions about how long the building should last) and setting priorities;
- An outline of the spaces needed, both internal and external, which may be expressed in terms of their expected functions – why spaces are needed and how will they be used;

- The number of people, staff, customers etc., for whom the building is intended.

The strategic brief should be prepared in sufficient detail to allow the appointment of the project team. It will be the main source of information that allows the project team to draft out the project brief, which in turn will expand it and summarise any important decisions made.

2.4.3 The Project Brief

The project brief is a document prepared by the project team and to be approved by the employer. According to the NBS (McPartland, 2018), the project brief:

- Contains information required to brief the production team and ensure understanding and agreement of scope and specification by the employer;
- Is presented as words, drawings and models;
- Is concerned with agreeing concepts, performance, and parameters such as time and costs; and
- Is approved and signed off in association with scheme design.

The design of the project is a direct response to the project brief, thus the statement of requirements in the brief must be clear, otherwise the result would be unsuitable, and some aspects of design would be 'guess work' (Eley, 2003).

The contents of the project brief include information regarding spatial requirements, technical requirements, component requirements and project requirements:

- Spatial Requirements:
    - Schedules of accommodation;
    - Areas;
    - Special requirements;
    - Schedules of users which include user number, user departments, user functions;
    - Organizational structure;
    - Spatial policies;
    - Day lighting requirements;
    - Temperature ranges;
    - Acoustic standards;

- Required adjacencies, separations, groupings;
- Zoning;
- Circulation guidelines;
- Phasing.

- Technical Requirements:
  - Structural strategy;
  - Servicing requirements;
  - Specialist requirements;
  - Level of user control;
  - Acoustic requirements
  - Equipment requirement including built-in equipment requiring mechanical or electrical connections, built-in equipment that does not require services, stand-alone equipment requiring service, stand-alone equipment that does not require services;
  - Specialist requirements for furnishings;
  - Information and communication technology requirements;
  - Requirements for specialist processes and plans;
  - Fire compartments;
  - Maintenance and cleaning requirements;
  - Likelihood of future change (such as staff numbers);
  - Sustainability objectives and energy use targets;
  - Safety and security requirements;
  - Waste and water management;
  - Pollution control;
  - Flexibility and future uses;
  - Durability and life span;
  - Other performance requirements;
  - Benchmarking information.
- Component Requirements:
  - Long-lead items;
  - Potential requirement for specialist design;
  - Lifts;

  - Escalators;
  - Cladding systems;
  - Switchgear;
  - Refrigeration units;
  - HVAC systems;
  - Cleaning cradles;
  - Cladding strategy and materials selection procedures.
- Project Requirements:
  - Planning requirements;
  - Outcome of any consultation processes;
  - Budget;
  - Construction cost;
  - Land or property acquisition;
  - Approval fees;
  - Planning costs;
  - Financing costs;
  - Site investigations;
  - Fixtures, fitting, and equipment;
  - Decanting and relocation;
  - Insurance;
  - Consultant fees;
  - Contingency;
  - VAT;
  - Project programme and key milestones;
  - Known risks;
  - Targets for post occupancy evaluation.

Saxon (Saxon, 2016) argues that the term 'Brief' stands for the Employer's Requirements for the function, form, economy and timescale of the project. But with BIM, new types of requirements have emerged, which include requirements for information structure and management. These types of requirements have become a major part of the brief, the term used for these requirements is the Employer Information Requirements (EIR). Saxon argues that this type of requirements can either stand separately from the brief, or be combined. Combining them according to Saxon is more logical and will be normal once the BIM process is fully integrated with the traditional way of working prior to BIM (Saxon, 2016). The next chapter will discuss the EIR.

2.5 Chapter Summary

This chapter examined closely client requirements used in design and build projects. It defined the term client and discussed the difference and relation between needs and requirements.

'Client requirements' is a process that starts by defining the business objectives of the client and the project and the needs that should be fulfilled to reach these objectives. A more detailed set of requirements are then put in place to meet those needs and estimate the ability of the project to fulfil these objectives. And finally, the detailed project requirements are prepared, to which the produce design is a direct response. This process of defining the client requirements is called the 'brief', which consists of the statement of need, the strategic brief and the project brief respectively.

It is important to fully understand the importance of clear requirements definition, and how this can be achieved. It is also important to incorporate the employer requirements discussed in this chapter in a way that accommodates the change occurring in the construction industry with the emergence of BIM.

Chapter 3 Employer Information Requirements (EIR)

As of April 2016, BIM was mandated for all public construction projects in the UK (Cabinet Office, 2011). BIM is seen essential to the digitalisation of the built environment sector. BIM is argued to save time and money. It is expected that BIM and other industry modernisation programmes — including better collaborations across the supply chain — will deliver 20% capital-cost savings along with faster delivery and lower carbon emissions from the built environment sector (bsi, 2016b).

One of the fundamental principles in achieving this aim and reaching a full Level 2 BIM (explained in Section 3.1.2) information modelling is the provision of a clear Employer Information Requirements (EIR).

EIR aim is to ensure user's information needs are clearly defined at the start of the BIM process and it provides a mechanism for collaboration allowing project stakeholders to communicate, manage and deliver client's requirements.

This chapter is an in-depth examination of EIR; and defines its importance in BIM projects and identifies the sources of information to reach a full and complete EIR, which will be covered in Section 3.3. It begins with a general look at BIM and the BIM Information Delivery Lifecycle, and the role EIR plays in managing and defining this lifecycle (Section 3.1 and 3.2).

This chapter also presents a critical review of the current practices in defining EIR, being standards, models, frameworks or tools, and discusses the challenges that face those practices (Section 3.4 and 3.5).

It concludes in Section 3.6 by making the point that there is a strong need for a requirements framework and a supporting tool, which will allow all types of clients to fully define their EIRs.

3.1 Building Information Modelling (BIM)

Being a process for creating and managing information of a construction project across the project lifecycle, BIM is seen essential to the digitalisation of the construction sector and was mandated for all UK government projects as of 2016 as part of the Government Construction Strategy in achieving the construction 2025 goals (Cabinet Office, 2011).

The idea of BIM was introduced to the construction industry at a time when there was some lack of important issues in the construction team and project, based on reports and studies introduced (Latham, 1994). These reports noted that the cost of construction consistently rise faster than general inflation, whilst those of manufacturing and distribution continue to fall. The UK Government's decision in mandating Level 2 BIM for publicly procured projects by 2016, is to address the fragmentation and complexity of the construction industry (Latham, 1994; Egan, 1998; Cabinet Office, 2011). Also, other studies suggest that the UK government is willing to invest in smart construction and digital design by investing in people, in collaboration with the AEC industry, in reference to the report published by the UK government in 2013; Construction 2025 (Bataw, 2015).

Building Information Modelling (BIM) is a result of a cumulative effort in the construction industry to incorporate information technology to facilitate the conceptualisation and realisation of the projects (Abbasnejad and Moud, 2013). Definitions of BIM differ from one organisation to the other, it could be defined as a set of interacting policies, processes and technologies generating a "methodology to manage the essential building design and project data in digital format throughout the building's lifecycle" (Bhuskade, 2015).

The National Institute of Building Sciences (NIBS) defines BIM as the following "BIM utilises cutting edge digital technology to establish a computable representation of all the physical and functional characteristics of a facility and its related project/lifecycle information, and it is intended to be a repository of information for the facility owner/operator to use and maintain throughout the lifecycle of a facility" (NIBS, 2007).

BIM is also defined as "the use of ICT technologies to streamline the building lifecycle processes to provide a safer and more productive environment for its occupants, to assert the least possible environmental impact from its existence, and to be more operationally efficient for its owners throughout the building lifecycle" (Arayici and Aouad, 2010).

When different team players and stakeholders collaborate in a project, communicating specific characteristics of the project amongst the different parties involved requires documentation of these characteristics, as seen in Figure 3.1 (Olofsson, Lee and Eastman, 2008; Trench, 2014). In the traditional ways, this documentation was executed on paper (BSI, 2010), while with BIM, this information moves from the paper-based tools and instead uses the virtual environment, which increases the level of efficiency, the ability to communicate, and easiness of collaboration (Olofsson, Lee and Eastman, 2008). This eventually leads to contributing to lean management goal of reducing non-value-adding waste (Olatunji, 2011).

The first step for the client to maximise the advantage of BIM benefits is to fully understand what BIM is, and what benefits BIM has to offer them, and more importantly take a more "active" role in the construction project (Saxon, 2016b).

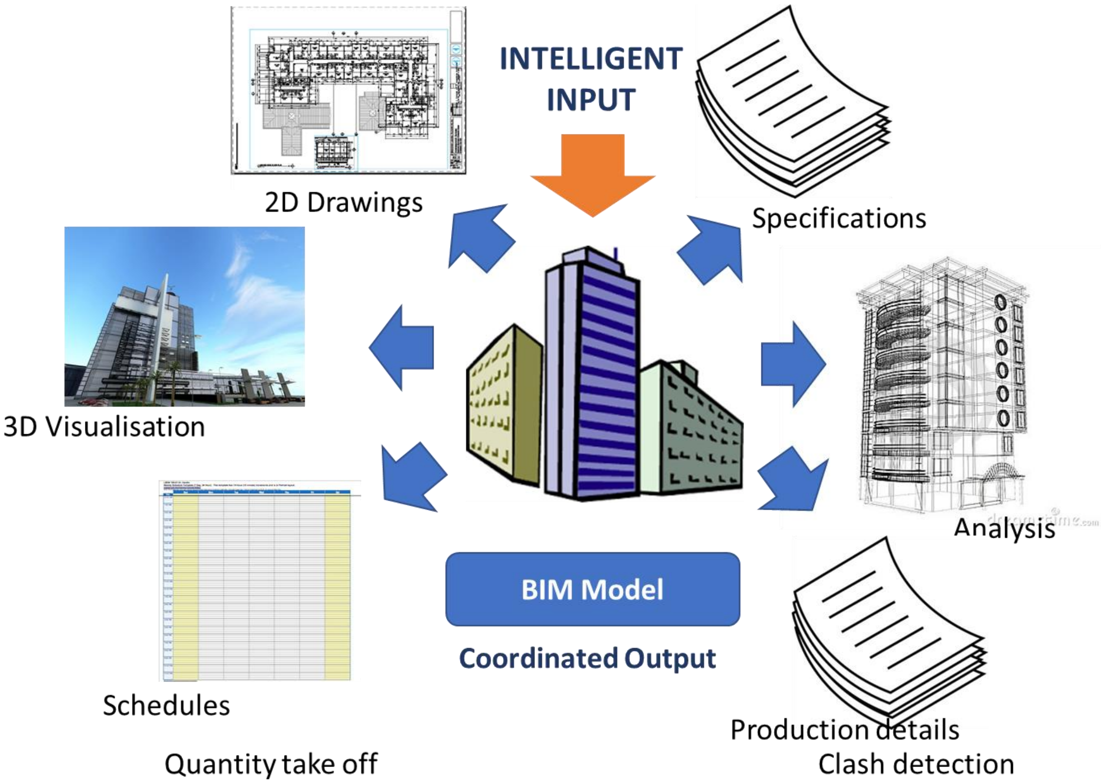


Figure 3.1: Information involved in the BIM process (Adapted from (Trench, 2014)

To understand more the BIM process and the information involved in it, the next Section discusses the different levels of BIM that have been used in the past (Level 0 and 1), that are used now (Level 2), and that is being planned for the future (Level 3)

3.1.1 BIM Levels:

By looking at the road map illustrated in Figure 3.2, the development of the construction process through the different levels of BIM is noticed to be based on increased collaboration, increase use of digitisation and automation in the exchange and production of information, and the increase focus on lifecycle and operational management of the asset.

Level 0 BIM

According to the NBS National BIM report 2017 (NBS, 2017) Level 0 BIM is the simplest form of BIM. Characteristics of this level includes: no collaboration, 2D CAD drafting is only used and the output is in the form of paper and/or electronic prints. Figure 3.2 illustrates an explanation of all the BIM levels, including Level 0.

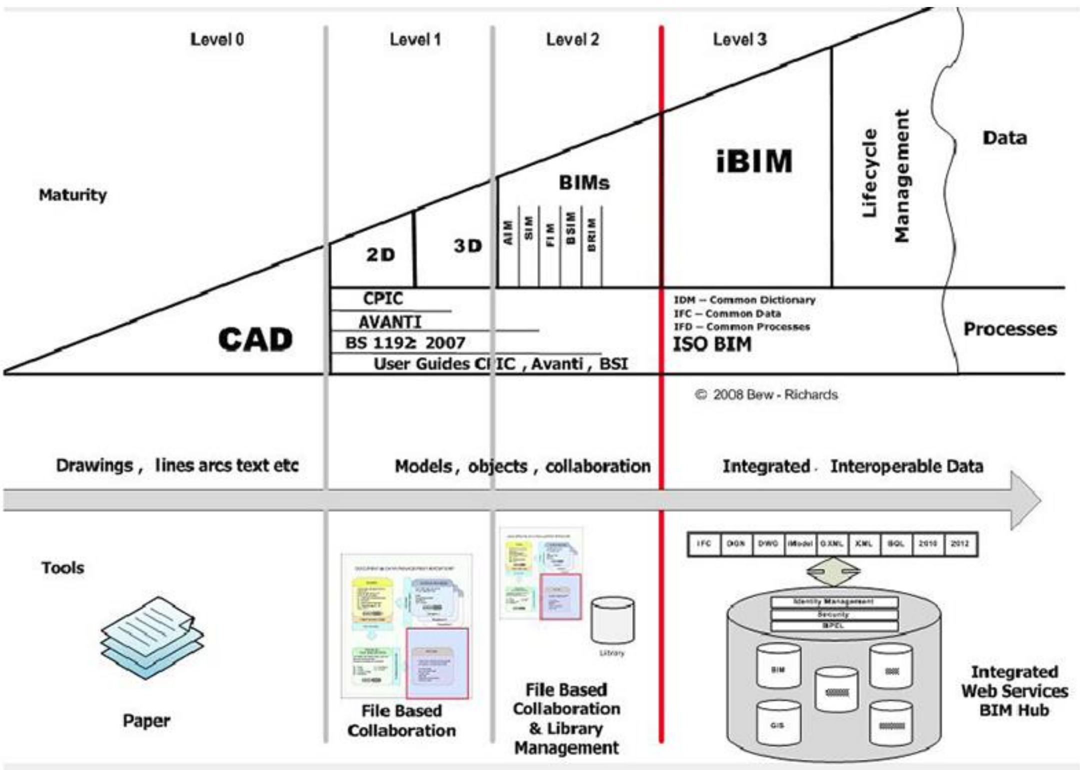


Figure 3.2: BIM Levels Explained (Mordue, 2016), reused with permission from © Mark Bew

Level 1 BIM

NBS (2018) explains Level 1 BIM to include 2D CAD and 3D CAD for drafting and production information and for concept work respectively, where the electronic sharing is carried out in a Common Data Environment (explained in Section 3.3.1), which is often managed by the contractor (McPartland, 2018).

To achieve Level 1 BIM, the following should be achieved (McPartland, 2018):

- Roles and responsibilities should be agreed upon;
- Naming conventions should be adopted;
- Arrangements should be put in place to create and maintain the project specific codes and project spatial co-ordination;
- A "Common Data Environment" (CDE);
- A suitable information hierarchy should be agreed which supports the concepts of the CDE and the document repository.

Level 2 BIM

Level 2 is the mandated Level in 2016, and is described as the collaborative BIM, which requires an information exchange process specific to the project and coordinated between the various stakeholders of the project (Mordue, 2016; McPartland, 2018).

“Models including 3D graphical and non-graphical data are federated together at defined points as information is exchanged within a Common Data Environment- it allows participants to define, share and validate outputs via digital transactions through a range of assets that are delivered in a structured and reusable form” (bsi, 2016b)

Level 3 BIM

Although Level 3 BIM has not been fully defined yet, the HM Government has outlined the vision in the UK Government’s Level 3 Strategic Plan (HM Government, 2015). In this plan the following key measures were set out for Level 3 BIM:

- The creation of a set of new, international ‘Open Data’ standards which would pave the way for easy sharing of data across the entire market
- The establishment of a new contractual framework for projects which have been procured with BIM to ensure consistency, avoid confusion and encourage, open, collaborative working.
- The creation of a cultural environment which is co-operative, seeks to learn and share
- Training the public sector client in the use of BIM techniques such as, data requirements, operational methods and contractual processes

- Driving domestic and international growth and jobs in technology and construction.

Another word used to describe BIM Level 3 is the ‘Digital Built Britain’. In a report published in 2015 by the Department for Business, Innovation and Skills, it is described how Level 3 BIM will change the way global construction industry operates (Digital Built Britain, 2017).

The report discusses how Level 3 BIM seeks to deliver high performing assets and exceptional client value as well as a knowledge base to enable the Smart-City and Community members to thrive in urban environments.

Level 3 has been described by the BIM Task Group as including:

- Whole life management
- Measurement
- New Commercial models: transparent, data provenance; paperless, whole life service.
- Enable new services and markets: smart cities / grids; social media.
- Scale and capacity.
- Ease of use and interoperable.

The principal aspects of the Task Group’s business plan for BIM Level 3 include increased focus on lifecycle management and the use of real time cost and carbon data. It also seeks more service and performance-based approaches, and the connection of built assets into the wider Internet of Things and smart cities.

The tool developed should have the potential to accommodate the needs of Level 2 BIM in addition to be able to adapt to Level 3 BIM, through assisting in the definition and specification of the requirements that will enhance whole life management of the asset. This could be achieved by ensuring the delivery of a correct and relevant AIM that allows for the operation and maintenance of the facility until end of life, which, and as will be seen in Chapters 5 and 8, will be provided by this research.

3.1.2 Level 2 BIM

Being the level mandated for use on all public projects in 2016, all the information in this thesis is only regarding this level of BIM.

The government's aim in mandating BIM for construction projects was to reduce the cost of public sector assets by 20% (Cabinet Office, 2011). To achieve this aim, Level 2 presented to achieve the fully collaborative 3D BIM in which all the asset information, documentation, and data are electronic (bsi, 2016a).

Too assist in the adoption of BIM, many standards were developed by BSI, that are publicly available and free to download from their websites.

PAS 1192-2 (2013) is the publicly available standards for the Specification for information management for the capital/delivery phase of construction projects using building information modelling (bsi, 2013).

PAS 1192-2 is specifically produced for the project delivery, and the information that is produced and delivered. It discusses the project lifecycle and the development of the Project Information Model (PIM) throughout the project and the complete AIM at the end of the process (bsi, 2013). The information delivery lifecycle of the project is illustrated in Fig 3.3.

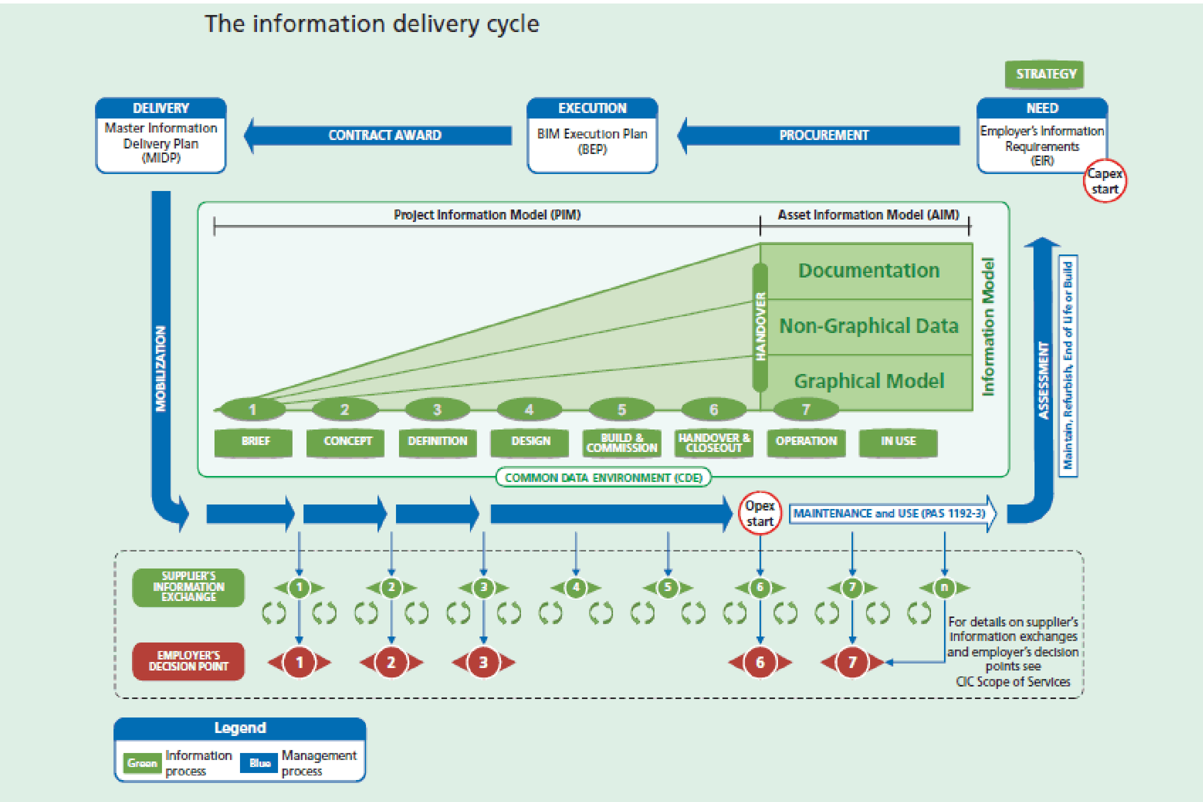


Figure 3.3: Information Delivery Lifecycle as in PAS 1192-2 (bsi, 2013), reused with permission from © BSI

As seen in Figure 3.3, the information delivery lifecycle in a BIM project begins with defining the EIR, which could be considered the corner stone of the BIM project. The EIR, and the Information Delivery Lifecycle in the BIM process will be explored in detail in the next sections.

3.2 Employer Information Requirements (EIR)

EIR is a pre-tender document setting out the information to be delivered and the standards and processes to be adopted by the supplier as part of the project delivery process (bsi, 2013). The purpose of EIR is to clearly outline the employer's need in respect of the information delivery and project management services, for construction or for the supply of the goods (Hore, 2015).

EIR is a document that is set to define:

- All the information needed regarding the built asset being procured;
- The process for the information development during the project stages.

There is still some kind of confusion among construction clients, who are not experts in the information management of the BIM process; and they may find it difficult to describe their information requirements (Dugal, 2015).

A complete and full set of EIRs is a key document when working with Level 2 BIM. The purpose of the EIR is to document the information requirements and also to establish a set of information management requirements. It is the basis on which BIM Execution Plans (BEPs) are developed, as a response from bidders to the EIR, which in turn is set to demonstrate the suppliers' capabilities in delivering and managing the information throughout the project (Pringle, 2015).

EIRs are created to organise and manage the information produced from the different processes. EIR is an important document in the construction projects for the information and instructions it holds for the creation, storage and transfer of the digital information when a building is delivered via BIM (BSI, 2007. BS1192:2007). Designing a successful EIR is an important solution for managing the collaboration and integration process that is the main feature of the BIM process. Integration and collaboration are important for reducing the project overrun and cost, removing the non-value-added activities, encouraging collaboration, and increase client satisfaction (Sun and Aouad, 2000).

Before setting out to create the EIR, it is important to understand what the BIM information requirements are, and their implications of the BIM lifecycle.

3.2.1 Information Requirements and Implications on the BIM lifecycle

A good and clear identification of the information required in building models is of great importance due to the value it holds in enabling key project decisions to be made, which include strategic, technical and operational decisions throughout the project lifecycle, which have a major effect on the delivery of both the built asset from the physical side and the digital information regarding the asset (AIM) which are of equal importance (Patacas *et al.*, 2016).

The concept of BIM seeks to integrate processes and information throughout the entire life cycle of the construction project, it focuses on creating and reusing consistent digital information by the stakeholders throughout the lifecycle (Arayici *et al*., 2012). The success of the BIM project is mostly determined by the success in managing the collaboration between the stakeholders involved in the project which will be using the different Information and Communication Technologies (ICT) to exchange the valuable information throughout the project lifecycle.

Managing the collaboration process should be prepared before the beginning of the construction project; all the issues regarding this matter should be addresses completely and clearly in the EIR. Unfortunately, much effort has gone into addressing those issues that have remained unattended for far too long (Jordani, 2008).

Despite the attempts made in increasing collaboration, the lack of communication and coordination between the actors and stakeholders involved in the different phases of the project has led to serious problems in practice, such as budget overruns, delays and end-users' dissatisfaction (Sebastian, 2011).

When different team players and stakeholders collaborate in a project, communicating specific characteristics of the project amongst the different parties involved requires documentation of these characteristics (Lee, 2008). In the traditional ways, this documentation was executed on paper (BSI, 2010), while with BIM, this information moves from the paper-based tools and instead uses the virtual environment, which increases the level of efficiency, the ability to communicate, and easiness of collaboration (Lee, 2008); which eventually leads to contributing to the goal of lean management, i.e. to reduce waste (Olatunji, 2011).

Another essential role EIR plays in the construction project, is the vital role it plays in the procurements process and being the corner stone in the project (bsi, 2013). In a study conducted by the CIOB, results indicated construction professionals view procurement as absolutely crucial to the delivery of a project on time, on budget and to a high quality, with 87% of respondents of the believe that good procurement is synonymous with a successful project (CIOB, 2010).

On the other hand, a study published in the National BIM Report 2017 showed that only 20% of clients understood how to develop a proper EIR (NBS, 2017).

All of this information regarding the project, which include the building information and all the requirements for this information in terms of who, what, how and when should be addressed by the client; and should be managed before the beginning of the project in the EIR. There should be a process that clients can understand and be able to produce a proper EIR that includes all the relevant information for a successful BIM project and that is able to cover all the requirements for a successful information delivery.

3.2.1.1 EIR and the BIM Information Delivery Cycle

PAS 1192-2 (2013) discusses BIM Level 2 in terms of specifications for the management of the information during the delivery phase of a BIM capital project and proposes an information delivery cycle for that project, as seen in Figure 3.3 (Section 3.1.2).

The cycle begins with defining the EIR for the project, which should hold sufficient information regarding the creation, storage and transfer of the digital information exchanged during the BIM project (BSI, 2007. BS1192:2007) this information should be adequate enough to enable the construction team in providing a clear plan for the whole construction process, which will result in delivering a more successful project in less time and effort.

The initial phase starts with the definition of the EIR, which is the first step in this phase. Other important documents depend on the EIR. Such as the BIM Execution Plan (BEP), and the

Master Information Delivery Plan (MIDP) (Bsi, 2013). These documents are very important to ensure that the construction process is according to the ER and will be finished on time and within budget. Information presented in the EIR, should ensure the delivery of a complete and consistent BEP and MIDP. EIRs should be able to set out the key sets of data information as well as the points along the project stages when the client requires them, it sets out an important guidance to drive the procurement and delivery processes (Kumar, 2015). The BIM protocol (CIC, 2013) identified the following key features of EIRs:

• EIRs are an important element of the project BIM implementation strategy because they are used to set out clearly to the bidder what models are required and what the purposes of the models will be.

• EIRs will be written into the BIM protocol and implemented through the BEP.

• EIRs are key documents with regards to communicating information requirements as well as establishing information management requirements.

• EIRs will act as a good basis from which to review the contents of the tenderer's BEP, confirming its completeness.

From the above argument it is seen the Information delivered in EIR will affect the whole construction lifecycle, and will provide essential information for important documents, such as the pre-contract BEP and the post-contract BEP that will be developed.

It should be made sure that EIR holds all the relevant information that will assure the delivery of a successful construction project. Figure 3.5 illustrates the relation between information provided in the EIR and the other important constructional documents (Early, 2015).

The "preparation" stage is the most crucial in the information delivery cycle. In this stage the most important documents are prepared. Therefore, this stage must be dealt with applying utmost professionalism, for these documents are what will manage and organise the whole construction project to come.

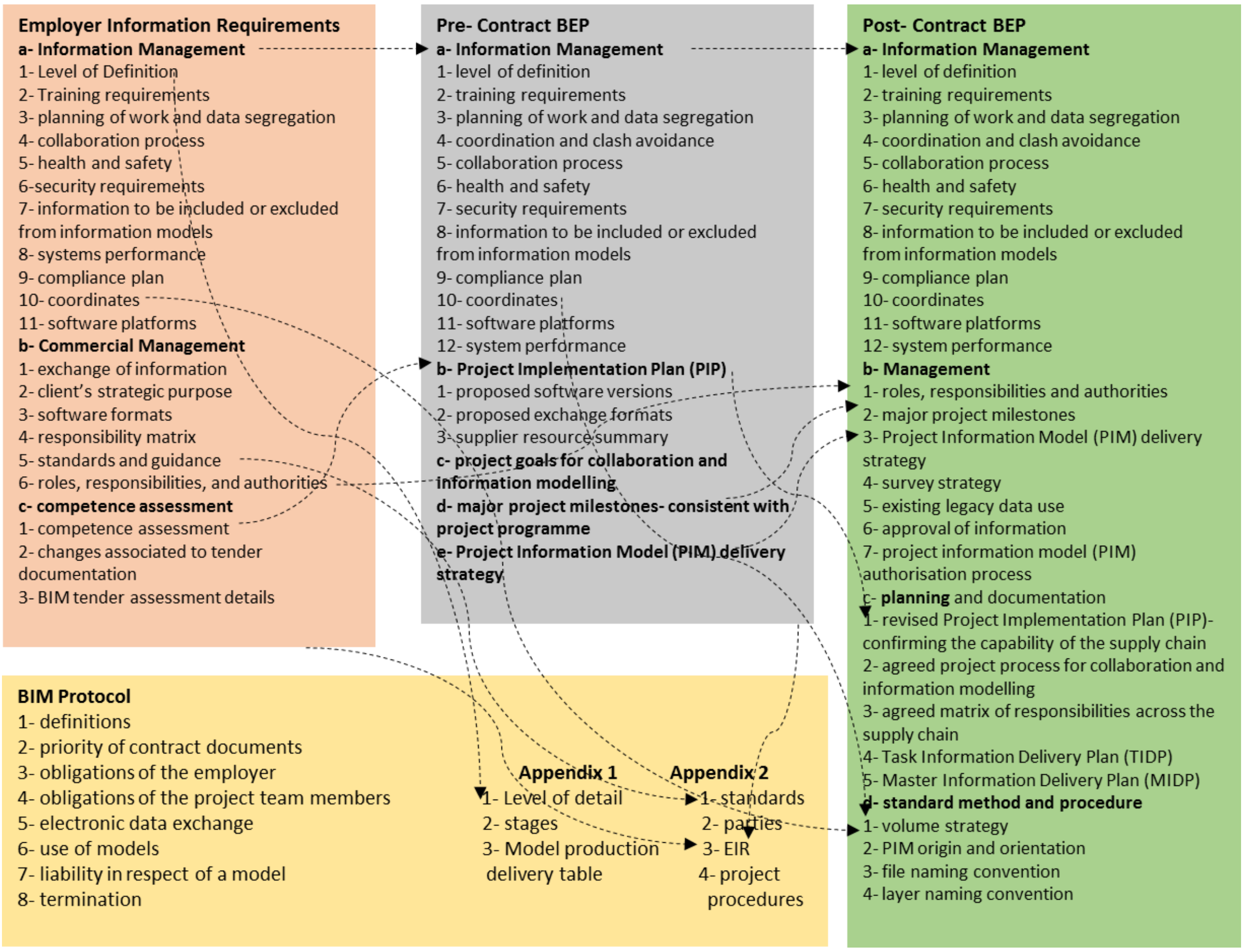


Figure 3.4: Impact of EIR on the construction process (Early, 2015), reused with permission from © Micheal Earley

3.2.1.2 BIM Execution Plan (BEP)

PAS 1192-2 (bsi, 2013) proposes the pre-contract BEP to be a direct response to the EIR, where the information required by the employer are defined, aligned with the key decision points and project stages, it provides the information required about the built asset that the client wishes to procure to ensure that the design is developed according to their needs, according to this information provided, the pre contract BEP will include:

- The Project Implementation Programme (PIP), which sets out the capability, competence and experience of the potential suppliers
- Goals for collaboration and information modelling
- Project milestones aligned with the project programme
- The delivery strategy of the project

According to the information provided in the pre-contract BEP, the employer body makes the decision whether to award the bidding team the contract (bsi, 2013). Figure 3.6 illustrates the bidding process and the development of pre-contract BEP and BEPs, and their relationship with the client's EIR.

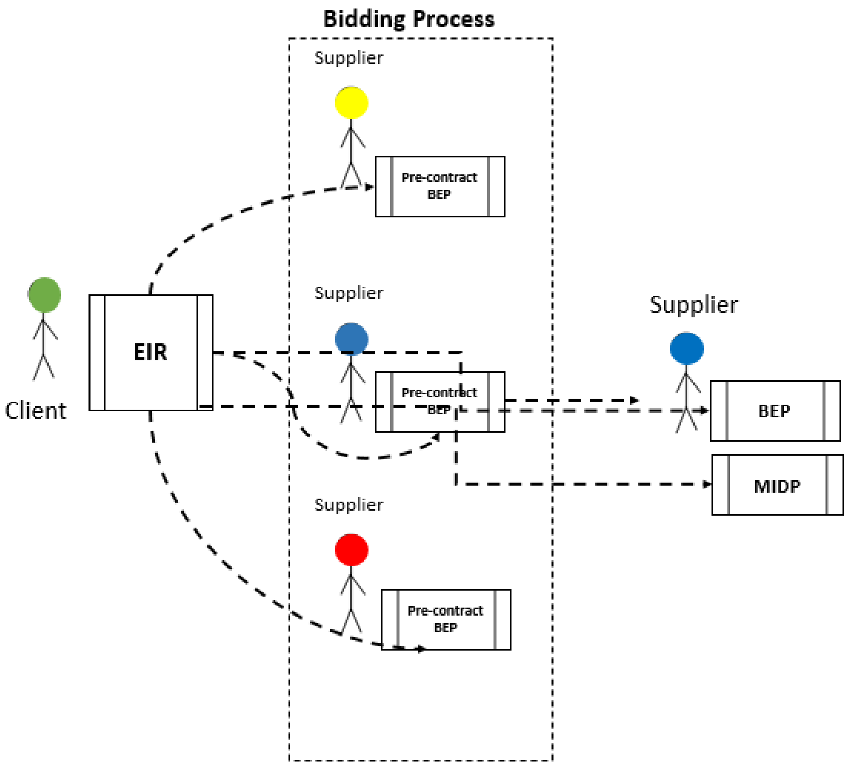


Figure 3.5: The relation between EIRs, pre-contract BEPs and BEPs

After winning the bid, the supply chain then develops the post-contract BEP and the Master Information Delivery Plan (MIDP), which are also acquired from the EIR. The main aim of the BEP is to set out how the information required in the EIR will be provided, it will define requirements of different aspects, such as:

- Management, including:
    - Roles and responsibilities and authorities;
    - Project milestones;
    - Deliverable strategy;
    - Survey strategy;
    - Existing legacy data use;
    - Approval of information;
    - Authorisation process.

- Planning and documentation, including:
    - Revised project implementation plan (PIP);
    - Agreed process for collaboration and modelling;
    - Agreed matrix of responsibilities;
    - Task information delivery plan (TIDP).
    - Master information delivery plan (MIDP) which sets out when project information is to be prepared by whim and using what protocols and procedures
- Standard method procedure, including:
    - Volume strategy;
    - Origin and orientation;
    - File naming convention;
    - Layer naming convention;
    - Construction tolerances;
    - Drawing sheet templates;
    - Annotation, dimensions, abbreviations and symbols;
    - Attribute data.
- IT solutions, including:
    - Software versions;
    - Exchange formats;
    - Process and data management systems.

3.2.1.3 The Master Information Delivery Plan (MIDP)

The MIDP is another important document prepared by the supplier and is based on the information provided by the client in the EIR. It sets out the information for the primary plan for managing the delivery of information during the project lifecycle incorporating all relevant task information delivery plans (bsi, 2013). The MIDP is responsible for answering the following questions (BIM Task Group):

- What information is to be detailed and delivered?
- When is this information delivered during the project lifecycle?
- Who is responsible for producing this information?

- And what procedures and protocols should be followed for each stage?

Information deliverables, which may be listed in the MIDP include (but are not limited to):

- Models;
- Drawings or renditions;
- Specifications;
- Equipment schedules;
- Room data sheets.

For the EIR to hold the needed requirements to produce a full BEP and MIDP to create a successful plan for the BIM project, a checklist of needs have to be created for the EIR. When these needs are fulfilled, the EIR is complete.

3.2.2 The EIR Needs

Information provided in EIR should be sufficient to enable the construction team in providing a clear plan for the whole construction process and create a comprehensive and complete BEP and MIPD as discussed in the previous section, this should be a great help in delivering a more successful project in less time and with less effort. Therefore, great emphasis should be put on ensuring that the EIR holds all the necessary information for that to happen. Information delivered in EIR will affect the whole construction lifecycle and will provide essential information for important documents that will be developed. In other words, it should be clarified that EIR holds all the relevant information that will assure the delivery of a successful construction project, as seen in Figure 3.3.

BIM offers an integrated solution for problems that face the collaboration process such as the extraction, interpretation, and communication of complex design information and information transfer. These requirements for the information exchange and communication between the different stakeholders should be defined from the beginning of the project in the EIR (Lea *et al.*, 2015). An effective EIR supported by an optimal use of BIM involves changing the roles of the clients to become more effective and integrated in the project, and a re-organisation of the collaboration process between the different stakeholders involved (Sebastian, 2011; Shafiq, Matthews and Stephen, 2013).

Due to the main mission of EIR in a BIM project, which is establishing the BIM framework for the project, EIR should be produced as early as possible, to ensure the collaboration process goes as planned, where everyone involved will understand their own and the others' information responsibilities. As for clients, EIR provides them with the opportunity to define what they exactly require from the project, and define the end results of the project, which will enable them to manage their asset(s) effectively.

The ultimate aim of BIM is to provide a complete AIM, and to do so a lot of collaboration and integration between different team players and different disciplines will have to take place during the BIM project (Mohandes, Abdul Hamid and Sadeghi, 2014; Navendren *et al.*, 2015). EIR is established from the beginning of the project and even before work on the actual stages because it will serve as a manager for the requirement for the information regarding the form, economy, and timescale for the project, the EIR will manage the structure and the requirements for this information (Saxon, 2016b). Essentially, the EIR should include the following (Kumar, 2015):

- Content that will be of use to the employers' organisation during and after the asset design and the build phase;
- The formats of the contents sought when they are delivered to them;
- Even before delivering the specified contents, their generation, storage and management through the different stages of the project;
- Specification of the information delivery points (i.e. data drops) throughout the project stages.

For the EIR to do that, the core and content of the EIR is divided into 3 categories: technical, management and commercial. Each of the categories have a list of items that should be fulfilled for reaching a complete EIR as shown in Table 3.1 and defined by PAS 1192-2 (bsi, 2013) and the EIR core content and guidance notes (BIM Task Group, 2013).

Table 3.1: EIR Content Categories and Needs as in PAS 1192-2 (bsi, 2013) reused with permission from © BSI

Technical	Management	Commercial
Software platform	Standards	Data drops and project deliverables
Data exchange format	Roles and responsibilities	Client's strategic purpose
Coordinates	Planning the work and data segregation	Defined BIM/project deliverables
Level of detail	Security	BIM-specific competence assessment
Training	Coordination and clash detection process	
	Collaboration process	
	Health and safety and construction design management	
	Systems performance	
	Compliance plan	
	Delivery strategy for asset information	

Table 3.1 shows how PAS 1192-2 (bsi, 2013) defined EIR according to the "High-Level Needs" that should be satisfied. Satisfying those needs, should ensure the delivery of a full and complete EIR, which include information that covers (Saxon, 2016b):

- Collaborative working requirements;
- Information exchange points, including the maturity of this information;
- Model management processes;
- Software formats, exchange formats and file limits;
- Training and health and safety needs;
- Security requirements for information;
- Guidance documents which are to be used;
- How the team selection will be made.

When studying the three categories that make up the EIR and their needs, we can see that the EIR should be able to answer four main questions, as seen in Table 3.2:

1. Why is there a need for this project? What are the client intentions for the built asset?
2. Who will be involved in the information delivery and the producing of the final product?
3. When will the information be delivered during the project lifecycle?
4. And how will this information be delivered?

Table 3.2: EIR Needs and the Questions they answer

Why	What	Who	How	When
Client's strategic purpose	Level of detail	Roles and responsibilities	Data exchange format	Data drops and project deliverables
	Data drops and project deliverables			
	Coordinates			

	Software platform		BIM-specific competence assessment	
	Defined BIM/project deliverables	Health and safety and construction design management		
Delivery strategy for asset information				
			Systems performance	
		Planning the work and data segregation		
	Security			
			Compliance plan	
		Training		

EIR obtains information needed to answer the questions and cover the items previously mentioned from different sources, which will be discussed in the next section.

3.2.3 EIR-Sources of Information

For the client to benefit most from BIM, he/she should be able to ask the right questions (Sharp, 2015). As discussed in the previous section, in order to have a successful EIR to which a successful BEP and MIPD will respond, the EIR should be able to answer four main questions: who, why, what, when, and how? Answers for these questions are found in a number of documents that together make up the EIR as identified by PAS 1192-2 (bsi, 2013) and as seen in Figure 3.7.

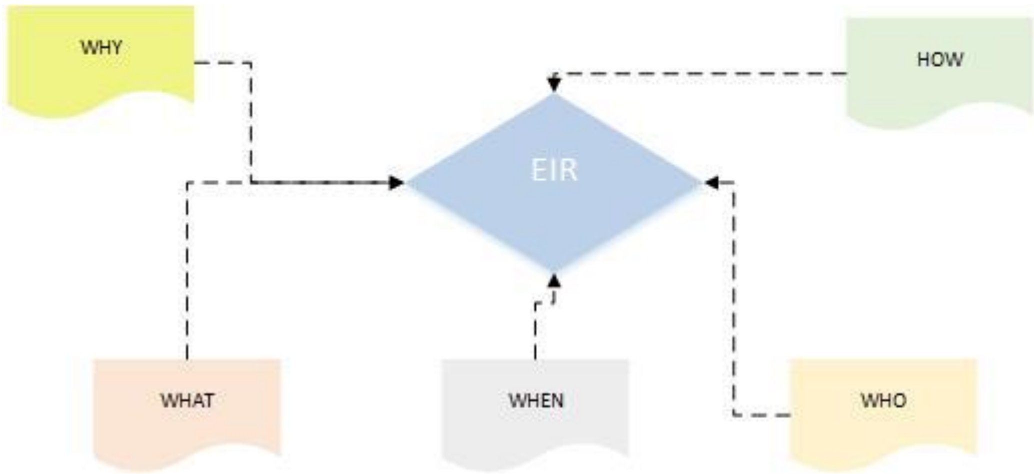


Figure 3.6: EIR inputs

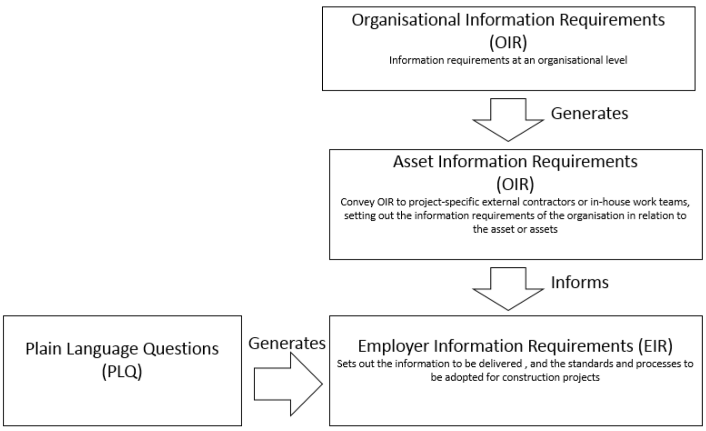


Figure 3.7: Sources of information for the EIR (bsi, 2013) reused with permission from © BSI

PAS 1192-2 (bsi, 2013) states that at the start of a BIM process, a clear understanding of the client's Organisational Information Requirements (OIR) and Asset Information Requirements (AIR) should be set, and that one of the "fundamental principles of Level 2 BIM, is the provision of a clear EIR". It defines the EIR as a "pre-tender document setting out the information to be delivered, and the standards and processes to be adopted by the supplier as part of the project delivery process" and that the "EIR should be incorporated into tender documentation to enable suppliers to produce an initial BIM Execution Plan (BEP)",

Defining the type of client and the business objectives of the project and the need for it should be clear from the beginning of the project and should be stated clearly in the Organisational Information Requirements (OIR) of the project. The OIR are important because they generate the Asset Information Requirements, which in turn inform the EIR, as shown in Figure 3.7 (bsi, 2013)

3.2.3.1 Organisational Information Requirements (OIR)

The process begins with defining the OIR for the organisation, as seen in Figure 3.9, according to Saxon (Saxon, 2016b), the main input for the OIR is the Brief. Briefing is one of the most important phases in building construction; it defines the client's requirements for the project, sets out the performance criteria in the terminology of the building, and continues to evaluate the project after it has been finished and occupied. Thus, briefing is a process that starts before the beginning of the project, runs throughout the project implementation and even deals with post project issues (Blyth and Worthington, 2010).

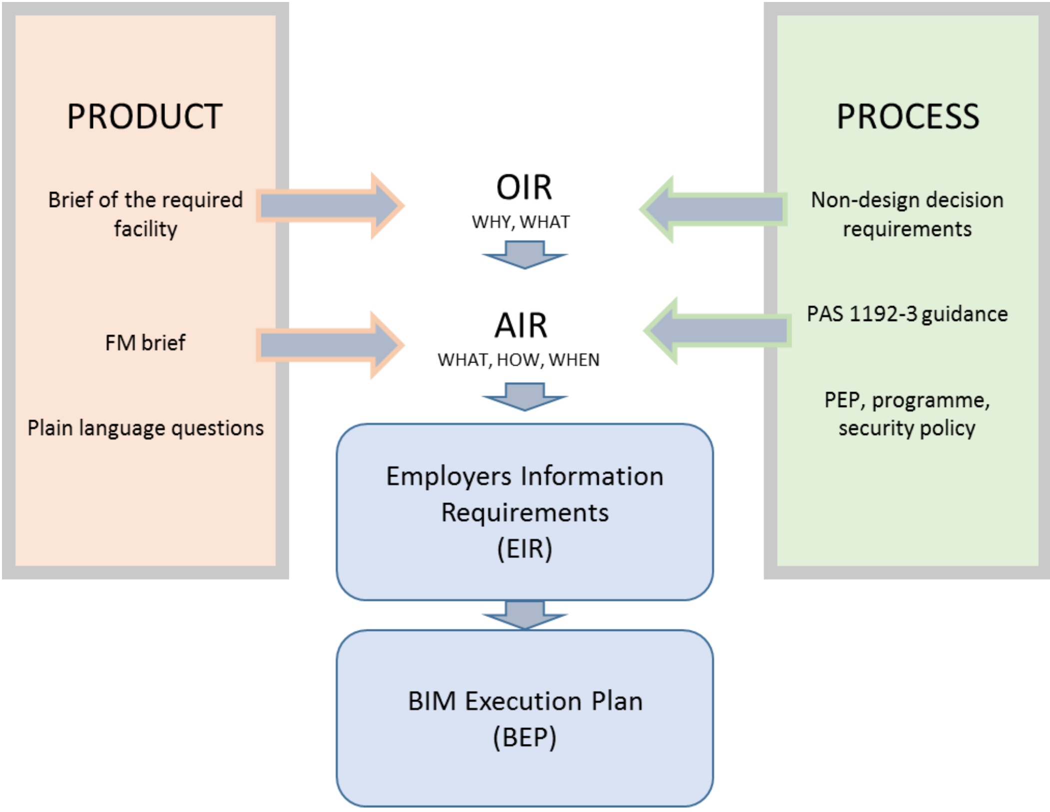


Figure 3.8: Inputs for EIR (Saxon, 2016c)

The first part in identifying the EIR of a project is for the client to answer the question why is there a need for this information that will be provided at the end of the BIM project? Each project has a different set of information requirements based on the reason the client will require this information. A project that is intended for "build and sell" will have information requirements different than a project that is intended to "build and use" (Eastman *et al.*, 2011). By answering the first question of "why" does the client need the information provided, the client can then peruse to identify the actual information required in the Asset Information Requirements (AIR).

The former answers provide what is termed the so-called "Organisational Information Requirements". Together with the conventional brief for the building's function, form, economics and time factors, the decision support needs to generate what has to come out of the model at each information exchange point. This helps the team to get better stakeholder engagement and to obtain sound and timely decisions, which keep the project moving without high risk of change (Saxon, 2016a).

The OIR requires information from BIM according to the type of Organisation it runs; there are two major types of clients that will be using BIM: clients who will occupy and use the asset, and clients that are developers and are only building the asset to sell (Wilkinson, 2013).

Both of these types of clients will benefit from BIM when using it in their project, but the information required in the AIM will differ according to the type of organisation that owns the project.

After defining for the project the nature and reason for it, and what are the physical and performance aspects that need to exist in it for it to be delivered according to the client requirements and wishes, the next step is to know how this information will be delivered and what information will be delivered throughout the project stages, and who will be involved in this delivery. Those questions should be answered in the asset information requirements which is the next input for the EIR.

3.2.3.2 Asset Information Requirements

The development of the Asset Information Model (AIM) which is the digital information of the built asset, mainly depends on the definition of the Asset Information Requirements (AIR) throughout the project lifecycle. Improving the AIR delivered will lead to improvement of the AIM, which in turn will have direct effects on the data handover at the end of the construction process and on the asset's performance throughout its lifecycle, due to the support the AIM model offers for the maintenance and other Facility Managemet (FM) tasks during the use phase of the building (Patacas *et al.*, 2016).

The delivery of a complete AIM is essential for the maintenance and management of the building throughout its lifecycle and operational phase. In fact, 80% of an average building's costs reside in its operation, while only 20% related to its design and construction (Wilkinson, 2013; Wallbank, 2014).

AIR is a direct translation of the owner's requirements of the AIM, they are generated from the client's OIR, which is the information requires to achieve the client's organisational objectives (BSi, 2014).

According to PAS 1192-3-2014, EIR is initially informed by information provided by the Asset Information Requirements (AIR). PAS 1192-3 Specification for information management for the operational phase of construction projects using BIM states that "...specific AIR shall be specified as part of a contract or as an instruction to in-house teams and may use data and information from the AIM relating to the asset management activities being carried out" (bsi, 2014)

The AIR shall also specify data and information to be captured and fed into the AIM. Where the activities relate to major works covered by PAS 1192-2, then the AIR will inform the EIR. PAS 1192-3 suggests that 'The AIR may start as descriptive text but should then be developed into a digital plan of deliverables. The effort to complete this should not be underestimated' (bsi, 2013)
The AIR is an important source of information for the asset to be retained and managed, and is needed by the occupiers, the facility managers, and the asset managers, which also includes an as-built description on the asset. These requirements have to comply with the BS 8536: 2015 for the soft-landing services.
The deliverables for the AIR are linked with the project stages, where these requirements are developed until reaching the mature AIM model.
Examples of possible Asset Information Requirements, can be based on guidance in PAS 55-2:2008 (Asset management. Guidelines for the application of PAS 55-1) and BS 8587:2012 (Guide to facility information management).

Information provided by the AIR should be able to contribute efficiently to the AIM, which should hold the necessary data and information related to or required for the management and operation of the asset after handover (bsi, 2013).

3.3 What Should EIR Cover?
Three main things determine what should be covered in the EIR:

- The BIM information delivery lifecycle;
- The BEP; and
- The MIDP.

After studying the EIR Needs as defined in PAS, and the sources of information for a complete and comprehensive EIR, which combine the relevant information from the OIR and the AIR, with the further input from the projects physical brief, it is concluded that the EIR should be able to cover the following requirements (Saxon, 2016b):

- Collaborative working requirements, setting out how the team members are expected to interact;
- Information exchange points in the project plan, and the maturity at which the information should be at each exchange to answer the client's question;
- Model management processes and the role of information manager;
- Software format required, exchange formats and size limits;
- Training and health and safety needs;
- Security requirements for information;
- Guidance documents which are to be used;
- How team selection will be made, tenders assessed, and competencies judged.

The client should also be aware of the importance to define certain issues before the beginning of the project and make sure that he understands what they are and is able to clearly define them. These issues are important for the client, stakeholders and project teams, and a clear identification is crucial. Figure 3.10 illustrates the BIM process plotted against the project stages of the BIM Information delivery lifecycle (Saxon, 2016b). It is essential for the client to be able to understand this process of the development and exchange of information during the project lifecycle in order to be able to produce an EIR that can provide essential requirements to manage and organise this process with the least overrun in time and waste, and to the client's utmost satisfaction.

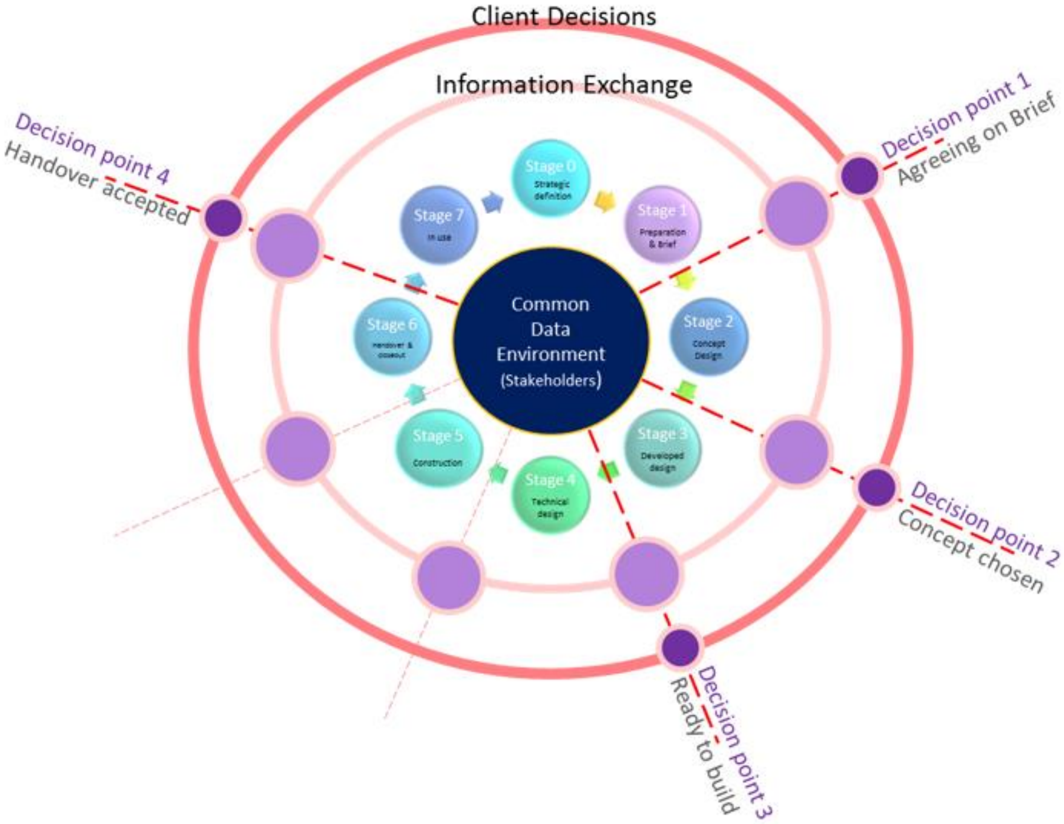


Figure 3.9: the BIM process plotted against the RIBA Plan of Work 2013 (Image Based on Information from Saxon, 2016c)

Looking back at Figures 3.2 and 3.8, in which the BIM project lifecycle was visualised, as well as the main components involved, the following points have shown to be vital for BIM information delivery and thus should be covered in detail in the EIR:

1. **The CDE and everything involved in it, which includes:**

- Defining the CDE for the project;
- Information-related roles and responsibilities giving a clear definition of information-related roles and what is expected from them;
- Standard methods and procedures providing clarity on information formats and naming conventions and guidance on how to supply information;
- An information delivery plan or information schedule identifying which information deliverables should be delivered, by whom and when;
- Information regarding the creation of the Asset Information Model and delivery.

2. **Information development needed to create the final AIM, and everything involved with the development of information throughout the project lifecycle, which include:**

- The **project stages** in the BIM process, and the roles and responsibilities of the project team;
- The **Data Drops** at the end of each stage, in terms of time, deliverables, and actors, and most importantly the contribution this stage has to the Project Information Model (PIM), as the process progresses in line with the maturity level for the PIM, which is determined by the **Level of Definition (LOD) and Level of Information (LOI)** for that stage;
- The **Employer Decision Points**, when the employer decides whether the project is ready to move to the next phase according to the sufficiency of the information provided;
- Soft landing, which is an important issue that should also be addressed by BIM, the EIR should help to ensure that the asset is being transferred from construction phase to handover and in use as smoothly as possible, by defining the adequate **Asset Information Requirements (AIR)** that will develop during the lifecycle into a complete AIM.

3.3.1 Common Data Environment (CDE)

The CDE is an online place for collecting, managing and sharing information (Mills, 2015). It is the digital site where all the information comes together, and all the digital data are created and shared during the project's lifecycle. The CDE is where the collaborative work on the project takes place (Mordue, 2015).

The first process of data flow on the single shared CDE is the EIR, which is the document in which the client states the information that will be needed from the project team in order for them to make a decision at key points in the project lifecycle, including during its operation and use.

After checking and approving the design team's graphical and non-graphical contributions to the project, the information will be moved to the shared area (CDE) for the other parties to be able to access and re-use this information (CIC, 2018; bsi, 2013).When the information is approved by the client at key decision points, and after the client signs-off the information, it is moved to the CDE, after this information is checked to be aligned with the EIR. The published information is used by specialists and contractors to develop their contributions, which is similar to the other cases; once the “work in progress” is approved, it is also shared on the CDE. As each milestone is met, published information is moved to the “Archive” for future reference and use.

This information which is accurate and approved, builds up what is known as the Project Information Model (PIM), which is developed as the stages progress and the information provided on the CDE matures as well. After being verified, this data is used in the asset management phase and will be known as the Asset Information Model (AIM), which comprises of graphical model, non-graphical data, and documentation, as shown in Figure 3.11.

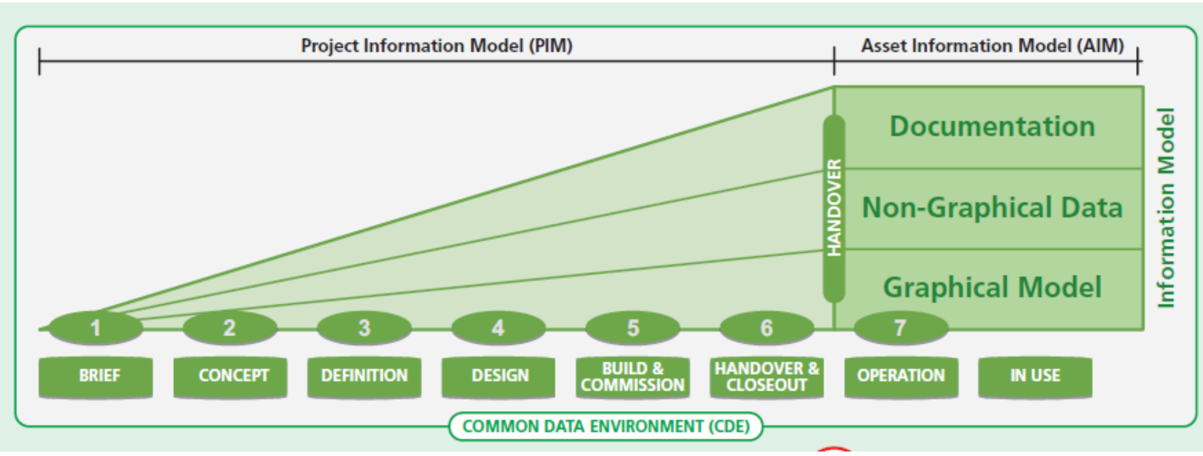


Figure 3.10: Project stages and the PIP leading to the AIM PAS 1192-2 (bsi, 2013) reused with permission from © BSI

3.3.2 Roles and Responsibilities

It is important to clarify the roles and responsibilities and authority of the different stakeholders involved in the BIM project, for its influence on having an effective management of information (bsi, 2013). These roles and responsibilities should be defined clearly in in the initial stage of the project in the EIR (CIC, 2018).

PAS 1192-2 defined the roles and responsibilities and authorities of major BIM stakeholders shown in Figure 3.12.

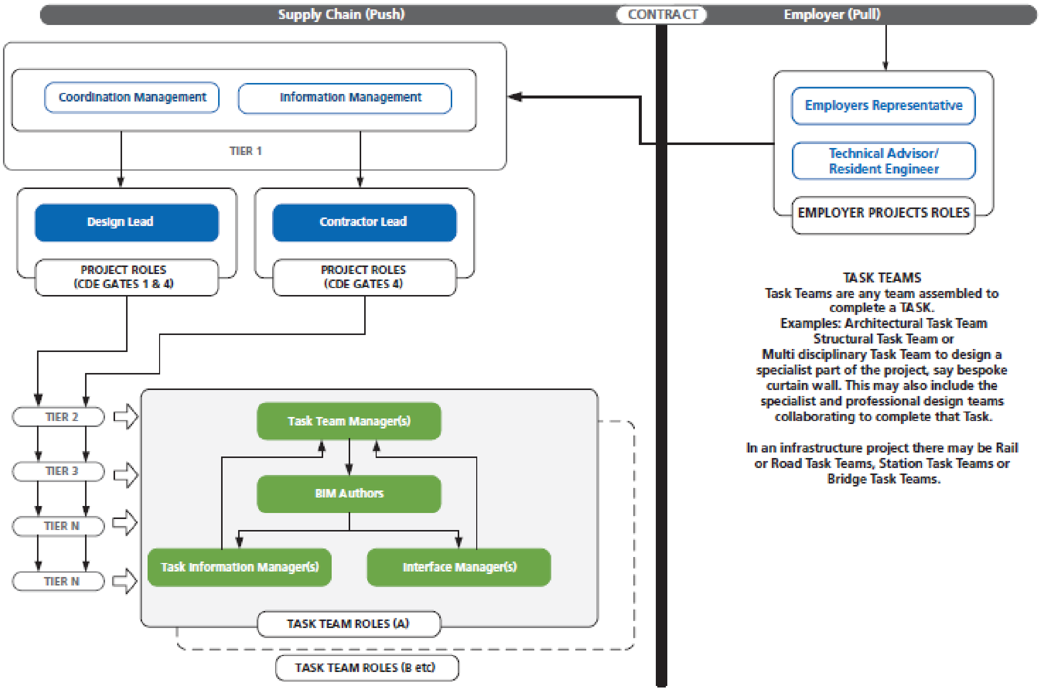


Figure 3.11: BIM roles, responsibilities and authority (PAS 1192-2) reused with permission from © BSI

According to PAS, these roles and responsibilities include:

Project Information Manager:

- Responsible to the project delivery manager
- Projects standards, methods and procedures (SMP)
- Assure information model compliance
- Ensure task team has the capability to deliver
- Identify and mitigate risks against delivery

Project Delivery Manager:

- Master information delivery plan
- Communication link between task teams
- Assures the delivery of the information model
- Ensures task teams have the capacity to deliver
- Identify and mitigate risks against delivery

Lead Designer:

- Develop the BIM Execution Plan (BEP)
- Task team appointments and assessments
- Assigning the level of definition (LOD)
- Volume strategy
- Authorisation of the project information model

Task Team Manager:

- Responsible to the design construction lead
- Ensures delivery against the task information delivery plan
- Approval of the task team information model(s)

Task Information Manager:

- Responsible to both the design construction lead and the Project Information Manager
- Point of contact for information management
- Ensures compliance with SMP
- Education and training

Interface Manager:

- Resolving spatial coordination issues with other task team interface managers
- Escalating unresolved coordination issues to the design/construction lead

Information Manager:

- Coordination of information
- Escalates issues to ensure delivery
- Escalates interface issues to interface manager

Other studies discussed the roles and responsibilities of the "Construction Team", which have shown that the purpose of BIM for the different players differ (Latiffi, Brahim and Fathi, 2015).

For clients, BIM is supposed to assist them to understand more of the project needs (Eastman *et al.*, 2011; Azhar, Khalfan and Maqsood, 2015; Bryde, Broquetas and Volm, 2013; Reddy, 2012). Architects and engineers use BIM for analysing and developing their designs, and contractors for managing the construction activity and scheduling (Latiffi, Brahim and Fathi, 2015). As for quantity surveyors, BIM enables them to produce an accurate project cost estimation (Azhar, Khalfan and Maqsood, 2015). Facility managers utilise BIM in the operation and maintenance of the facility (Azhar, Khalfan and Maqsood, 2015; Bryde, Broquetas and Volm, 2013).

Table 3.3 demonstrates the roles and responsibilities of the construction players as presented by Latifi *et al.,* (2015):

Table 3.3: Roles and Responsibilities of Construction Players (Latiffi et al., 2015)

Construction Player	**Role and Responsibilities of Construction Players in** **Project using BIM**
Client/Owner	▪ Defining a suitable method of using BIM
Architect	▪ To develop conceptual design. ▪ To develop detail design and analysis. ▪ To develop construction level information ▪ To develop construction documents.
C&S and MEP Engineer	▪ To develop detail design. ▪ To develop shop drawings with detail elements.
Contractor	▪ Perform constructability analysis ▪ Scheduling and planning using 4D model Produce cost reliability
Quantity Surveyor (QS)	▪ To extract quantities and produce cost estimation from ▪ the 3D model

Facility Manager	▪ To put the information of building into the 3D ▪ model for the purpose of FM.

Roles and responsibilities should be clearly be defined in terms of tasks each role should do in terms of:

1. What responsibility does this role authorise?
2. What responsibility does this role consult?
3. What responsibility does this role inform?

3.3.3 The Project Stages

PAS 1192 defines the project stages according to the RIBA work stages, which are made up of 7 stages, Brief, Concept, Definition, Design, Build and commission, Handover and closeout, and operation.

The stages should be clear for the project team from the beginning of the construction project in terms of timescale, actors, and information to be delivered at the end of each stage, this information should be set out clearly in the MIPD which is developed in the preparation stage before the construction project begins, at the end of each stage, and after approving the information, the information lifecycle moves to the next level, which is the Data Drops.

The aim of the stages is to develop the Project Information Model (PIM), which develops according to the development of the stage, for which the development is measured according to the Level of definition (LOD) and Level of Information (LOI) of the model in that stage, which will be discussed in detail in Section 3.4. The PIM should be developed in accordance with a Master Information Delivery Plan (MIDP) and delivered to the employer through a series of information exchanges or data drops, as shown in Figure 3.11, and will be discussed in the next layer. At the end of Stage 6 “Handover & Closeout” and by the beginning of Stage 7 “Operation”, the model should have reached its ultimate maturity level, according to the requirements defined by the client in the EIR, at this point, the PIM is called the Asset Information Model (AIM), which hold information about the model in different forms: Documentation, non-graphical data and the graphical model, as shown in Figure 3.6.

3.3.4 Level Of Definition (LOD) and Level Of Information (LOI)

As defined in the CIC BIM Protocol (2018), Level of Information means the level of detail of non-graphical content as defined in the Information Particulars. Level of Model Detail means the graphical appearance of Information Model objects as specified in the Information Particulars.

The end product of the BIM process is the Asset Information Model, which should contain both graphical and non-graphical information (bsi, 2013). As the stages progress and the model develops, both types of this data are shared on a digital space (the CDE) as discussed in Section 3.3.1.

Each stage has a different amount of level of information (LOI) and level of definition (LOD). The difference between the both, is that LOI refers to the amount of non-graphical information, and LOD for the graphical information (B1M, 2015).

PAS 1192-2 (2013) details the requirements for the LOD over the project's lifecycle. PAS describes what the information model can be relied upon for at each stage – such as co-ordination activities, logistics planning, programming, cost-planning – the expected outputs, and the required detail within the 3D representations.

Stage number Model name	1 Brief	2 Concept	3 Definition	4 Design	5 Build and commission	6 Handover and closeout	7 Operation
Systems to be covered	N/A	All	All	All	All	All	All
Graphical illustration (building project)							
Graphical illustration (infrastructure project)							
What the model can be relied upon for	Model information communicating the brief, performance requirements, performance benchmarks and site constraints	Models which communicate the initial response to the brief, aesthetic intent and outline performance requirements. The model can be used for early design development, analysis and co-ordination. Model content is not fixed and may be subject to further design development. The model can be used for co-ordination, sequencing and estimating purposes	A dimensionally correct and co-ordinated model which communicates the response to the brief, aesthetic intent and some performance information that can be used for analysis, design development and early contractor engagement. The model can be used for co-ordination, sequencing and estimating purposes including the agreement of a first stage target price	A dimensionally correct and co-ordinated model that can be used to verify compliance with regulatory requirements. The model can be used as the start point for the incorporation of specialist contractor design models and can include information that can be used for fabrication, co-ordination, sequencing and estimating purposes, including the agreement of a target price/ guaranteed maximum price	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 3.12: Part of the LOD table (PAS 1192-2) reused with permission from © BSI

The concepts of LOD and LOI have been developed, to answer the question of "how much information should be exchanged during the project lifecycle"? PAS 1192-2 notes: "Key to the success of information management is clear definition of requirements as defined by the information exchanges and including COBie and geometry" (CIC, 2018; bsi, 2013)

The importance of deciding the suitable LOD for the model during the different stages of the lifecycle, is also important in minimizing the waste if the supply chain would deliver a greater level of detail than is needed, which will overload the IT systems and networks available (BSi, 2013).

It is important to specify the LOD and LOI from in the initial stages of the project, more precisely in the EIR. Doing that will give the suppliers a better idea of what will be delivered at the end of each stage. It will enable them to plan the work accordingly, which will save time and waste.

3.3.5 Data Drops

Information management life cycle proceeds through a number of data drop points. Data drops are project milestones aligned with the project stages, as shown in Figure 3.3, in Section 3.1.2. Information provided at these milestones should be able to reflect the level of development the project has reached at that stage. This information should be set out in the EIR in the preparation stage. Data drops are likely to include information such as:

- Models (Graphical data);
- Data (non-graphical data); and
- Reports (documentation).

According to PAS there should be at least 5 data drops during the construction process that guide and manage it, these drops as defined in PAS 1192-2 are (Kumar, 2015):

- Data Drop 1: This is the first key information exchange point in the life cycle, and at this point the model essentially represents REQUIREMENTS and CONSTRAINTS.

- Data Drop 2: At this key information exchange point in the lifecycle the model essentially represents an outline solution.

- Data Drop 3: This is the drop that signifies the end of the design phase and when the model represents construction information.

- Data Drop 4: This drop signifies the end of the construction phase and the model should be able to represent all of the O&M information ready to be handed out to the employer.

- Data Drop 5: This data drop deals with the post-occupancy validation information.

3.3.6 Legal issues in BIM

Setting out the Intellectual Property Rights of the model from the beginning will ensure that the collaboration during the project life-cycle without the adverse legal consequences (Udom, 2012).

The prevalent lack of determination of ownership of the BIM data and the need to protect it through copyright laws and other legal channels is one of the main risks that BIM faces (Azhar, 2011). Issues regarding copyrights, ownership rights, exploitation rights and responsibilities should be addressed before the beginning of the project and preferably in the EIR (Rosenburg, 2007); which will be useful to avoid hang-ups and disincentives that may hinder participants from realising the model's potential (Thompson, 2001).

Other contractual issues to be addressed are the control of data entries and the responsibility for any inaccuracies (Azhar, 2011). Matters concerning the responsibility of updating of the BIM model, and ensuring its accuracy, is yet another essential concern that should be addressed clearly and resolved early in the EIR to avoid any complications before the BIM technology is used.

3.4 Challenges facing Requirements Specification

Many studies have been conducted in the area of requirements specifications and requirements management at the beginning of a project, and concluded that there are several obstacles that hinder the requirements specification and requirements management (Arayici, Ahmed and Aouad, 2006; Kamara and Anumba, 2001; Shen and Chung, 2006), for example:

- Failure to manage end-user expectations: There is no existing framework for the induction of end-users into construction projects. User participation seems impossible in managing market-driven requirements. Late involvement of end-users leaves little room for alterations, and the user requirements are sometimes contradictory to employer needs (Kujala *et al.*, 2005).
- Lack of frozen requirements: Delays can be caused by changing project requirements from stakeholders, inaccurate documents or unanticipated conditions (Othman, Hassan and Pasquire, 2005). Apart from creating unforeseeable impacts, changes often follow the will of the employer and professionals, who occasionally overlook the initial intention of the project. Changes violating the original goals often bring about negative impact to the facility due to the mismatch of the master plan and details.

Due to the importance of requirements specification and management, many studies have been carried out to study the limitations regarding current practices. Many have pointed to the errors generated from the initial brief as follows (Arayici, Ahmed and Aouad, 2006; Kamara and Anumba, 2001; Finch *et al.*, 2005; Shen and Chung, 2006):

- Incomplete and inconsistent requirements and specifications; where they only cover limited perspective of the proposed facility and stakeholders overlook some vital parts of the building. Employers and professionals seldom perceive the project as a whole at the inception stage (Leite, Miron and Formoso, 2005), and they often underestimate the critical requirements that appear to be negligible at first glance. Future change of brief contents is made necessary.
- Misunderstanding and misinterpretation of requirements; the language used (Zielczynski, 2007) and the clarity of employer requirements always frustrate stakeholders. An employer either believes in a clear brief indicating a greater potential dispute (Barrett and Stanley, 1999), or pays little attention to brief writing.
- Inadequate time allocated for requirements specification; many employers consider requirements specification as an event which does not generate any value to the project and refuse to put resources to the briefing process (Othman, Hassan and Pasquire, 2005). They tend to save time on the briefing side in exchange for an earlier start of the design work. Requirements are not properly identified, which in turn impairs the satisfaction level of employers.
- Lack of user involvement; only a limited number of stakeholders in a project are involved in the preparation. For efficient use of time on brief writing, employers and other key stakeholders may prefer having a small group who share similar interests, objectives and agenda involved (Barrett and Stanley, 1999).

Due to the importance of defining good requirements in producing successful projects, many studies have been conducted in this area. Finch *et al.,*(2005) and Yu *et al.,*(2010) put forward some recommendations that lead to clearer and more comprehensive requirements:

- Comprehensive preliminary project statements

This is important because it allows contractors and consultants to understand thoroughly the employer’s requirements. According to Murray (1995), the preliminary project statement is essential in:

- Clarifying and making clear what are the employer organization’s objectives;
- Illuminating goals of the project; and
- Outlining the requirements.

A well written requirements specification should be in detailed form (Lam, Chan and Chan, 2008); in a way that it also would leave room for some design development to be added by contractors.

- Well defined project goals at inception stage:

  Many research studies show that object-oriented approach is a useful tool in capturing requirements, improving traceability, and the effective prioritizing of requirements (Songer and Molenaar, 1997; Arayici, Ahmed and Aouad, 2006; Kamara and Anumba, 2001).

- Formal procedures in gathering requirements:

  Using a more formal procedure in capturing requirements helps in traceability of alterations, this leads to improving communications between the different stakeholders.
- Specific roles and responsibilities of each contracting party:

This will lead to more involvement of the employer and other stakeholders in the project; it will encourage the active participation of stakeholders both in roles and responsibilities, and will be more defined especially in capturing, improving, and managing employer requirements.

3.5 Previous Studies

Although the management of client requirements in the construction industry has been the subject of numerous studies, problems in addressing and complying with these requirements are still visible in the industry, which is the main reason for producing assets that underperform when compared to their original goals (Parsanezhad, Tarandi and Lund, 2016; Kiviniemi and Fischer, 2005).

Research work is in the field of requirements postulated by Kamara et al. (2000), which advocated construction briefing as “client requirements process” within the discipline of concurrent engineering for life cycle design and construction. Bruce and Cooper (2000) highlighted the importance of understanding both hard and soft processes when developing requirements for clients. The document that contains the written instructions/requirements of the client is referred to as the "brief" which should include the following information:

- The background, purpose, scope, content and desired outcomes of the project;
- The functions of the intended facility and the relationships between them;
- Cost and time targets, instructions on the procurement and organization of the project;
- Site and environmental conditions, safety, interested third parties, and other factors that is likely to influence the design and construction of a facility. (Kamara and Anumba, 2001).

Other studies assume the role of developing requirements through the practice of architectural programming. Pena and Parshall (2001) describe programming as the pre-design activity that develops the considerations or design determinants that define a comprehensive architectural problem. The information is gathered and processed following a five-step iterative approach: 1) Establish goals; 2) Collect and analyse facts; 3) Uncover and test concepts; 4) Determine needs; and 5) State the problem. This approach culminates in an information index that adequately defines the problem and solution for design and construction development. These considerations are function, form, economy and time. Pena and Parshall developed various programming methods to establish client and project values to allow designers to respond with alternative solutions to defined problems.

Other models that have been implemented in this area is the Client Requirements Processing Model (CRPM), which adopts structured methods in translating the "voice of the client" into the "voice of the designer" (Kamara *et al.,* 2000). The model has three main stages: define client requirements, analyse client requirements, and translate client requirements. These stages sub-divide further into activities and utilise appropriate information gathering tools, decision support tools and quality assessment tools (e.g. Quality Function Deployment) to develop solution neutral specifications. CRPM is computerised within a software system called ClientPro and has been received as generally satisfactory in effectiveness. Test feedback reports that requirements generation, prioritization, clarity and visibility were adequately supported within the formal process. Kamara and Anumba (2002) maintain that client requirements be:

• Precisely defined, with as little ambiguity as possible, and reflective of all the perspectives and priorities represented by the client body;

• Stated in a format that is solution-neutral (i.e. not based on any design concept that could serve as a solution to the client's problem) and which makes it easy to trace and correlate design decisions to the original intentions of the client.

ClientPro was evaluated by four industry practitioners and relatively rated low in areas such as the facilitation of communication among members of the processing team, the usefulness of the software to the overall construction process, and the ease to use the system (Kamara et al., 2002). Another limitation of the CRPM was identified by (Jallow, 2011), which was that the CRPM only feeds into the design phase of the construction project but does not apply through the whole lifecycle of the project.

Another tool for processing clients' requirements is the Quality Function Deployment, which can be used for understanding and tracking requirements, and improving communication among various product development team members (Kamara et al., 1999). This method is based on representing the requirements through matrixes as well as documenting. However, the use of QFD has been very modest in construction (Dikmen et al., 2005). One limitation of the use of QFD in construction as pointed out by Lima et al. (2008) is that it is relatively time-consuming to process this information, particularly if the proportions of the matrix become very large; and related to this, it is not easy to involve the busy product development team members in the processing stages that are necessary to produce the matrix.

Other studies conducted showed evidence that clear definition of requirements can achieve tangible benefits for asset owners and raise the benefits of investing in BIM (Love *et al.*, 2014), which demonstrates the importance of defining requirements that conform to the client requirements to produce an AIM that fulfil the clients and FM needs for the operational phase (Love *et al.*, 2014). Patacas *et al.* (2016) presented a framework that defines the owner's requirements in AIR and the visualising of the data in a virtual environment through the use of a game engine.

Another model that deals with the information integration in the BIM project is the Information Integration Sphere (IIS) (Feng, *et al.,* 2011). IIS was developed to identify the requirements of the various stakeholders of the project. In addition to generate, manipulate and visualise the flow of information along different processes. Also, IIS can establish the responsibilities of various stakeholders in terms of providing and receiving information within the construction project (Feng, Mustaklem and Chen, 2011).

Feng *et al*., (2011) describe the concept of the IIS model is that it represents the information integration process with a sphere. Where the information starts in the centre point of the sphere and evolves according to the increasing size of the sphere, as shown in Figure 3.14.

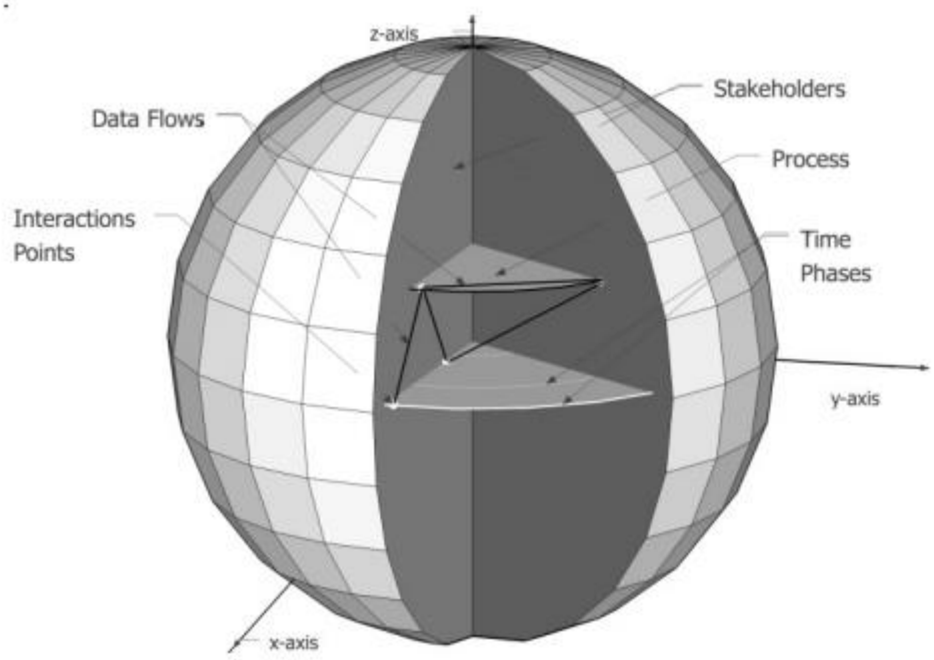


Figure 3.13: The IIS components (Feng, Mustaklem and Chen, 2011) reused with permission from © Chung-Wei Feng

The components of the IIS model are divided into: the timeline, the processes, stakeholder and data flow. The deliverables of the IIS model could be gathered into four groups (Feng, Mustaklem and Chen, 2011): time perspective, stakeholder perspective, process perspective, and data requirements perspective.

Despite the efforts of this model, and the attempts to visualise the relationships of the information integration, there is still a gap to be filled regarding the early stages of the construction project (Zanni, Soetanto and Ruikar, 2013), which starts with the definition of the EIR. The IIS model mainly deals with the project requirements and deliverables during the actual design and construction stages of the project, and ignores the information deliverables of the BIM process as whole. It is important to incorporate all disciplines involved in the project from early stages (Bouchlaghem *et al.*, 2005). Early decision making is crucial to achieve sustainability and the resulting design outcome (Schlueter and Thesseling, 2009).

Furthermore, in the field of EIR, not many studies were found as discussed earlier. One of the popular tools available is the publicly shared BIM Toolkit developed by the NBS on behalf of the Department of Business Innovation and Skills, the UK BIM Task Group and Innovate UK (NBS, 2015). The BIM toolkit comprises a digital plan of work, a unified classification system, thousands of definition templates and a verification tool.

The BIM toolkit offers Classification and Definition guides – a single unified classification system that will work across the industry and a Digital Plan of Work tool – to define responsibility for information within a project and clarity as to who is responsible for each part and when. Despite the great benefits this toolkit has to offer, it would not be appropriate to identify it as an EIR toolkit, because in fact it only covers a very small fraction of the EIR needs as described in PAS 1192-2. Tina Pringle (2015), NBS Head of Technical Content, noted on the NBS technical support page in April 2015 that: “The NBS BIM Toolkit can be used to generate the content for sub-section 1.1.4 (Level of Detail) of an EIR. This defines the specific information requirements that are aligned to the project stages.” Figure 3.15 provides a screen shot of the interface of the toolkit. The project stages are defined according to the RIBA plan of work, in 7 stages.

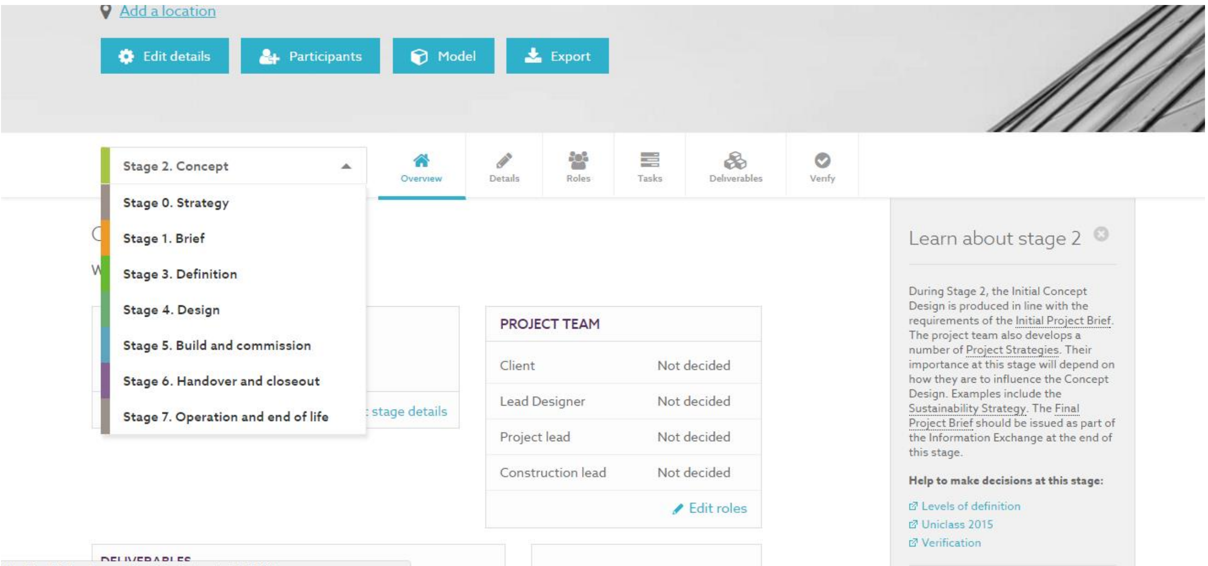


Figure 3.14: Graphical User Interface of the NSB Toolkit (NBS, 2015)

For each stage the client should define 5 aspects:

- 1. The overview of the project, in which the names of the client, lead designer, project leader, and construction leader are defined.
- 2. Details, in which the stage deadline is defined, in addition to construction start, construction end, cost and the environmental assessment rating, as shown in Figure 3.16.

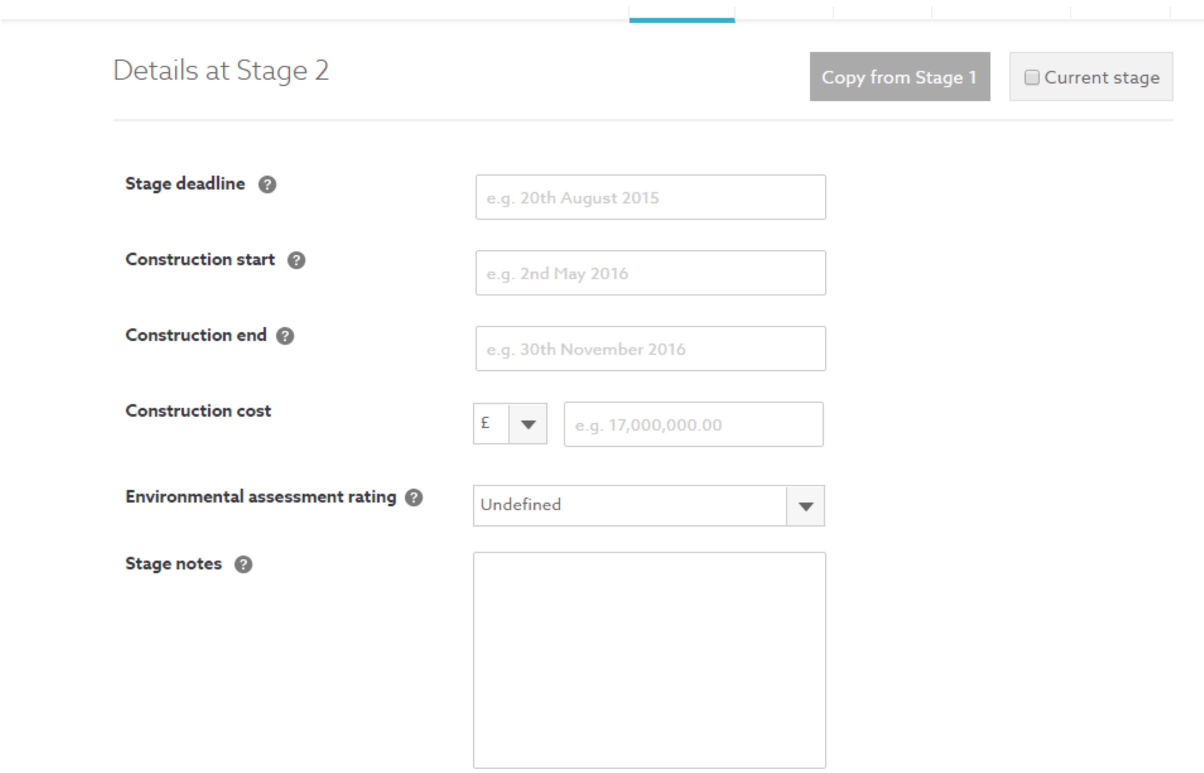


Figure 3.15: The NBS toolkit details option (NBS, 2015)

- 3. Roles, as discussed before in Section 3.3.2 are important in the construction process. The NBS toolkit defines 10 roles in the construction process as shown in Figure 3.17. Not only are the roles not sufficiently defined, they also present a challenge for the unexperienced client and do not offer help in defining the EIR.

Role	Participant
Architect	Not decided
Building services engineer	Not decided
Civil engineer	Not decided
Client	Not decided
Construction lead	Not decided
Cost consultant	Not decided
Health and safety adviser	Not decided
Lead designer	Not decided
Project lead	Not decided
Structural engineer	Not decided

Figure 3.16: Roles and responsibilities tab in the NBS toolkit (NBS, 2015)

- 4. Tasks. This tab refers to the responsibilities of the roles previously identified, shown in Figure 3.18. Although the tasks defined cover the construction process, they do not do so from a BIM point of view. There are many related BIM tasks that are not mentioned in the toolkit. Those tasks are related to collaboration, BIM tasks and the AIM.

search tasks...

Ref	Task	Responsibility
2.010	Comment on Concept Design proposals.	Client
2.020	Sign-off Concept Design and Final Project Brief.	Client
2.030	Comment on Project Strategies as requested.	Client
2.040	Monitor progress of Concept Design.	Project lead
2.050	Prepare and issue Final Project Brief.	Project lead
2.060	Review Handover Strategy and Risk Assessments with project team.	Project lead
2.070	Review and update Project Execution Plan.	Project lead
2.080	Review Project Programme and agree any changes with project team.	Project lead
2.090	Comment on stage Design Programme and Cost Information.	Project lead
2.100	Monitor and review progress and performance of project team.	Project lead
2.110	Comment on design proposals and Project Strategies from design team members.	Lead designer
2.120	Prepare Sustainability Strategy.	Lead designer

Figure 3.17: Responsibilities linked to stage 2, the NBS toolkit (NBS, 2015)

- 5. Deliverables. The last tab in the NBS toolkit is the deliverables tab. In this tab, the client chooses from a large unified classification list saved on the system, which hold specifications for a large number of construction items and products. In addition to the LOD and LOI of that item, as seen in Figure 3.19.

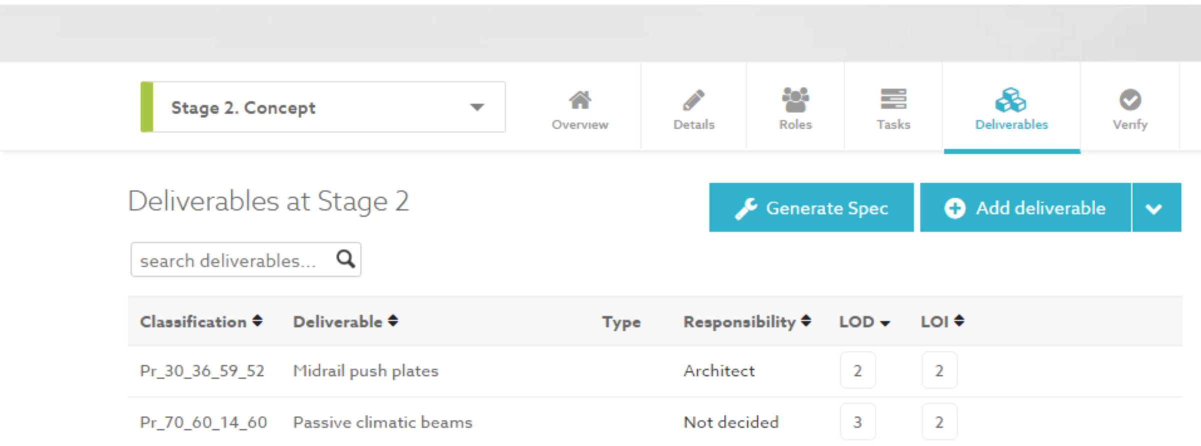


Figure 3.18: The deliverables tab in the NBS toolkit (NBS, 2015)

After discussing the NBS toolkit and its different options the client has to complete in detail, it is clear that the toolkit is more of a construction project toolkit and not BIM related. There are no references to any of the BIM processes and procedures such as providing and managing CDE, COBie requirements, collaboration requirements, copyright issues, the AIM requirements, and so on.

This will be the information that the bidders and then project team subsequently build on through the digital plan of work. In other words, the main, if not the only job the NBS toolkit has to support is identifying "some" information related to the project stages. Table 3.4 shows the relation between the EIR Needs as presented in PAS 1192-2 and the needs the toolkit covers.

Table 3.4: NBS Toolkit coverage of EIR Needs as presented in PAS1192-2 (2013)

EIR NEEDS (PAS 1192)	NBS Toolkit coverage of Needs
Software platform	N/A
Data exchange format	N/A
Coordinates	N/A
Level of detail	Yes
Training	N/A
Standards	N/A
Roles and responsibilities	Partially covered
Planning the work and data segregation	N/A
Security	N/A

EIR NEEDS (PAS 1192)	NBS Toolkit coverage of Needs
Coordination and clash detection process	N/A
Collaboration process	N/A
Health and safety and construction design management	N/A
Systems performance	N/A
Compliance plan	N/A
Delivery strategy for asset information	N/A
Data drops and project deliverables	Partially covered
Client’s strategic purpose	N/A
Defined BIM/project deliverables	N/A
BIM-specific competence assessment	N/A

There is still a need for a more comprehensive EIR framework that is able to cover ALL “Needs” of the EIR and the “Requirements” that satisfy them, which will be the outcome of the OntEIR framework that will be discussed in Chapter 4.

Another study conducted on EIR was by Hafeez *et al.,* (2016) which presented recommendations for the development of EIR in the Qatar construction industry, presented in Table 3.5.

Table 3.5: Recommendations for Developing EIR in the Qatar Construction Industry (Hafeez et al., 2016)

Technical items	Commercial items	Management items
- Software tools: should not be mandated except those for collaboration, information exchange, facility management requirement - Data exchange format: define formats to deliver data at data drops - Coordinates: adopt common coordinate system for special coordination - Level of detail/ level of development: levels of details to be aligned with stages - Training: specify training requirements for bidders and from bidders	- Data drops and project deliverables: communicate the contents of data drops and their alignment with work stages - Client strategic purpose: communicate the purpose of the client's information requirements and deliverables - Defined BIM/project deliverables: define BIM deliverables aligned with project work stages - BIM specific competence assessment: communicate the competence criteria for bidders as part of bid submission	- Standards: define BIM standards incorporated into information requirements - Roles and responsibilities: allocate roles associated with the management model and project information - Planning work ad data segregation: set out requirements for the bidders proposal's for the management of the modelling process - Security: communicate client specific security measures for data security - Coordination and clash detection process: define coordination process along with quality control requirements - Collaboration process; define how, where, and when information will be shared - Health and safety and construction design management: define how BIM based working will support H&S and construction design management - System performance: communicate employer's requirements for IT and systems - Compliance plan: communicate requirements for model integrity and other data sources - Delivery strategy for asset information: define information exchange standard for asset information and obtain proposals with regards to asset information delivery to employer facility management environment

Additionally, the National Building Specifications (NBS) has also issued a set of Plain Language Questions (PLQs) that are intended for the client to answer at the end of each phase of the construction process to decide whether to proceed to the next phase or not. PLQs were initially set out by PAS 1192-2 (bsi, 2013) and support the EIR in defining requirements for the phases of the process. The initial PLQ should respond to the aims and objectives of each phase of the construction process; answering them should demonstrate how successful the collaboration process between the team members was in achieving the aims of each phase, and how pleased the client was with the process and information provided. The PLQs should be able to cover the needs of the EIR as introduced by PAS 1192-2. Although the previous questions are written in plain language and are easy to interpret and answer, they have not been able to fully capture the client's requirements. Clearly there are many other important aspects that should be covered in order for the client to be able to deliver a complete and comprehensive requirements document for the construction team. According to PAS 1192-

2:2013 (bsi, 2013), the EIR should include information regarding 3 main aspects: Information Management, Commercial Management, and Competence Assessment, in addition to employer's requirements and the vision the client has for the project. In a survey conducted by Ashworth et al. (2017), it was found that clients felts like "walking through a minefield" trying to "understand all the BIM standards/guidance" when preparing their EIR. And when asked about the BIM task group Level2 websites, they indicated they were overwhelmed by the sheer volume of information and do not know where to start when they need to prepare an EIR.

Other studies also discussed the importance of a proper EIR in the project, and how it could actually prevent accidents and loss in lives, such as the Hackitt report (Hackitt, 2018). The report was published by the State of Housing, Communities in the UK Government following the disaster if the Grenfell Tower fire in 2017, that left 71 people dead and hundreds homeless (Hoar, 2018). The aim of the report is to explore regulatory bodies and the construction industry with regards to resident safety in high rise.

The main finding from the report is that "*the current system of building regulations and fire safety is not fit for purpose and that a culture change is required to support the delivery of buildings that are safe, both now and in the future.*" (Hackitt, 2018).

And specifically in the areas of:

- Roles and responsibilities: where the report that in current practices, roles and responsibilities of those procuring, designing, constructing and maintaining buildings are unclear
- The package of regulations and guidance (in the form of Approved Documents) can be ambiguous and inconsistent;
- The processes that drive compliance with building safety requirements are weak and complex with poor record keeping and change control in too many cases;
- Competence across the system is patchy;
- The product testing, labelling and marketing regime is opaque and insufficient; and
- The voices of residents often go unheard, even when safety issues are identified.

The report goes on in identifying a new regulatory framework that addresses these weaknesses, while focusing on creating and maintaining safe buildings (Hackitt, 2018).

According to the report (Hackitt, 2018), the framework should be able to:

- Strengthen regulatory oversight to create both positive incentives to comply with building safety requirements and to effectively deter noncompliance.
- It must clarify roles and responsibilities.
- It must raise and assure competence levels, as well as improving the quality and performance of construction products.
- Residents must feel safe and be safe, and must be listened to when concerns about building safety are raised.

All the issues mentioned as concerns in the report should have already been addressed clearly in an EIR before the beginning of a project. Clear roles and responsibilities, health and safety requirements, regulations and standards and competence assessment are all needs that should have already been defined in the EIR (bsi, 2013). But with current practices in the EIR, those issues are still not clear.

3.6 Chapter Summary

Chapters 2 and 3 discussed the importance of a clear and comprehensive EIR, and the need for an EIR framework. Previous attempts in designing a requirements framework, and related studies have been discussed in Chapter 3, where the various, increasing research efforts in the field of requirements in the construction industry were explained.

From the above it can be seen that the formalisation of the client's requirements will assist in improving the construction outcome (Patacas *et al.*, 2016), which resulted in the acknowledgment of many authors of the usefulness of BIM to support the formalization of the requirements definition in order to improve their management process (Patacas *et al.*, 2016; Arayici, Ahmed and Aouad, 2006; Kiviniemi and Fischer, 2005; Teicholz, 2013; Love *et al.*, 2014).

Despite the efforts made in this field, there is still a lack of clarity regarding the definition of the client's requirements and limited engagement of the client in the requirements definition process (Yu *et al.*, 2010). (Parsanezhad, Tarandi and Lund, 2016) suggest that in order to use

BIM to the greatest advantage, there should be some kind of a formalising approach for the requirements definition for all the stakeholders involved.

The gaps identified regarding the current practices in the field of EIR include:

- Lack of clarity in defining the EIR for the project; there is a need for a framework that will be able to address all types of clients being private or public, developers or owners, and experienced or non-experienced clients.
- The issues that should be covered by the developed EIR framework should be able to cover all the aspects of the construction project to ensure the delivery of:
    - A successful project with minimum waste and overruns in time and cost.
    - A complete Asset Information Model (AIM) that will obtain all the information needed to manage the asset throughout its entire lifecycle.
- The EIR framework should be able to define clearly the roles and responsibilities of the whole project team, including the BIM team and the construction players.
- The EIR framework should allow a clear identification of all the deliverables of each stage of the construction project, including everything that has to do with the digital side.
- Legal and copyright issues should be dealt with clearly, and effectively to mitigate any possible risks of disruption of the process, which will result in unwanted delays.

Although the work on the previous studies have significantly advanced the state of the art, the gaps previously identified have not been completely bridged. It is clear that some developments are still needed to exploit the full potential of BIM.

The aim of this study is to develop a framework that is able to cover all the aspects of the EIR, completely, correctly and consistently. The OntEIR framework introduced by this research will capture, analyse, and deliver EIR in a way that will improve the quality if the delivered construction projects, and reduce the overrun in time and cost.

Chapter 4 Research Methodology

4.1 Introduction

The present research investigates how the definition of employer information requirements for BIM projects can be enhanced or improved. This aims at helping in the reduction of cost and time. By defining complete and proper requirements from the beginning will result in less waste, and the reduction of lead time, in addition to increasing performance and productivity, as well as achieving high quality of built facilities.

The literature review on defining employer requirements and employer information requirements shed the light on research gaps, highlighted in Section 1.4, which was the basis for the formulation of the aim and objectives of this research (Section 1.5).

For a study to be conducted and the aim and objectives realised, a systematic research approach and its underlying activities were designed, which were based on scientific research techniques.

This chapter discusses how the research was designed and conducted. It is divided into two parts. The first part is a literature review of research design and implementation. It reviews the research philosophy (approaches, paradigms, methodologies and strategies) and data collection methods. This review was done to facilitate the selection of the appropriate techniques and methods to achieve this research.

The second part, which starts from Section 4.2, presents the techniques that were used in this research, in order to achieve its aim and objectives. It discusses the chosen research approach, strategy, methodology and data collection methods; and it describes how the research was implemented.

4.2 Research Philosophy

Investigating the research problem using the available methodological techniques, is one of the main factors of the success of academic research (Fellows and Liu, 2015). The research methodology adopted include the principles, procedures and logical thought that have been used for the scientific enquiry of the research (Knight and Ruddock, 2009).

According to Saunders *et al.*, (2007), the research process is similar to an 'onion' in consisting of many layers, as can be seen in Figure 4.1. Where the consideration of the research methodology goes through a systematic process starting from the outer layer, peeling off into the core. The 'onion' process is adopted in this research, which will guide the review of the most suitable concepts and methodological approaches for the study.

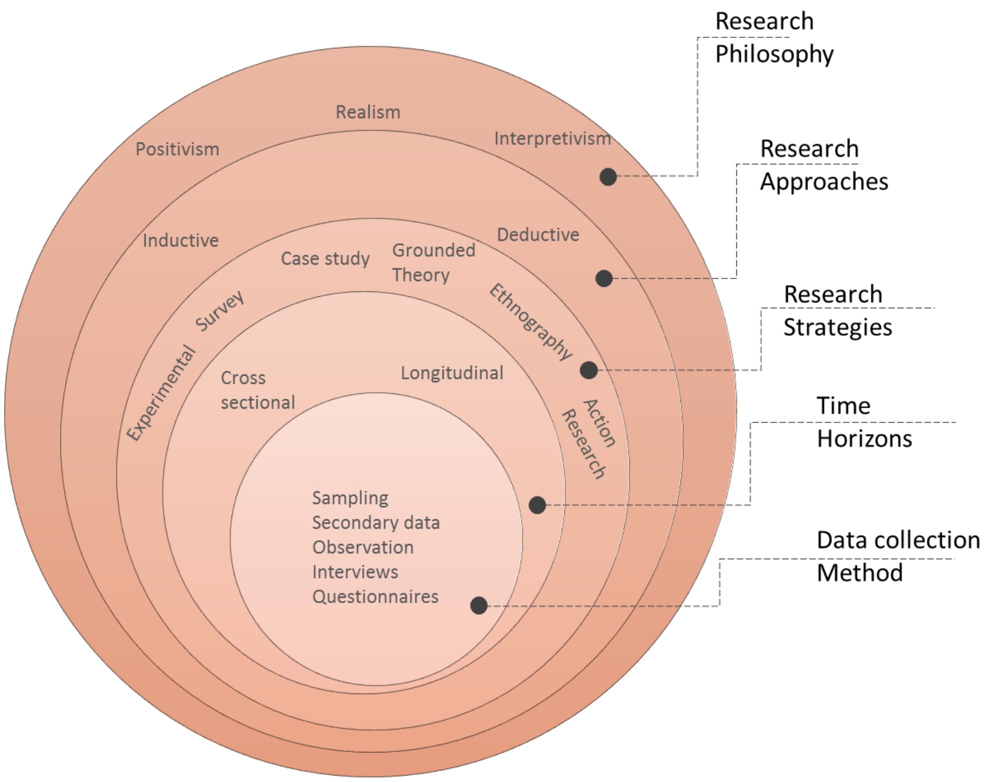


Figure 4.1: Research Onion (Saunders, Lewis and Thornhill, 2007)

For this study, the onion research layers are adopted, to guide its methodological approaches and techniques. Saunders and Tosey's (2012) classification and definition of layers is adopted and outlined as follows:

• **Research Philosophy:** discusses the researcher's world view on the ontological and epistemological foundations of the research.

• **Methodological choice:** discusses the different research approaches in relation to the use of quantitative method or methods, a qualitative method or methods, or a mixture of both.

• **Research Strategy:** highlights different qualitative and quantitative strategies in relation to the answering of the research questions. This includes: case study, survey, grounded theory, ethnography, archival research, narrative enquiry and experimental strategies.

• **Time horizon:** discusses and highlights the time horizon over which the research is undertaken.

• **Techniques and Procedures:** discusses techniques and procedures engaged for data collection and analysis.

In order to define a solution for a research problem, knowledge of that problem is required. In many cases this knowledge is not already available, and the researcher needs to investigate and construct it. According to Bryman (2015), a research philosophy is the set of beliefs concerning the nature of reality being investigated, which means it is in charge of justifying how the research will be conducted (Flick, 2015). The research philosophy chosen may differ from one study to another according to the type of knowledge being investigated and the research project (May, 2011).

The research philosophies or paradigms, as Lincoln *et al.,* (2011) refer to, introduced are the positivism and the Interpretivism. According to (Dainty, 2008), Positivism and Interpretivism are different paradigms that result in different kinds of knowledge.

Positivism and Interpretivism differ in their viewpoints and approaches when pursuing knowledge (Love, Holt and Li, 2002). Positivism on one hand pursues generalisation in order to establish principles to govern its object (Smyth and Morris, 2007). It involves using both the deductive and the inductive approach (Bryman, 2015).

On the other hand, Interpretivism appeared as a reaction to positivism. It studies the reaction and feeling that people have and interprets them (Bryman, 2015). Gray (2014) argues that “interpretive studies seek to explore people’s experiences and views and perspectives of these experiences”. Which makes it more of an inductive nature and often associated with qualitative approaches in the collection and analysis of data (Gray, 2014).

Realism philosophy tends to explain the logical assumption that the recognition of reality exists independently from the human mind (Saunders, Lewis and Thornhill, 2007). It poses questions like “what the presence of knowledge is” and “how our understanding of it is interlinked” (Saunders, Lewis and Thornhill, 2007).

No matter what research paradigm is used to generate knowledge, all research remains open to criticism (Knight and Turnbull, 2008).

4.2.1 Qualitative and Quantitative Research Methodologies

Research is a 'systematic, organised and planned investigatory or inquiry work, which can involve enquiry and learning with the aim to contribute to knowledge' (Fellows and Liu, 2015; Sekaran, 2007; Stevenson, 2010). Methodology is defined as "the plan of action"; the process and approach that governs the preference to certain techniques for the research (Crotty, 1998).

The categorisation of the research methodologies have been identified by Saunders and Tosey (2012) into three classifications: the Mono methods; which rely on one research method, either qualitative or quantitative, and the Multi methods and the mixed methods that encompass both.

4.2.1.1 Quantitative Research

According to Fellows and Liu (2008) "quantitative research approaches adopt a 'scientific method' in which initial study of theory and literature yields precise aims and objectives." These 'scientific methods' involve the collection of 'numerical data' that is analysed systematically to test the theory or the hypothesis. The investigation process is done through the study of the relationships between the fact collected, and how relate to theory and the set of defined variables (Robson, 2002; Fellows and Liu, 2015; Neuman, 2002).

Quantitative research is often used to describe empirical enquiry into phenomena through statistical or computational techniques (Denscombe, 2014). This methodology has been found most suitable to use in answering research questions of 'what', 'how much' and 'how many' (Fellows and Liu, 2015).

Rigidity, lack of context, inadequacy and inaccuracy of sampling techniques may, however, affect the reliability of findings (Denscombe, 2010). It is one of the suitable methodologies for this research, along with Qualitative Research, since studies have shown that qualitative research is an accepted approach in academia and in particular, for applied sciences (Robson, 2002; Fellows and Liu, 2015).

4.2.1.2 Qualitative Research

The second type of research methodologies is the qualitative research. Creswell (2013) argues that this type of research is based on objective views of a phenomenon. It is inclined towards measuring "how much" and includes using experiments, surveys amongst other methods to conduct findings, which can be expressed numerically. Qualitative research often involves the investigation of problems within the natural settings and environments. It is subjective, and aims at investigating social beliefs, opinion and the understanding of human problems (Robson, 2002; Fellows and Liu, 2015). Denscombe (2014) argues the ability of qualitative research to promote natural and spontaneous development of the enquiry. It is useful in answering research questions that relate to how and why (Fellows and Liu, 2008). Many studies have discussed the suitability of this method for studies that seek to enhance the understanding of a phenomenon, especially when this phenomenon is deeply entrenched in its context (Knight and Turnbull, 2008; Denscombe, 2014).

Qualitative research involves using research strategies such as case study, grounded theory and/or ethnography, and uses 'words' rather than 'numbers' to express findings, by using data collection methods such as interviews, observations and questionnaires (Robson, 2002; Gray, 2014; Bryman, 2015).

It is important to highlight that the previous methodologies discussed have all their limitations and disadvantages when used on their own, which resulted in the establishment of 'triangulated research' (mixed methods approach), to eliminate or at least reduce the disadvantages of each individual method (Robson, 2002; Fellows and Liu, 2015; Creswell, 2013; Gray, 2014; Gray *et al.*, 2007; Howard and Davis, 2002).

4.2.1.3 Triangulation (Multi- and Mixed Methods) Research

Triangulation is a research study approach, where two or more research study techniques are employed. Dainty (Dainty, 2008) discusses that "Qualitative and quantitative approaches may be employed to reduce or eliminate disadvantage of each individual approach, whilst gaining the advantages of each". Triangulation does not only refer to combining the qualitative and quantitative methods. It could also refer to the combination of several qualitative methods, such as conducting both individual interviews in addition to focus groups, which will help in both getting an overview of the problem in addition to a detailed discussion for a solution (Flick, 2009; Corbin and Strauss, 2008; Gibson and Brown, 2009; Fellows and Liu, 2015). Other reasons why triangulation is considered useful for these kinds of studies are because it helps for validation purposes or for obtaining more information on the same problem, such as by combining observations with interviews (Corbin and Strauss, 2008).

In this research, a triangulation method has been applied through the use of more than one qualitative method to gather and analyse information. Although observation and literature review analysis were conducted, there was still a gap in the understanding of some issues in the field. By using the triangulation method through conducting interviews, validation and understandability of the field was reached. As a result, expert judgment was sought on unclear issues and for the validation of the reached conclusions.

4.2.2 Research Approach

The two research approaches outlined in the onion are the deductive and inductive approaches:

4.2.2.1 Deductive Approach

In research, 'deduction' refers to reaching conclusions out of theory. The deductive approach is used to develop the hypothesis, then formulates the research approach to test it (Silverman, 2013). According to Wiles *et al.,* (2011), this approach is best suited to contexts where the research is concerned with examining whether the observed phenomena fit with expectation based upon previous research. The deductive approach is characterised as the development from general to particular: the general theory and knowledge base is first established and the specific knowledge gained from the research process is then tested against it (Kothari, 2004). (Bryman, 2015) describes the process of the deductive approach to start by defining a problem, and developing a hypothesis using existing theories. Then, testing of the hypothesis will take place using the suitable techniques. Analysis of the findings will be conducted, from which the outcome will confirm or reject it. And finally, the existing theory may be revised based on the results reached. Figure 4.2 illustrates the deduction process.

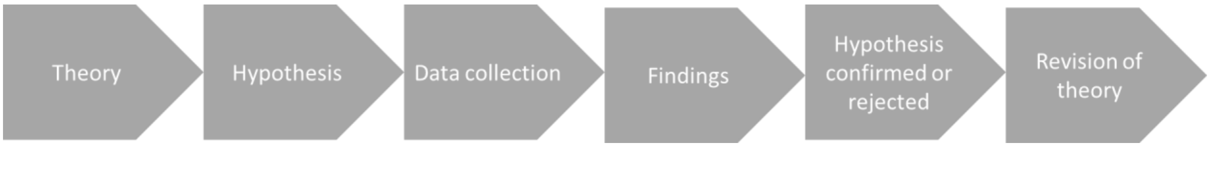


Figure 4.2: The deduction process (Bryman, 2015)

4.2.2.2 Inductive Approach

The inductive approach, on the other hand, is moving from the specific to the general (Bryman and Bell, 2015). According to Beiske (2002), in this approach the observations are the starting point for the researcher, and patterns are looked for in the data. In this approach, there is no framework that initially informs the data collection and the research focus can thus be formed after the data has been collected (Flick, 2015). According to Fellows and Liu (2015), the difference between deductive reasoning and inductive reasoning lies within the boundaries of knowledge. While deduction occurs within the boundaries of existing knowledge, induction extends the boundaries of current knowledge.

However, it is important to understand that the deductive process will usually entail some elements of induction; and the inductive process is likely to entail some modicum of deduction (Bryman, 2008). Thus, it is important to note that the two approaches can be combined and are not mutually exclusive (Gray, 2009).

4.2.3 Research Strategies:

This section outlines 'how' the researcher intends to carry out the research (Saunders, Lewis and Thornhill, 2007). The strategy can include a number of different approaches, such as experimental research, action research, case study research, interviews, surveys, and/or a systematic literature review.

4.2.3.1 Case Study

The case study strategy involves a detailed and extensive analysis of (a) case study/ies, where this case is interpreted very widely to include the study of the researcher (Robson, 2002; Bryman and Bell, 2015; Gibson and Brown, 2009). The case study approach is used to reach the relationship between a phenomenon and the context it is occurring in (Gray, 2014). This phenomenon may include programmes, events, activities and practices of individuals or groups of people, and could be studied using a variety of procedures (Knight and Ruddock, 2009). The implementation of a case study strategy according to (Yin, 2013), entails the investigation of a single instance or event with great detail; and focusing on the investigation of small number of cases rather than large number of cases (Fellows and Liu, 2015). This strategy is used when the researcher needs to 'understand' rather than quantify variables (Kumar, 2011). The strategies and methods for data collection depend mainly on the research questions, and on the time and resources available to conduct the research (Proverbs and Gameson, 2008).

Regarding the number of case studies to be investigated, the researcher must take into consideration the objectives of the study (Proverbs and Gameson, 2008). Yin (2003) identifies key areas to be considers when deciding the number of cases. A single case can be used if it represents a critical case to test the theory, or a longitudinal study, where the same case will be studied for a longer period of time.

4.2.3.2 Survey

Having a quantitative nature, surveys are research strategies used to collect data in order to understand patterns, and to explain the attitudes and behaviours of the subject. The data is often collected using structured questions in questionnaires, structured interviews, and structured observations (Robson, 2002; Bryman, 2015; Gray, 2014). Robson (2002) argues that "Surveys work best with standardized questions where it is possible to be confident that the questions mean the same thing to different respondents, a condition which is difficult to satisfy when the purpose is exploratory". Gray (2013) categorises surveys into two types: analytical and descriptive surveys. Analytical surveys are mainly uses the deductive research to emphasise the reliability of data and statistical control of variables. On the other hand, Gray argues that the descriptive survey uses the inductive approach employing open-ended questions to explore perspectives and may be quite ethnographic in character. Surveys are mainly employed to study customers' attitudes, opinions, and moods toward products and services provided (Gray, 2014).

4.2.4 Research Time Horizon

Saunders et al. (2007) define the time horizon to be: the time framework which within the project is intended for completion. In the research onion, two types of time horizons are defined: the cross sectional time horizon: where the research mainly considered a phenomenon and should be done at a certain point on time, and the longitudinal time horizon: in which the research is conducted over a long period of time (Robson, 2002; Saunders and Tosey, 2012). Saunders and Tosey (2012) argue mainly experiment, action theory, and grounded theory often use longitudinal time horizons, while surveys usually involve the use of cross-sectional time horizons.

4.2.5 Data Collection Techniques and Procedures

This section discusses the techniques that are used in the data collection. According to Kumar (2011), there are three main techniques used: observations, questionnaires and interviews. In addition to classifying surveys as an additional data collection technique, Naoum (2012) argues that the choice of the data collection technique used depends on the aims and strategy of the research.

4.2.5.1 Interviews

Interviews could be considered the most effective technique in qualitative research, due to the vast amount if data that could be collected in a short period of time (Bryman, 2015). Interviews are a good way to collect highly personalised data, where people express their feelings and understandings about things (Robson, 2002; Gray, 2014; Arksey and Knight, 1999). Interviews allow the interviewees to offer clarification to the questions asked, and to expand on their own responses, but at the same time, there is a high risk of bias from the interviewer (Denscombe, 2014).

According to Robson (2002), there are three main types of interviews: structured, unstructured, and semi-structured.

a- *Structured interviews*: in this type of interviews, there is a predefined scope, within which answers should remain. This why the interviewer would prepare the questions that would fit in this scope, and usually aim to answer research questions and objectives (Denscombe, 2014).

b- *Unstructured interviews*: during these interviews, there are no predefined questions, and questions are open ended and can take any order, which allow interviewees the flexibility to elaborate in an unrestrictive manner (Robson, 2002; Denscombe, 2014). However, the general concept and scope should be identified to prevent deviation.

c- *Semi-structured interviews*: this type of interviews combines features from structured and unstructured interviews, while questions are predefined to answer specific questions and inquiries of the interviewer, the interviewee is given more freedom to discuss further, and questions are both closed and open ended (Denscombe, 2014; Saunders, Lewis and Thornhill, 2007; Thomas, 2003).

4.2.5.2 Questionnaires

Using questionnaires is an effective data collection technique that would preserve the anonymity of the respondents, while producing results that are easy to compare and analyse (Denscombe, 2014). Maciaszek (2007) also argues the effectiveness of questionnaires in in gathering information from respondents where interviews are not possible, such as gathering information from respondents that are located in different places. Although he also argues that questionnaires are less effective than interviews in terms of lack of clarification regarding the questions or possible responses.

Questionnaires are a list of questions to which the subjects are required to answer (Kumar, 2011). It should be designed in a way that the respondents shall have a similar understanding of the requirements for the answers (Robson, 2002). To tackle to problem of clarity in the questions and the understanding of the respondents to them, Whitten et al. (2000) prefer using closed questions (e.g., multiple choice, rating, and ranking) over using open ended questions. Types of the closed ended questions were discussed by Whitten et al. (2000) as follows:

- Multiple choice questions: allows the respondent to choose one or more answers from a set of answers provided for each question, and sometimes they are allowed to add their comments;
- Rating questions: is when respondents give their opinion from given opinions to a certain statement, such as ‘strongly disagree’, ‘disagree’, ‘neutral’, ’agree’, and ‘strongly agree’;
- Ranking questions are another way to rank a statement or a question by using sequential numbers or percentage values, or the Likert-scale. Such ranking would usually have a scale from 1 to 5, where 1 is the lowest and 5 is the highest;

In addition to types of questions, there are different types of questionnaires that could be used according to factors argued by Saunders et al. (2007), Oppenheim (1994) and Robson(2002), which include: characteristics of respondents; extent to which specific people need to respond; extent to which responses should not be subject to distortion; sample size; type and number of question to be asked; time consideration; and cost. Types of questionnaires discussed include: self-administered, Interview-administered, internetmediated questionnaires, postal questionnaires, and delivery and collection questionnaires (Fellows and Liu, 2008).

Knight and Ruddock (2009) argue that each one of the previous types of questionnaires have their advantages and disadvantages.

4.2.5.3 Focus Groups

The aim of focus groups is to gather a group of people for the purpose of being interviewed on a specific issue, in the research inquiry (Robson, 2002; Bryman and Bell, 2015; Gray *et al.*, 2007).

Although the focus group technique has originally been used in market research, where consumers would test their thoughts and outlooks to a new product, focus groups have also been implemented in wider areas of study and research (Krueger and Casey, 2014; Robson, 2002; Gray *et al.*, 2007).

Robson (2002) argues that the use of focus groups could be more useful than one-to-one interviews because it allows the collection of data from several participants at the same time with avoiding the problems associated with the traditional interviewing techniques. Other advantages of focus groups also include significant reduction in cost in comparison to one-to-one interviews and a higher response rate (Gray, 2014).

Bryman (2015) suggests that a typical size of group could range between four and ten, while Litosseliti (2003), Krueger and Casey (2014), Kitzinger and Barbour (1998), all suggest that it could be as low as three.

4.3 Analysis

The next step after collecting the data is interpreting and analysing it, or in other words making sense of the data (Creswell, 2013). How the results are analysed depend of the research approach used to gather the data (Creswell, 2013).

Table 4.1 demonstrates the different analysis procedures of data depending on the different research approach used.

Table 4.1 Different Analysis Procedures

Data analysis and representation	Narrative	Phenomenology	Grounded Theory Study	Ethnography	Case Study
Data Managing	Create and organise files for data	Create and organise files for data	Create and organise files for data	Create and organise files for data	Create and organise files for data
Reading, memoing	Read through text, make margin notes form initial codes	Read through text, make margin notes, form initial codes	Read through text, make margin notes, form initial codes	Read through text, make margin notes, form initial codes	Read through text, make margin notes, form initial codes
Describing	Describe the story or objective set of experiences and place it in a chronology	Describe personal experiences through epoch Describe the essence of the phenomenon	Describe open coding categories	Describe the social setting, actors, events; draw picture of setting	Describe the case and its context
Classifying	Identify stories Locate epiphanies Identify contextual materials	Develop significant Statements. Group statements into meaning units	Select one open coding category for central phenomenon in process Engage in axial coding–causal condition, context, intervening conditions strategies, consequences	Analyse data for themes and patterned regularities	Use categorical aggregation to establish themes or patterns
Interpreting	Interpret the larger meaning of the story	Develop a textural description "What happened" Develop a structural description, "How" the phenomenon was experienced Develop the "essence"	Engage in selective coding and interrelate the categories to develop "story" or propositions Develop a conditional matrix	Interpret and make sense of the findings –how the culture "works"	Use direct interpretation Develop naturalistic generalizations
Representing, visualizing	Present narration focusing on processes, theories, and unique general features of the life	Present narration of the "essence" of the experience; in tables, figures, or discussion	Present a visual model or theory. Present propositions	Present narrative presentation augmented by tables, figures, and sketches	Present in-depth pictures of case (or cases) using narrative, tables, and figures

4.4 The Process of Research Design: Selection and Application of Methodology and Methods

The process of research design refers to "planning how the research will be conducted". (Gray, 2014; Gibson and Brown, 2009) specified the process in 4 steps:

- Defining the purpose of this research and the research topics;
- Selecting the techniques to be used for data collection; selection of methods and implementation techniques
- Selecting the research site and population
- Presenting the findings

4.4.1 Research Purpose and Selection of Methods

This research is designed to develop a framework and tool for defining better information requirements for BIM projects by achieving better understanding of client requirements and the BIM information delivery lifecycle, which was reached after identifying critical factors for the success of good requirements definition and elicitation, which will contribute to a successful BIM project (i.e., projects that meet the budget, cost, quality, information requirements and client requirements specified). To achieve that, the most appropriate research paradigm, strategy, methodology, approach and data collection methods were carefully selected, according to their complete review.

This study's purpose is to facilitate the understanding of the BIM information delivery cycle in terms of: the information involved and 'how', 'when' and 'why' this information is exchanged in addition to 'who' is involved in the process and 'what' is expected as the end result. This Increase in clarity and understanding will enable the client to benefit and take better advantage of the full benefits of BIM by completing the first and most important step, which is to define their EIR.

To achieve the aims of the present research, a series of iterative steps were conducted. Figure 4.3 illustrates the research phases to achieve one of its main results, which is the development of the OntEIR framework.

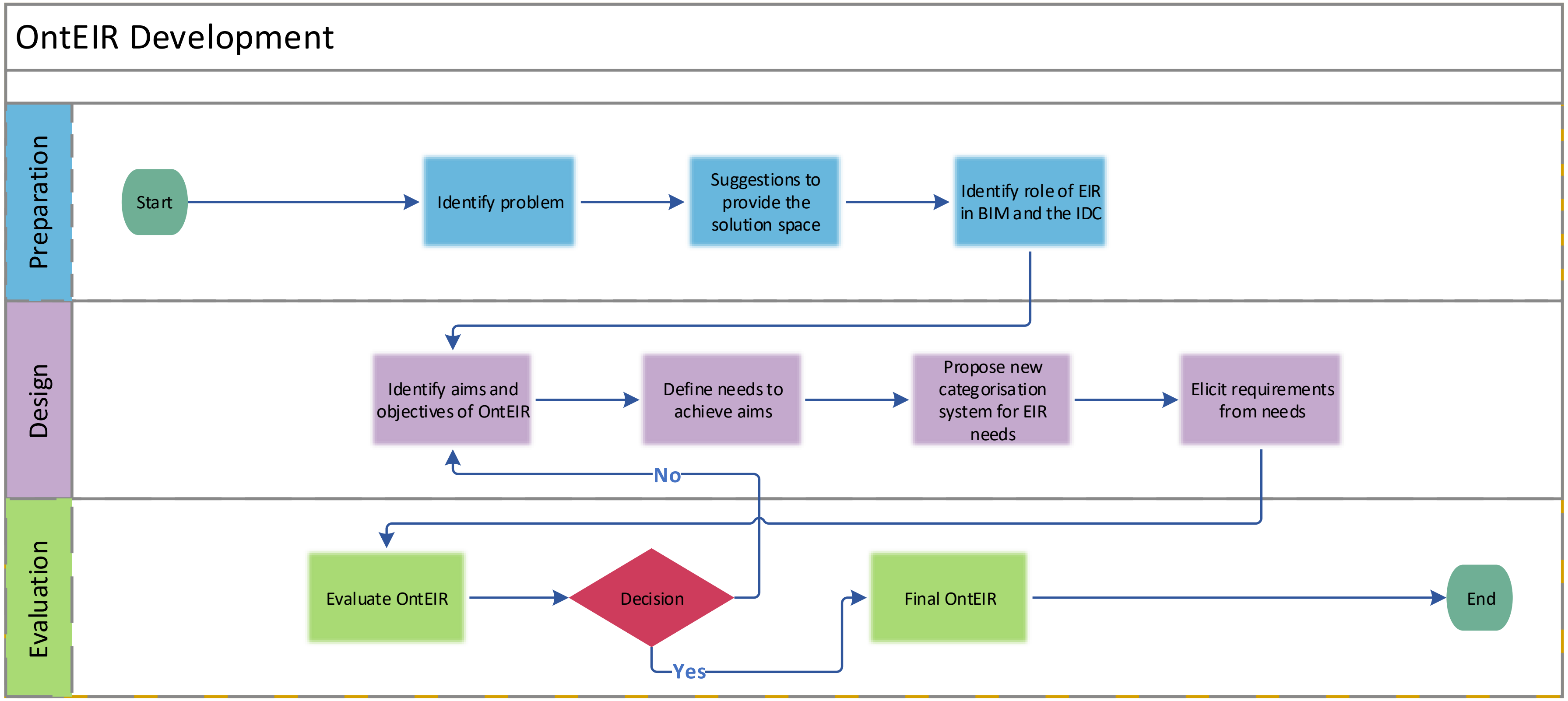


Figure 4.3: Iterative methodology for the development of the OntEIR framework

The methodological decisions associated with this research are controlled by various circumstances. These circumstances such as such as availability of data; access to the social set-up to be studied, i.e. construction projects to conduct case studies; availability and willingness of participants to participate in the study. These circumstances and limitations were the basis, on which the research was founded and constructed.

Another important influence was the nature and purpose of the research, which uses a combination of exploratory, descriptive and explanatory to understand the method for requirements elicitation, in order to define an innovative approach. According to Robson (2011), the selection methods are based on the information the researcher seeks out to obtain, their sources, and under what circumstances.

The stages in which this study went through could be defined as follows:

Exploratory stage: This is the initial stage of the study, which was necessary to obtain the knowledge and information regarding the realities behind client requirements, client requirements elicitation, and managing those requirements. This stage was also crucial for formulating questions for later stages of the study.

Descriptive stage: This stage followed the exploratory stage of the study, in which explicit details were reached regarding client requirements and employer information requirements in BIM, and their challenges and limitations. Both the exploratory stage and the descriptive stage were the basis on which the explanatory stage was founded.

Explanatory stage: In this next stage, findings from the previous two studies on EIR specifications were examined. Accordingly, the research design built on those findings which could be considered as the governing factors of the research design.

Consequently, both a qualitative and quantitative methodology were selected, due to the nature of the research, which requires a social setup in which the interaction of people and the construction environment was studied, in order to understand the current practices in defining EIR and client requirements.

Both the deductive and the inductive research approach were suitable to be used in this study. Deductive approach was used to develop the framework and tool, while the inductive was used to learn from its application.

Furthermore, it must be established that despite choosing the previous methodologies and approaches in conducting the research, a mixed method was applied to further increase the validity of the research.

For the research strategy of inquiry, interviews and questionnaires were the main sources of information. Questionnaire techniques were used to collect the quantitative data of the study, which are among the most widely used techniques associated with quantitative research (Denscombe, 2014). Inquiries were done in two iteration: The first iteration includes the use of surveying the opinion of a representative part of experienced practitioners in the first OntEIR framework Meta model. Iteration 1 was to validate the initial OntEIR framework, by conducting semi-structured interviews and distributing questionnaires on experienced stakeholders in BIM, feedback gathered from this first iteration was used as a source of information to update and develop the framework. The updated framework was the basis on which the online OntEIR tool was developed. In iteration 2 of the validation process, Emails and messages using LinkedIn were sent out to stakeholders in BIM, with both login information to the online tool and link to the online questionnaire. Results and findings of the two iterations of the validation process are detailed and explained in Chapters 6 and 7.

4.4.2 Research Design

Thomas (2003) describes research design as the master plan adopted upon identifying the appropriate approaches within the layers if research methodological research. Creswell at al. (2003) explains research design to be the general plan for successfully answering the research questions after the identification of the research philosophy, methods, strategies and techniques. As argued before, this study incorporates a sequential, exploratory, mixed methodological research strategy to provide deep understanding of the BIM Information Requirements and the EIRs. For that to happen, semi structured interviews and questionnaire surveys were used to address the research objectives as shown in Table 4.2.

Table 4.2: Chosen Strategies to Address Research Objectives

Strategy	Target audience	Research objective
Literature review		▪ Identify and categorise BIM Information requirements ▪ Identify gaps in knowledge in requirements specification ▪ Learn from previous studies ❖ Objectives: 1 & 2
Critical analysis of literature review		▪ Develop the initial OntEIR framework
Develop framework		
Validation of initial framework (iteration 1)	Domain experts with EIR experience (n=20)	▪ Critically evaluate OntEIR and identify any weaknesses and means for improvements. ❖ Objective 3
Update of framework and development of tool		▪ Using feedback obtained from iteration 1 of the validation process to update framework ▪ Develop the OntEIR tool according to the updated framework ❖ Objective 5
Validation of undated framework and tool (iteration 2)	Stakeholders with EIR experience (n=50)	Validate the final OntEIR framework ❖ Objective 5

4.4.2.1 Literature Review

Literature review is a used as way to educate the researcher about the researched topic, and previous studies in the area, for the researcher to be able to identify the research gaps and formulate the aims and objectives of the research, through illustration of major issues and refining the focus of the research (Gray, 2014).

Gray (2013) identifies the three main purposes for doing a literature review as:

a- "demonstrate the key theories, arguments and controversies in the field;
b- highlight the ways in which the research area has been investigated to date;
c- Identify inconsistencies and gaps in knowledge that are worthy of further investigation."

This research was able to achieve this by firstly identifying key words in the topic researched to find relevant literature in the area. Literature included: books, journal papers, conference papers, blogs, governmental publications and others. The keywords used to find literature could be divided into two parts: general keywords and specific keywords. The general keywords were generated within the general idea of the research which was "requirements specification and employer (client) requirements". Specific keyword on the other hand were more specialised in the topic but supported the general topic, such as "Information requirements in BIM", "classification of requirements", and "employer information requirements".

Due to the large amount of literature retrieved, the search had to be further refined to eliminate the publications that were not relevant to the research. Taking into consideration that the literature left with did not only focus on the requirements in the construction industry, but in other industries were requirements specification is well established, such as software engineering.

4.4.2.2 Learning from Other Industries

In the construction industry, researchers have generally agreed that lessons could be learned from similar experiences of other industries, such as Aerospace, Software Engineering, and Business especially when it comes to applying IT capability within construction. In fact, it has been noticed in the past two decades a growing interest in learning from other industries in to help in the development and improvement pf performance of the construction industry (JOENG and Sexton, 2004; Bresnen and Marshall, 2001; Fernie *et al.*, 2003).

Many reports have also prompted the construction industry to realise that the construction process has a lot of similarities and collaborations with other industries (Latham, 1994; Egan, 1998; Fairclough, 2002).

In this research, the experience in the area of requirements elicitation and categorisation was utilised. This included how requirements elicitation was applied in other industries such as software engineering. And how requirements categorisation was done in other industries too, such as business management and software engineering. In addition to requirements, the use and success of ontology was also explored in other industries, such as in aerospace and software engineering.

Learning from knowledge, experience and good practice in other industries helps exploring new ideas and saving time and efforts by avoiding mistakes and focusing on high-value-adding research.

4.4.2.3 Population and Sampling

Before the data collection started in this research, participants of the investigation were identified. Due to the nature of the study, the first thing the participants should share is to be part of the construction project stakeholders.

As discussed in Section 4.4.1, the validation process of the framework and tool will go through two iterations; this first is to validate the initial framework, and the second is to validate for the final framework and tool.

Two different types of participants were chosen for each iteration, to participate in the discussion and surveys. For the first iteration, participants were chosen based on their experience in working with BIM and EIRs. Experience in this stage is needed, because feedback collected at the end of iteration 1 is the basis on which the final OntEIR framework and tool are developed, so it is essential to have the correct feedback, from experts in the domain. For this validation process, major contracting companies with experience working on BIM projects were contacted via email or linked in, and asked to participate in the study, and meetings were scheduled for interviews and focus groups.

The second iteration did not require having extensive experience in EIR and BIM. During this iteration, the tool was validated in terms of usability, understandability and quality. Feedback from everyday users of the tool is wanted at this stage. It should measure if the tool is able to satisfy and be understandable for all types of users including experienced and inexperienced users. For this iteration, participants were chosen by either contacting major contracting companies via email, or through contacting less experienced stakeholders through linked in. For both iterations, participants were chosen to represent the construction industry in the UK. They were selected from all parts of the UK, and had different experiences in different disciplines and in different types of projects.

4.4.2.4 Ethical Considerations of the Research

As being a very important factor in protecting the integrity of the research, ethical issues such as the dignity, privacy and confidentiality of the participants were considered highly important.

This research was designed and conducted according to the ethical requirements for the conduct of post-graduate research in the University of the West of England (UWE), Bristol.

The ethical form was submitted for approval by the Faculty of Environment and Technology (FET) ethics committee, before the collection of data began.

Before the start of data collection, it is important to consider the ethical issues that ensure the integrity and confidentiality of the research. Before the validation process started, and “Application Form for Ethical Review of Research Involving Human Participants” approved by the UWE’s Research Ethics Committee, according to the UWE policies and procedures regarding research ethics. The Ethics Form covered the following issues:

- The aims and objectives of the research
- Research and evaluation methodologies to be used
- Sample size and the recruitment process
- Consent and withdrawal procedures
- Confidentiality and anonymity of the participants
- Risk and risk management – risks faced by participants.
- Risk and risk management – potential risks to researchers.

- Publication and dissemination of research results.

4.4.3 Data Inquiry Process and Methods

4.4.3.1 Semi-structured Interviews

Interviews were conducted as one of the data collection methods for this study. Individuals were selected for the first iteration of the validation process that was conducted with the initial OntEIR framework. This was done with BIM experts in the industry. Participants were selected to have experience in BIM and EIR, to discuss the requirements reached in the initial framework and gather feedback for update. In total 20 interviews were conducted, in which the issues of requirements categorisation of the framework were discussed in addition to the elicitation of the information requirements and the quality of data they provide. Participants included project managers, BIM manager, Academics in BIM, building service advisors, BIM leaders, facilities managers, Architectural technologist and Revit technicians. The selection process was done through contacting major contracting companies in the UK industry that have experience with working on BIM projects through emails or linked in. The reason that conducting interviews was essential in the first iteration of the validation process, and before the questionnaires, is because this iteration was to validate the ontology framework, it was important for the participants to understand the framework and the different components of it for them to be able to validate the framework itself. A possible limitation in this case could be questionnaire bias, however steps were taken to encourage participants to be critical as possible when filling in the questionnaires, and the resultant responses showcased a range of critical suggestions for improvements (as will be seen in Section6,4) illustrating that any bias present was minimised.

4.4.3.2 Focus Groups

Focus groups were conducted with domain experts working in real life companies with real life projects. Participants were selected based on their experience and opinions on the information requirements needed during the BIM project and in the AIM. Two focus groups were conducted in total, and feedback from them fed into the development of the final OntEIR framework and tool.

The procedure of the focus group started with thanking the participants for attending and introduced the purpose of this discussion. The participants then introduced themselves and their expertise and their roles within the organisation. The researcher then presented a power-point presentation of the initial OntEIR framework including the categorisation system used and the elicitation method, with an overview of the requirements reached. The presentation lasted half an hour. A discussion was then conducted with the group in which the researcher performed the role of the facilitator and recorded the discussions per handwritten notes.

In both cases the discussions lasted 3 to 4 hours. At the end of the discussions, the facilitator summarised the points of the discussion and the feedback reached. Participants would add comments and clarification. Finally, the participants were thanked for their participation and input.

The first focus group meeting was held at AIRBUS in Filton, Bristol, in which 9 participants from the UK, France and Germany participated in the focus group discussion.

The second focus group meeting was held at Kier Construction Group in Gloucester. 3 participants attended the discussion.

Both groups were highly valuable in the feedback and input used to update and develop the OntEIR tool. Details of these groups and discussion can be found in Section 6.4 of this thesis.

4.4.3.3 Questionnaire

Questionnaires were designed and sent out in two iterations of the evaluation process, to evaluate the OntEIR framework and tool. In the first iteration it was sent to domain experts in BIM and EIR, who have key roles and understanding of the information requirements needed from the BIM project. In the second iteration questionnaires were sent to two types of participants; both experienced and inexperienced to evaluate the usability and understandability of the tool and the quality of the produced EIR. In the first iteration of the evaluation process, questionnaires were distributed after conducting interviews with the subjects. The questionnaire had 26 questions which included both scale questions and open-ended questions. Questions discussed the framework in detail, the categorisation of the requirements in the framework, and the elicited requirements. it was important to have experienced stakeholders participate in this iteration, to reach results crucial for the update of the framework and the development of the tool. For the second iteration of the evaluation process, questionnaires had 13 questions and were distributed on line via email and LinkedIn along with the link and log in details for the tool. This questionnaire discussed the usability of the tool and quality of requirements reached as the end product. For this iteration, 50% of the participants were experienced BIM experts or users, and the other 50% had only little experience with EIRs or BIM.

4.4.3.4 Data Analysis

As indicated in Section 4.4.3.3, five-point Likert scale was adopted to design the questionnaires for DSS validating survey. In which, (1) represents "Strongly Disagree", (2) represents "Disagree", (3) represents "Neither Agree nor Disagree", (4) represents "Agree", and (5) represents "Strongly Agree". Therefore, adopting technical method to analyse collected data were also taken into consideration.

For analysing the data collected for the tool validation, first of all descriptive statistics was used to describe and present the data collected from the questionnaire, which includes describing the frequencies of respondents and representing them with simple graphic analysis.

Also, the T-test was adopted as analysis method, due to its popularity in analysing Likert scale questions. In fact, Boone and Boone (2012) and De Winter *et al.,*(2010) suggest that T-test are the most appropriate in analysing interval scale items. T-test can also be used to test the significance difference if more than one group were involved in the study (Qvortrup, 2015). For this study, three groups of participants were categorised based on their experience in BIM and EIR, the T-test was used to detect any significance in their answers, with the result less than 0.05 being significant.

The T-test formula used was (Ezugwu *et al.*, 2016):

- $T\text{-test} = \frac{\overline{X_1} - \overline{X_2}}{S_p\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}}$

- Where:

- $\overline{X_1}$: Means of very experienced respondents.

- $\overline{X_2}$: Means of inexperienced respondents.

- n_1: Number of experienced respondents.

- n_2: Number of inexperienced respondents.

- S_p: The Pooled Standard Deviation of the combination of experienced and inexperienced.

- $S_p = \frac{(n_1-1)S_1^2+(n_2-1)S_2^2}{n_1+n_2-2}$

- Where

- S_1^2: Standard deviation of experienced respondents.

- S_2^2: Standard deviation of inexperienced respondents.

- In this study, both descriptive statistics and T-test were conducted through the SPSS software platform.

4.4.4 Triangulation of Data Validation

Triangulation refers to the approach in which two or more research techniques are employed. Dainty (2008) describes triangulation as an approach where qualitative and quantitative approached may be used to eliminate the disadvantage of each individual approach whilst gaining the advantages of each. Triangulation could also be a combination of several qualitative methods, as for example the use of both focus groups and individual interviews (Corbin and Strauss, 2008; Gray, 2014; Gibson and Brown, 2009; Flick, 2009).

In this research, triangulation of data techniques was used in the evaluation of the study: questionnaires which help questions both in the qualitative and quantitative nature, interviews, and focus groups were all used in the validation and evaluation in both the framework and tool and a case study for the final evaluation of the tool.

4.5 Chapter Summary

For any research to be successful and be able to achieve its aim and objectives, important considerations should be made to the methodology adopted. This refers to the principles, procedures, processes, and logic of thought of the investigation taking place in the study.

This chapter presented all the philosophical views in general, and then the methodology used in this study in particular. The proposed methodology for this study is based on a:

- Pragmatic philosophical view;
- Sequential exploratory mixed methodological research design.

The research consists on both a qualitative and quantitative phase, where both interviews and surveys were used to solicit expert opinion on the validation and update of the framework.

The next chapter will represent the actual steps and process this study went through to produce the initial OntEIR framework.

Chapter 5 Development of the OntEIR Framework

This chapter will discuss the OntEIR framework in detail, and how the initial framework was developed, and the underlying concepts used. It starts with discussing the need for an EIR framework, and what makes it different and more successful in the construction industry than other available requirements' frameworks.

Section 5.2 explores the methodology used to develop the OntEIR framework, and the steps that were required to reach the final OntEIR framework. It will also introduce the categorisation system of static and dynamic requirements used in the OntEIR framework that aims at increasing the understandability and usability of the framework. This section will also look in detail into issues that affect the BIM information delivery lifecycle and EIRs. It will also introduce the categorisation system used in OntEIR and the high-level needs for the OntEIR framework.

Section 5.3 will discuss the use of ontology and modelling based on the standardised Ontology Web Language (OWL) with the leading open-source ontology editor tool Protégé in developing the OntEIR framework; its final form being presented in Section 5.4

5.1 The Need for the OntEIR Framework

The literature review has shown that there is a strong need for a holistic and comprehensive EIR framework, that is clear and user friendly for all types of clients as concluded in Section 3.6. It also discussed previous work related to this topic in Section 3.5, and the gaps and challenges they face in bridging the existing gap between the client and the construction and BIM team in delivering an asset at reduced costs and in less time, in addition to being manageable during its whole lifecycle.

Problems facing the current EIR practices and frameworks are associated with clarity and understandability and in being complete and comprehensive to all the requirements and needs essential for producing a complete EIR. For example, the NBS toolkit (NBS, 2015), and although being successful in covering the Unified Classification system (UniClass), does not cover the needs and requirements to produce an EIR. There is still an obvious lack in covering the lifecycle requirements which include the project and asset requirements. In addition to more general requirements such as software to be used, legal issues and ownerships. Current practices are not sufficient to produce an MIDP and a BEP, which are essential aims of producing an EIR.

There is still a need for a framework that is available to cover all the needs necessary to produce a comprehensive EIR. This framework should be clear and understandable for all types of clients regardless to their level of experience in BIM projects and EIR.

OntEIR is presented as an answer to the challenges facing the current practices in EIR. OntEIR enables the production and development of a clear and complete EIR that covers all aspects, needs and lifecycle of the construction process.

The OntEIR framework will be the basis on which a standardised EIR document is produced. It will benefit all types of clients: public and private, experience and non-experienced, and for owners and developers. The success of OntEIR emerges from the fact that it considers all issues that are essential for the delivery of a full and comprehensive EIR. Which will lead to the definition of better-quality requirements. The main issues considered in OntEIR are:

- Ensure that a multi-disciplinary team is appointed, which is suitable for the project, and have all their roles and responsibilities clearly defined.
- Ensure that the project requirements and asset requirements are suitable for the purpose of the building and will allow proper management during its lifecycle.
- Ensure that the level of definition and the level of information of the model, is aligned with the project stage and the project purpose.
- Define the requirements of the project stages which are aligned with the COBie data drops.
- Manage and maintain over time the CDE
- The full development of the AIM upon completion and handover.

The aims and objectives of the OntEIR framework are:

- Create a comprehensive and clear EIR on which a BEP could be built.
- Create a strong basis on which a complete MIDP could be created. OntEIR manages to define all the requirements needed to develop a compete MIDP.

- Cover completely and comprehensively all the requirements linked to the following needs:

  Roles and responsibilities, standards, ownership of the model, HSE CDM compliance plan, data security, software platforms, coordinates, coordination and clash detection, Asset Information Model (AIM) delivery strategy, stages, data drops, CDM requirements, Project requirements, Asset Information Requirements (AIR), as well as Level of definition (LOD) and level of information (LOI).
- Decompose the previously mentioned needs and breaking them down until reaching the end leaf requirements that need to be met to satisfy those needs.
- Develop a categorisation system for these requirements that makes sense to all stakeholders and is easy to track and define.

Those aims and objectives were the steering wheel that guided the development of the OntEIR framework.

5.2 The Development of the OntEIR Framework

The development of OntEIR was carried out in a series of iterative steps, to reach the final OntEIR framework. The next section will examine the process which was followed in developing the framework, starting from the initial idea until reaching the final version.

5.2.1 OntEIR Development Process

The development of the OntEIR framework went through many stages before reaching the final form, which was evaluated and presented as the final OntEIR. The OntEIR framework started from an idea based on literature review that there is a strong need for an EIR framework that will enable in assisting all types of client in creating a complete and consistent EIR. As discussed in Section (3.5), there is a lack of understandability between clients when it comes to what an EIR should include and how this information is presented and organised.

For the OntEIR Framework to be developed, first two important issues have to be resolved, that will be discussed in full in the coming sections, those two issues are:

1- Understanding the BIM lifecycle, and what information should be delivered when;
2- Reaching a new kind of categorisation that will facilitate the understanding of the requirements and how they are used.

5.2.1.1 The BIM Information Delivery Lifecycle

PAS 1192-2 (bsi, 2013) explained the BIM Information Delivery Lifecycle (BIM IDL) with the image in Figure 5.1.

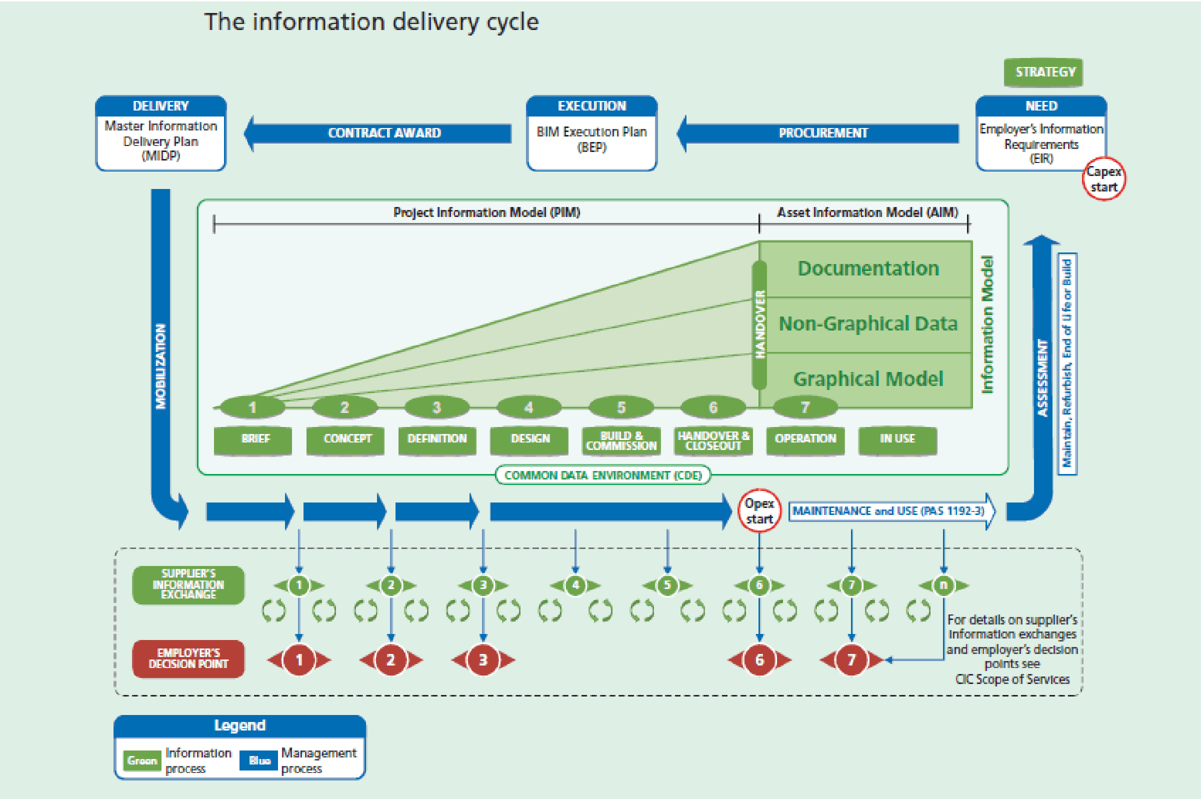


Figure 5.1: BIM Information Delivery Lifecycle (IDL) (PAS 1192-2) reused with permission from © BSI

Figure 5.1 shows how the BIM IDL starts with the definition of the EIR, which is the base of the procurement process, and upon which the supplier will present the BIM Execution Plan (BEP) and the Master Information Delivery Plan (MIDP). Those documents are the main documents that manage and plan the whole construction process from beginning to end and even until end of life for the asset. The EIR should hold all the necessary information that will allow the development of the BEP and the MIDP, and all the necessary information for the storage and exchange of information.

During the construction process, and from the initiation (Stage 1) until handover (Stage 6), the Project Information Model (PIM) is being developed, until reaching its full maturity with all the information needed to manage and maintain the asset, until its end of life, which is called the Asset Information Model (AIM), which should contain information in a graphical data, no graphical data, and a documented mode.

During the 7 stages of the project lifecycle, data drops occur, in which the supplier delivers information to the client according to EIR presented to the supplier before the beginning of the work.

From the BIM IDL presented in Figure 5.1, it is seen that there are four main layers that make up the cycle. These layers are presented in Figure 5.2.

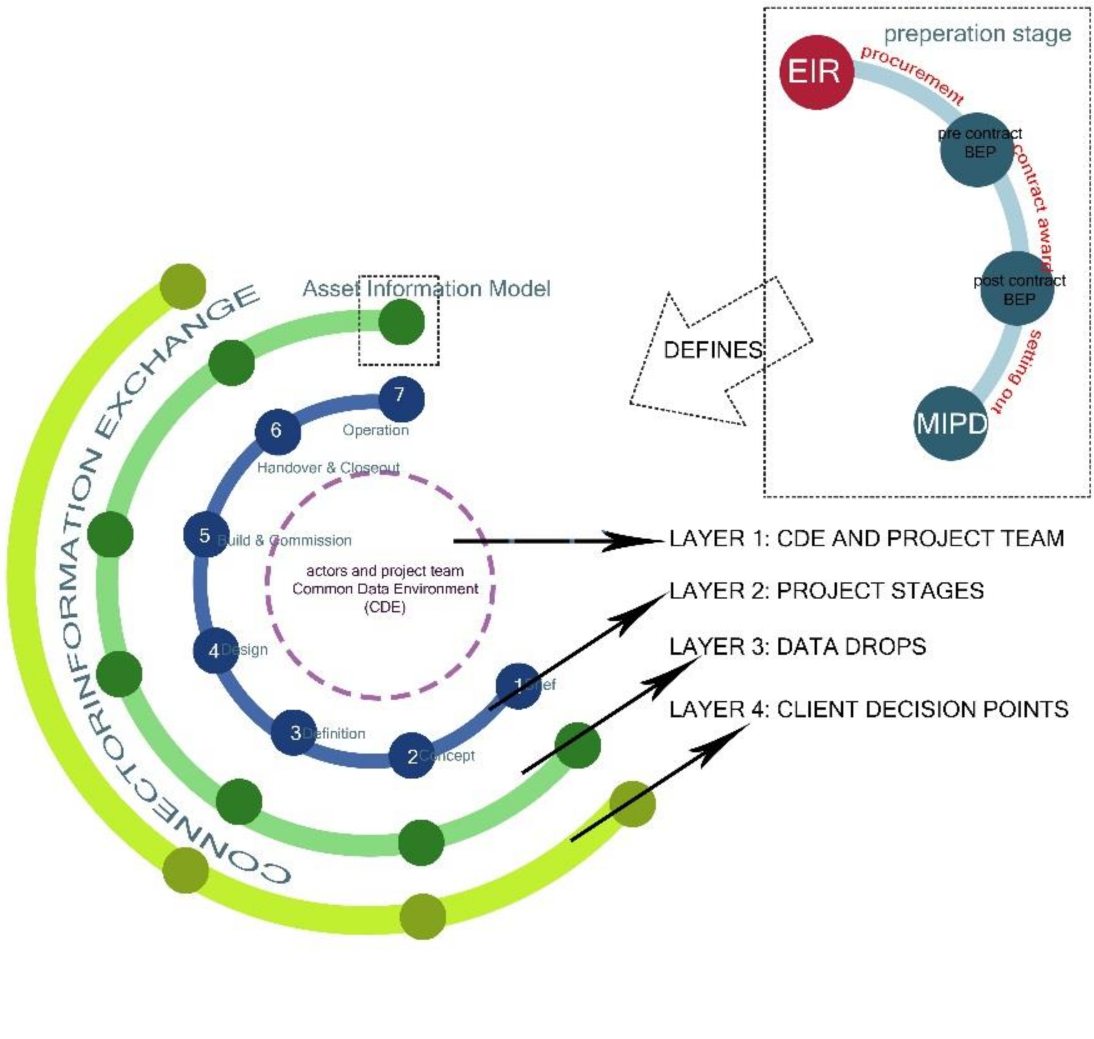


Figure 5.2: Layers that make up the BIM Information Delivery Life Cycle

The four layers are:

1- The Common Data Environment (CDE) and the roles and responsibilities of the all the team members of the project, including the client;

2- The project stages in terms of project requirement for each stage, the AIR for each stage, the maturity level of each stage defined by the LOD and LOI of the deliverables;
3- Data Drops: which are the deliverables that should be presented to the client at the end of each stage, which include the requirements defined by the client in the EIR, at the end of each data drop the PIM model develops, until reaching a fully mature AIM model, in the final stage “Hand over”;
4- The client decision points are connected to the data drops, in which the client decides to progress to the second stage or not. And the information exchange requirements which are an important part of the delivery cycle, because it guides the information exchanged between the different team players and the information exchanged with the client as well.

When examining the BIM IDL Layers, illustrated in Figure 5.3 it can be noticed that there are two main components of the IDL, the base on which other information rely on, such standards, guidance, strategy, definitions, CDE, roles and responsibilities, and information exchange strategies. The other type of information is the information that ‘flows’ between the different stages and between the stages and the CDE, it is the information that is responsible of the development and maturity of the PIM, and the development of the AIM at the end. Figure 5.3 illustrates the overlap between the BIM IDL layers and the two types of information.

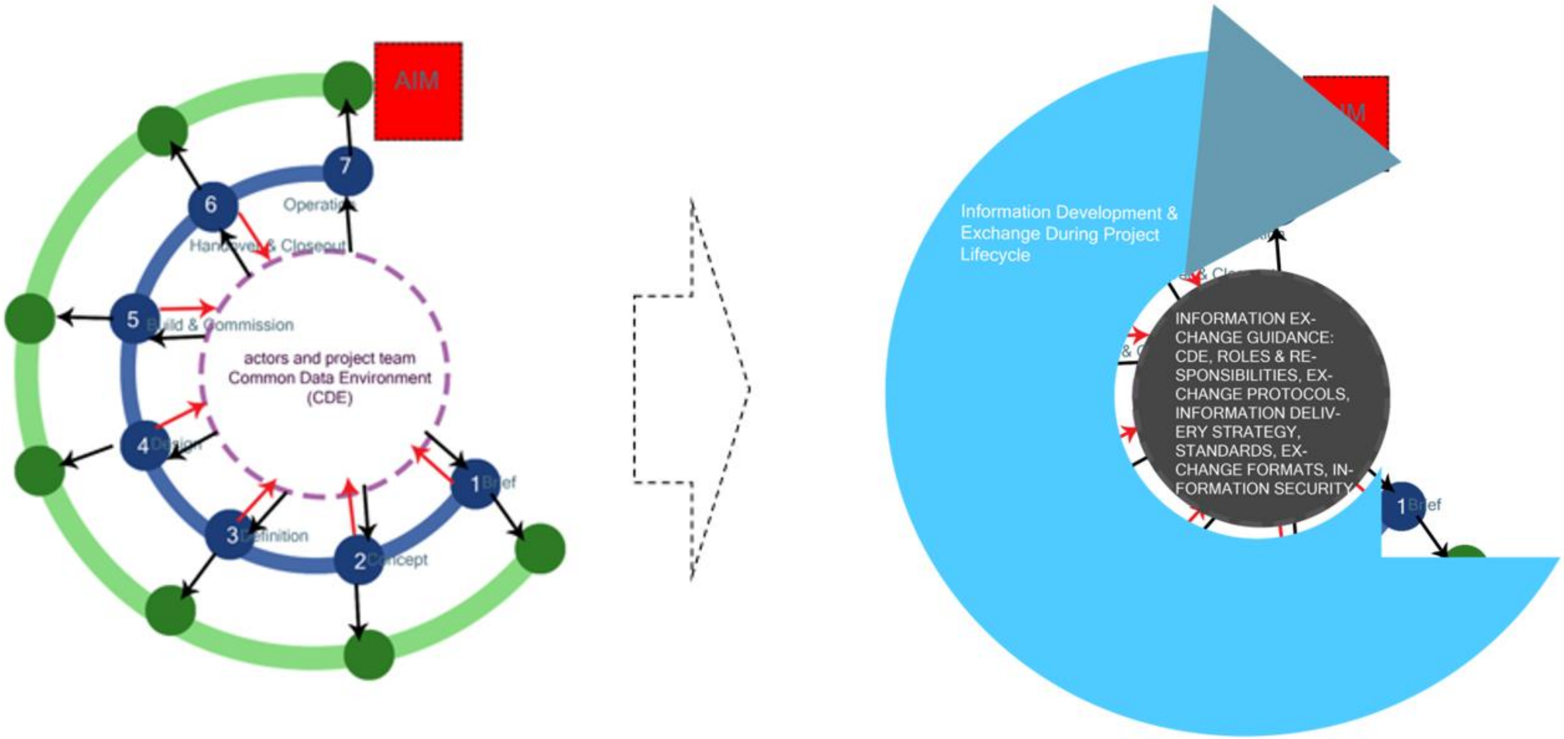


Figure 5.3: Overlap between BIM IDL and its two main component

5.2.1.2 OntEIR Basic Components

Based on the previous arguments and analysis of the BIM IDL, it can be seen that the EIR should be able to cover completely two main components and their requirements. These two components are:

1- The project stages;
2- The high-level needs of the BIM IDL.

5.2.1.2.1 Project Stages

For any project, including BIM projects, to be successfully delivered, it should be planned thoroughly through all of its stages, from beginning to end. This includes the definition of all phases and stages before the beginning of the work. In BIM projects, to be able to produce a clear and comprehensive EIR, and BEP, clear references to the project stages are required. Project stages are crucial for establishing programme periods and responsibilities such as within the MPDT.

In terms of the project stages used in OntEIR, there were initially three options to choose from:

- PAS 1192-2 process map
- RIBA Plan of Works stages which are one of the implementations of the BS 8536-2 work stages (bsi, 2016c)
- CIC BIM Protocol

Table 5.1 shows the differences between the three sources:

Table 5.1: Comparison Between the Three Construction Stages

PAS 1192-2 process map	**BS 8536-2 work stages**	**CIC BIM Protocol**
	0 Strategy	
1 Brief	1 Preparation and brief	1 Brief
2 Concept	2 Concept design	2 Concept
3 Definition	3 Developed design	3 Developed design

4 Design	4 Technical design	4 Production
5 Build & commission	5 Construction	5 Installation
6 Handover & closeout	6 Handover & closeout	6 As constructed
7 Operation	7 In use	7 In use

"Arguably, the RIBA Plan of Works (BS 8563-2) provides the most detailed definitions of what should be undertaken within a project stage and should probably be used as the starting point for defining the stages for each individual project" (BIMToolBox.org).

Stages chosen for the OntEIR framework will be the RIBA plan of work, as shown in Table 5.1. The stages in the OntEIR framework start from "stage2- Concept design".

5.2.1.2.2 High Level Needs

High-level needs are the base from which requirements are elicited. They serve as a checklist to make sure all aspects of the EIR are covered.

Sources of the high-level needs:

The sources of the high-level needs in the OntEIR framework include:

- PAS 1192-2
- Other sources: standards and protocols, case studies (best practices in EIR) and literature review

a. PAS 1192-2:2013

PAS 1192-2 (bsi, 2013), discusses the Specifications for information management for the capital/delivery phase of construction projects using BIM. In it the contents of the EIR are examined. PAS 1192-2 categorises the EIR into 3 main aspects, technical, commercial and management, as seen in Table 5.2.

Table 5.2: EIR aspects and needs as shown in PAS 1192-2

Technical	Management	Commercial
Software platform	Standards	Data drops and project deliverables
Data exchange format	Roles and responsibilities	Client's strategic purpose
Coordinates	Planning the work and data segregation	Defined BIM/project deliverables
Level of detail	Security	BIM-specific competence assessment
Training	Coordination and clash detection process	
	Collaboration process	
	Health and safety and construction design management	
	Systems performance	
	Compliance plan	
	Delivery strategy for asset information	

According to the International Institute of Business Analysis (IIBA), the difference between a need and a requirement, is that the former is a high-level representation of the requirement needed. On the other hand, a requirement refers to a condition or capability required by a stakeholder to solve a problem or achieve an objective. The need is the end result or purpose. It is "why we are doing this" (Elgendy, 2016).

According to the above arguments, the PAS 1192-2 table should be considered the EIR needs. They serve as a checklist to ensure that all requirements are covered, requirements that are elicited from needs, as will be discussed in Section 5.2.1.2.3 to come.

However, and according to the aim and definition of the EIR, which is to be the basis on which the BEP and MIDP are developed, the information in the PAS 1192-2 table is still insufficient. The needs described in it is not enough to be able to develop complete BEPs and MIDPs. Accordingly, other sources of information to complete the EIR set should be acquired.

b. Other sources

Sources of information for reaching a complete and comprehensive EIR included other standards and guidelines in addition to case studies in best practices in EIR. Table 5.3 shows the different sources and the needs associated with them.

Table 5.3: High-level needs and sources of information

Need	Source	Source definition
Tasks (responsibilities)	PAS 1192-2:2013	Specification for information management for the capital/delivery phase of construction projects using BIM
		Review of current practices in EIR
Roles	RIBA Plan of Work:2013	Defines the deliverables required at each stage of the project delivery process. It gives a clear definition of the information that should be

		delivered at each stage of the work.
Data security	PAS 1192-5:2015	Specification for security-minded BIM
Ownership of the model	CIC BIM Protocol (2018)	Standard protocol for use in projects using BIM
HSE CDM Compliance	CDM 2015	The construction design and management regulations
	PAS 1192-6:2018	Specification for collaborative sharing and use of structured Health and Safety information using BIM
Information exchange	BS 1192-4:2014	Collaborative production of information fulfilling employer's information exchange requirements
AIM delivery strategy	CIC BIM Protocols (2018)	Standard protocol for use in projects using BIM
	PAS 1192-3:2014	Specification for information management for the operational phase of assets using BIM
Stage tasks	RIBA plan of work 213	Defines the deliverables required at each stage of the project delivery process. It gives a clear definition of the information that should be delivered at each stage of the work.

Collaboration	BS 1192:2007	Collaborative production of architectural engineering and construction information code of practice.
Data drops	BS 1192-4:2014	Collaborative production of information. Fulfilling employer's information exchange requirements using COBie. Code of practice
	PAS 192-2:2013	Specification for information management for the capital/delivery phase of construction projects using BIM
Project requirements	RIBA plan of work:2013	Defines the deliverables required at each stage of the project delivery process. It gives a clear definition of the information that should be delivered at each stage of the work
	Case studies	
AIR	NRM	New Rules of Measurement
	UniClass	Unified classification system
COBie deliverables	PAS 1192-2:2013	Specification for information management for the capital/delivery phase of construction projects using BIM

	BS 1192-4:2014	Collaborative production of information fulfilling the employer's information exchange requirements using COBie-code of practice
	COBie UK 2012	Required Information for Facility Operation
LOD & LOI	PAS 1192-2:2013	Specification for information management for the capital/delivery phase of construction projects using BIM
	LOD specification 2017	Level of Development specification

After defining the high-level needs from the different resources, the next step was to elicit the requirements from those needs.

5.2.1.2.3 The Elicitation of Requirements

Kujala *et al.,* (2001) argue that developing a usable (software) product involves fitting into context of use and meet user requirements. They propose that there should be a process that enables the elicitation of requirements from needs. Also, they emphasise the necessity of understanding the needs of the users as a way of informing the design process.

Coble et al. (1997) discuss that in order to be able to develop useful and usable systems, the needs should be identified and understood first, then those should be expressed in requirements.

The elicitation of requirements from the high-level needs is one of the main objectives of OntEIR in reaching a complete EIR that covers all the needs. In OntEIR, the decomposition of goals process was adopted (Loucopoulos and Karakostas, 1995), which allows us to elicit the requirements from the high-level needs.

Develop goal hierarchies from the needs

During this step, requirements are generated from each need. Developing goal hierarchies through decomposing the goals helps in breaking the high-level need into goal, then sub goals, until reaching the last leaf in this decomposition, which is the requirement(s) that satisfies the need. Each need could end up having one or more requirements that is generated to satisfy it, as shown in Figure 5.5.

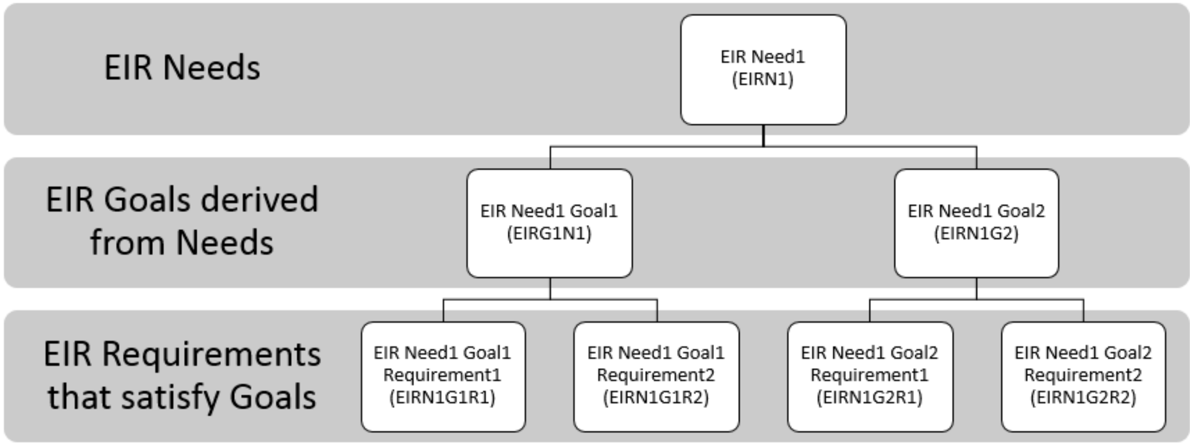


Figure 5.4: The decomposition of goals process, from high-level need to requirements

The decomposition of goals is a concept that is used in the SE discipline, which involves decomposing high-level goals to lower-level sub-goals, and then decomposing these in turn, until leaf-goals are reached that express requirements for computer-based systems (Loucopoulos and Karakostas, 1995).

Loucopoulos also introduced 'goals' as: 'A defined state of the system. Since a state is described in terms of the values of a number of parameters, a goal can be alternatively defined as a set of desired values for a number of parameters" (Loucopoulos and Karakostas, 1995).

In the construction industry this direction is visible in a lot of requirements related studies. The QFD approach used this process in capturing the client requirements in the CRPM by first identifying the customers' needs and decomposing them into primary, then secondary and detailed tertiary requirements (Griffin and Hauser, 1993). The same concept of the decomposition of goals was also used in the development of the CPRM (Kamara, Anumba and Evbuomwan, 2000). In fact, this process of decomposing goals in a hierarchal way, from general to more detail has proven to facilitate the understanding and the traceability of requirements (Griffin and Hauser, 1993; Hill, 1991; Kott and Peasant, 1995; Ulrich and Eppinger, 2008).

The decomposition of goals in creating a goal hierarchy, helped in identifying more than 200 requirements for EIR, which will be discussed in detail in sections to come.

Due to the large number of requirements, categorisation of these requirements is seen as an effective way to filtering these requirements, in a way stakeholders can access just the information they need from among all the information that surrounds the requirements, which will save time and effort.

5.2.1.2.4 Categorisation system in OntEIR

The categorisation process in OntEIR, starts with categorising the high-level needs for the EIR. The practice of categorisation of requirements has been practiced in different disciplines to make it easier to manage the control of requirements (Dick, Hull and Jackson, 2017). It is also used to support requirements elicitation that aims at completeness (Buede and Miller, 2016), and it helps in defining some kind of priorities that assist designers in defining suitable solutions in less time (Jain *et al.*, 2008).

The concept of requirements categorisation has been applied in many disciplines to ensure that stakeholders obtain what they need from the requirements. Categorisation of requirements is based on the attributes that further define these requirements. Categorising requirements allows stakeholders to access the information they need from the vast amount of available information that affects the requirements, and enables us to communicate the different levels of requirements to the appropriate audience, each at their own level (Kupersmith, Mulvey and McGoey, 2013).

There are different ways to categorise requirements according to the discipline and the reasoning behind the categorisation. As discussed in Section 2.1.2.2, In the field of Systems Engineering, various approaches of categorising requirements are used depending on the type of industry and project; one widely used list of requirement types is based on the systems functionality, mainly into functional and non-functional (Sommerville, 2016; Robertson and Robertson, 2012; Holt, Perry and Brownswor, 2012).

Categorisation of requirements has also been practiced in the construction industry as also examined in Section 2.1.2.2. Kamara *et al.,*(2002) categorised requirements according to their detail into primary, secondary and tertiary. Kiviniemi *et al.,*(2004) on the other hand took another approach in categorising the requirements of the building into direct and indirect based on the relation of this requirement to the building.

Saxon (2016) involved the process that lead to the project in his categorisation into product and process.

The OntEIR categorisation of requirements system used could be seen as a combination of all the previous attempts in categorising requirements. It starts by categorising the high-level needs (which involve both needs for the 'process' and needs for the 'asset') on which the requirements will follow. Categorising the needs and not the elicited requirements will ease the categorising process because of the smaller number of items. The OntEIR needs (requirements) are basically categorised on their functionality and their behaviour towards each other and towards other important aspects of the project. The process started when representing the components of the OntEIR framework discussed which include mainly the project stages and the high-level needs using nodes and links and visually representing them using the online tool "graph commons", Figure 5.5, it can be seen that some kind of clustering occurs to those needs. These clusters represent the categories of the OntEIR.

It is seen that 'Cluster 1 needs' have only links and relations to each other, they are not connected to the stages, and they are only defined at the beginning of the project. Cluster 2 represent needs that have different characteristics: they are linked to each other in addition to the stages, and they tend to move through the stages and developing and maturing through them, appearing in every stage of the project, as shown in Figure 5.6

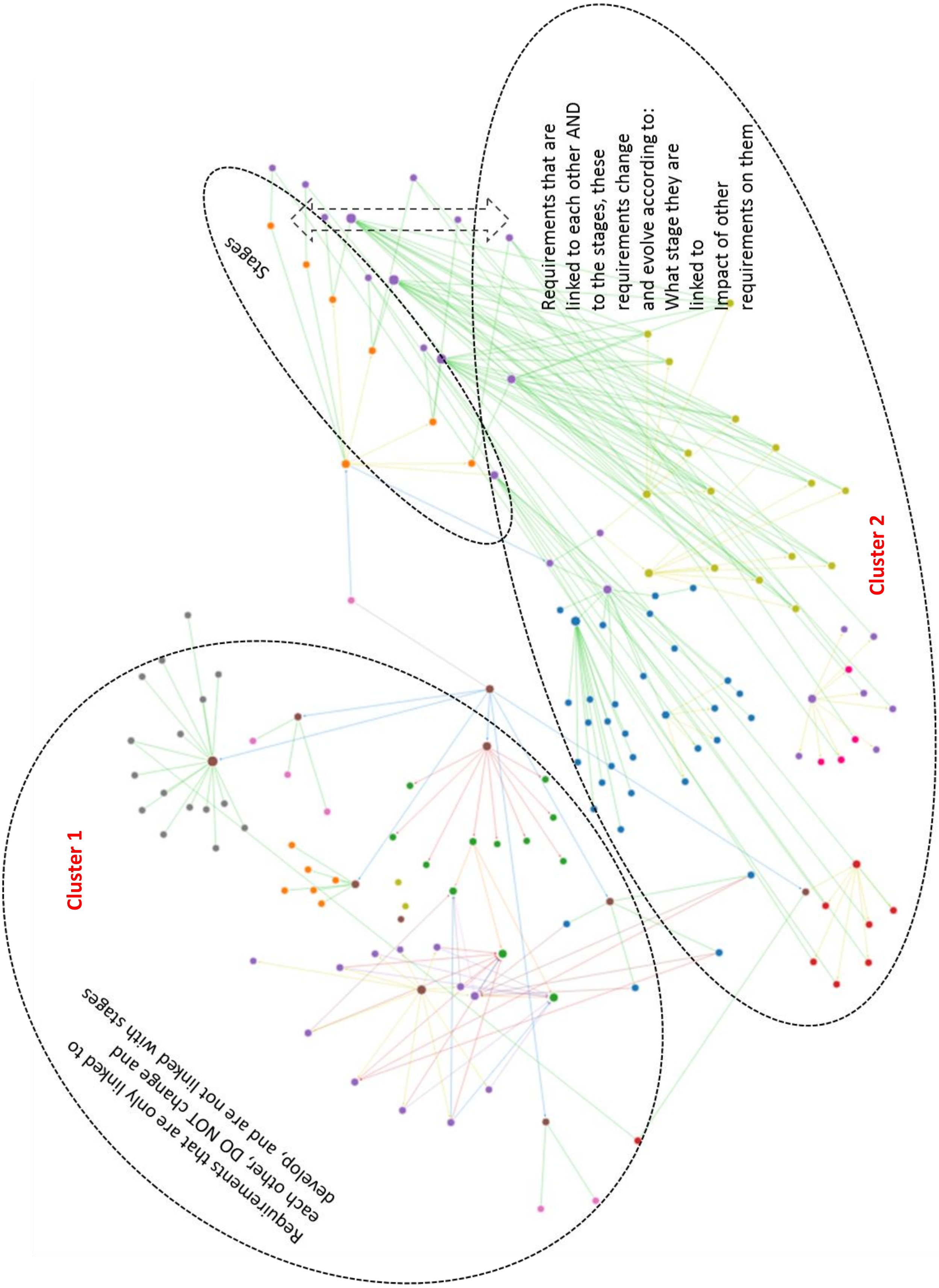


Figure 5.5: Visualisation of the OntEIR needs, requirements and their relationships

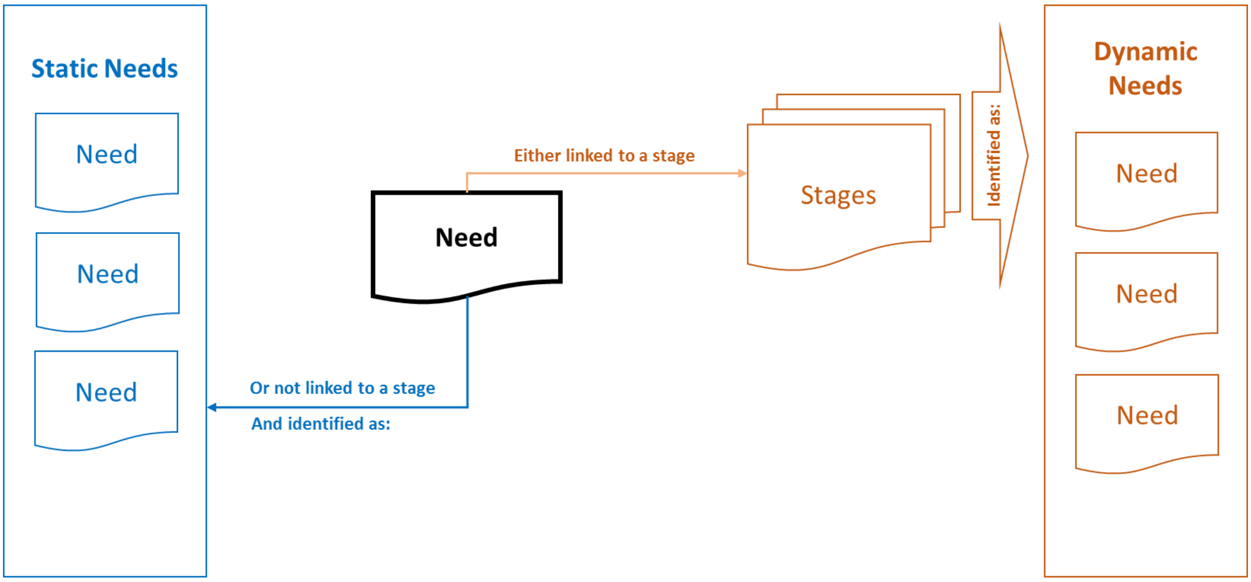


Figure 5.6: Relation between different components of the OntEIR framework

The definitions “static” and “dynamic” needs were chosen to refer to those two different types, according to the characteristics and behaviour they demonstrate.

5.2.1.2.4.1 Static needs

Static needs in OntEIR could also be called the generic needs. They are the needs that should be defined for all projects despite their type or size. They are defined at the beginning of the project and are not affected by the development of the stage which the project is in. They are only linked with the other static needs in its group.

Static EIR needs include:

- Tasks (responsibilities);
- Roles;
- Standards;
- Ownership of the model;
- HSE & CDM Compliance;
- Data security;
- Software platforms;
- Coordinates;

- Coordination and clash detection;
- AIM Delivery strategy.

When applying the decomposition of goals process, discussed in Section 5.2.1.2.3 on the static need, more than 100 requirements could be identified. Table 5.4 demonstrates how those requirements are generated, the full list of all the needs and requirements are found in Appendix A.

Table 5.4: Example Applying the hierarchy of goals for eliciting static requirements in OntEIR

Needs	Goal	Requirement
Data security measures and guidelines	Home and Mobile Working	Develop a mobile working policy and train staff
		Apply the secure baseline building to all devices
		Protect data both in transit and at rest
	User Education and Awareness	Produce safer security policies covering acceptable and secure use of the organisations systems
		Establish a staff training programme
		Maintain user awareness of the cyber risks

5.2.1.2.4.2 Dynamic Needs

On the other hand, as discussed in Section 5.2.1.2.4, the dynamic needs get its name from being changing and continually developing with the development and maturing of the stage. Mainly, dynamic needs are the basis on which the MIDP is developed. This section holds all the information and requirements linked to the stages, which include:

- Stage team;
- Tasks;
- Data drops;
- CDM requirements;
- Project requirements;
- Asset Information Requirements;
- COBie deliverables;
- LOD and LOI.

From Non-active to Active Dynamic Requirements

The origins of the dynamic requirements are "non-active" dynamic requirements. Non-active dynamic requirements are the dynamic requirements while they are still in their 'idle' phase. Non-active dynamic requirements change into being active when assigned and linked to a particular stage, as illustrated in Figure 5.7. They are the requirements that should be defined before the beginning of the project and reflect general needs of any construction project, irrespective of its type and size.

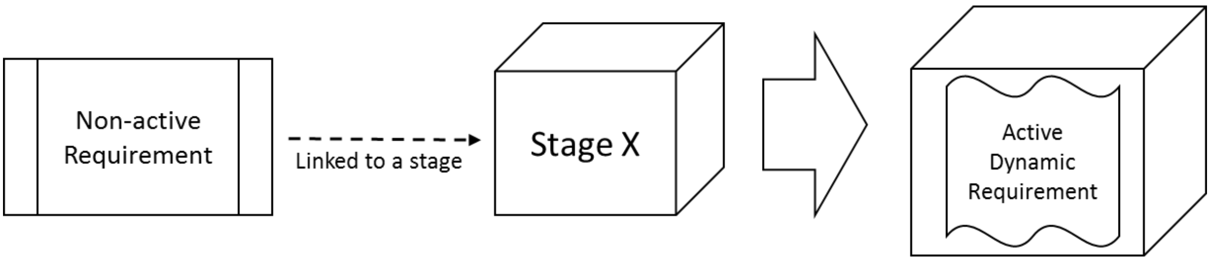


Figure 5.7: Changing from non-active to active dynamic requirement when linked to a stage

Active Dynamic requirements, on the other hand, are idle in nature, but turn into active-dynamic when they are linked to a stage. According to the RIBA plan of work, there are 7 stages in the construction project (Sinclair, 2013). Each of those seven stages share the same requirements with each other in terms of the type of requirements assigned. At the same time, these requirements differ from one stage to another in the way they are linked to one another. Each of those stages has their own different requirements, which distinguishes it from the others. Each of the dynamic requirements, come from the same source, but they change in meaning and attributes as they are linked to a stage. The dynamism of the requirement is only determined if it is linked to a stage, if not it will just be a non-active requirement.

An example of this are the project requirements. These requirements are defined at the beginning of a project as non-active requirements, which means they do not change in nature and in meaning until they are linked to a stage. For example, the requirement "Internal Layout" which is part of the project requirements has different meanings, different actors, and different level of details, when linked to different stages. This requirement, like all other dynamic requirements, changes and moves according to the stage it is in, as can be seen in Figure 5.8.

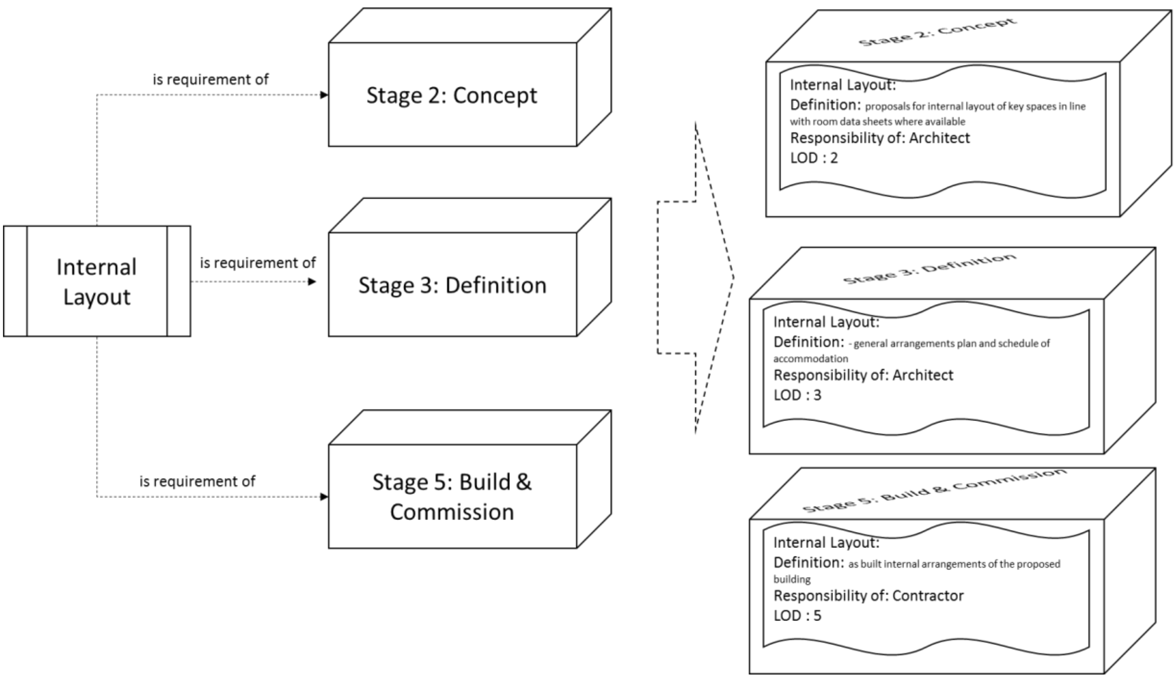


Figure 5.8: The change of a non-active requirement to an active dynamic when linked to a stage

Figure 5.9 represents the final visualisation of the OntEIR composition, which consist of:

- all types of needs and requirements: static, dynamic and active dynamic
- The project stages
- The relations between the different components

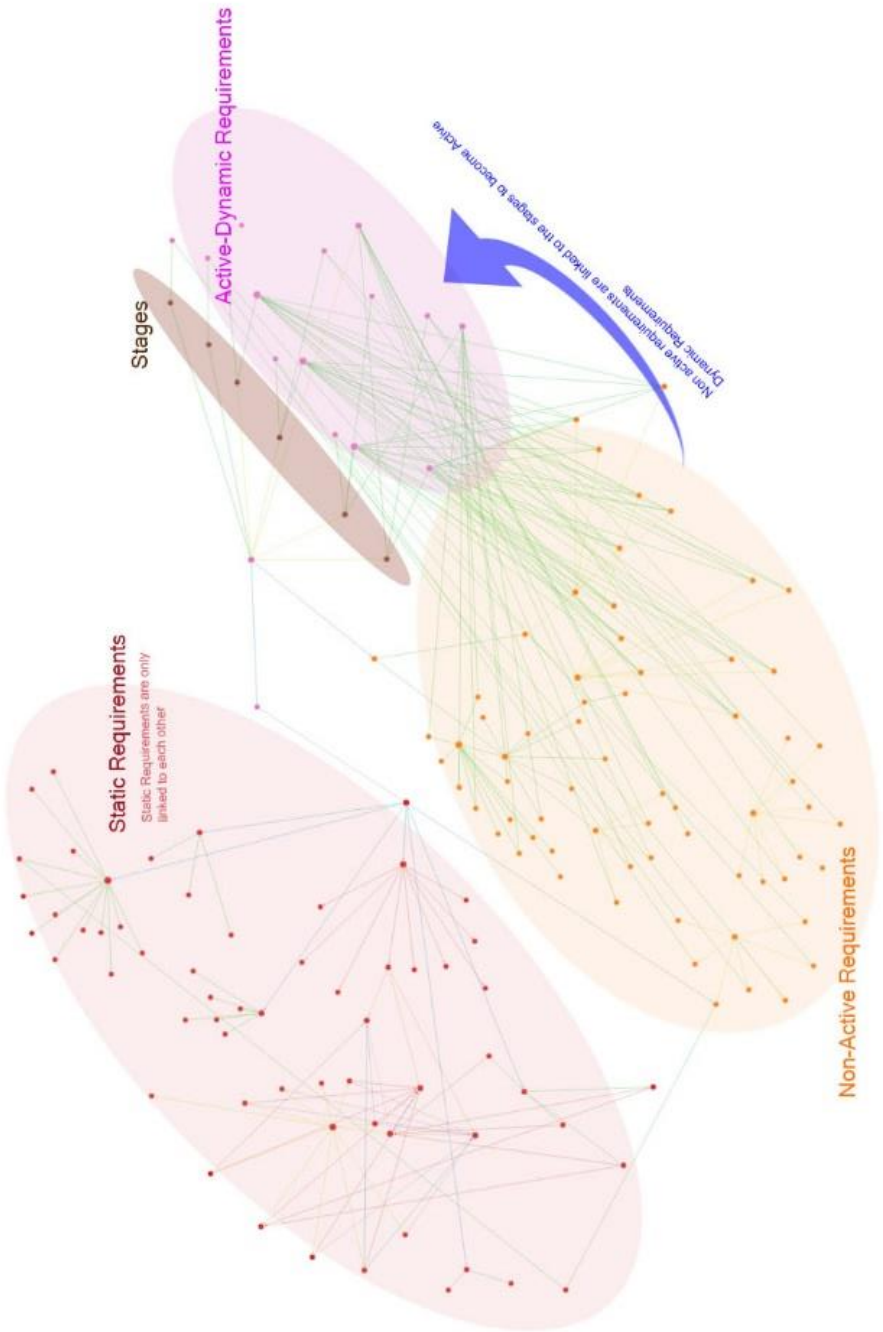


Figure 5.9: Final visualisation of OntEIR requirements including non-active dynamic requirements and their transition to active dynamic requirements

5.2.2 Ontologising EIR

5.2.2.1 What is Ontology?

Studer *et al*., (1998), refer to ontology as a formal explicit specification of a shared conceptualisation; formal means that it could be communicated across people and computers, explicit means that the concepts and relations are explicitly defined, and conceptualisation means to an intended model of the world's phenomena identified by its concepts and relations (Cao, Li and Ramani, 2011).

Iqbal *et al.,* (2013) also describe the role of ontologies in explicitly defining the concepts in a domain and the relationships between those concepts. The importance of ontologies in knowledge-based applications rise from their ability to detail the description of a domain in a formal model, machine readable way, which will allow it to be utilised in many ways (Iqbal *et al.*, 2013).

But still, the wider accepted definition is presented by Gruber (1993): "Ontology is a formal representation for a conceptualisation", where according to Lacy (2005) "an ontology specification is a formally-described, machine-readable collection of terms and their relationships expressed with a language in a document file" as illustrated in Figure 5.10.

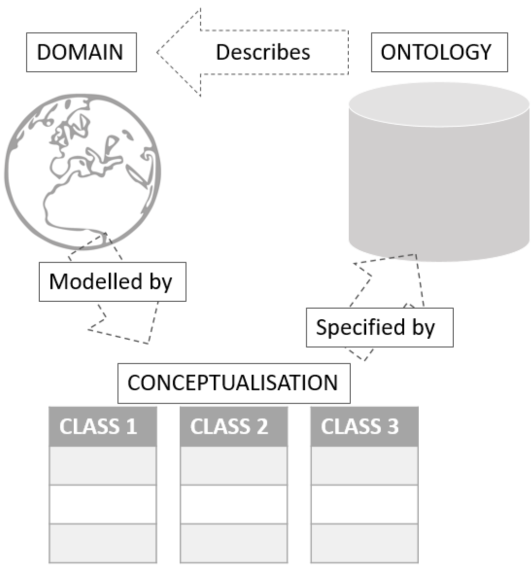


Figure 5.10: Gruber ontology definition (Lacy, 2005) , reused with permission from © Lee Lacy

5.2.2.2 Using Ontology in Construction

Ontologies have become a very popular topic in many disciplines of AI and computing, in addition to efforts on developing ontologies in many other branches of science and technology (Gaševic, Djuric and Devedžic, 2006). Many guidelines have been put forward for the creation and maintenance of ontologies (Noy and McGuinness, 2000; Horridge *et al.*, 2004; Breitman and do Prado Leite, Julio Cesar Sampaio, 2003). Hence ontologies are growing fast into a distinct scientific field with its own theories, formalisms, and approaches (Staab and Studer, 2010).

In BIM, studies and use of ontology have gained wide attention recently. Chen and Lou (2016) explain this as being due to the ontology-based representation method that allows integration and sharing of existing knowledge across different domains as well as intelligent reasoning of tacit knowledge via concept classification, semantic description, and logic reasoning (Chen and Luo, 2016).

Some of these studies include OntoFM, developed by Dibley *et al.,* (2012), which is a series of interrelated ontologies which include: building ontology, sensor ontology and other supporting ontologies to launch an intelligent multi-agent software for real time building monitoring (Dibley *et al.*, 2012; Chen and Luo, 2016). OntoSCS (Ontology of Sustainable Concrete Structure) is another formal ontology developed by Hou *el al.,* (2015) to optimise structural design solutions and the material supplier selection process

Other ontologies were also developed for construction safety and checking, such as CQIEOntology, developed by Zhong *et al*. (2012) which is a meta model facilitating construction quality inspection and evaluation. In addition to CSCOntology (Construction Safety Checking Ontology), which is a meta model for construction safety checking developed by Lu *et al.,* (2015).

5.2.2.3 Modelling with Ontology

An ontology is a machine-processable representation of knowledge about a domain of interest (Tamma and Dragoni, 2016). The Ontology Web Language (OWL), is one of the formal languages in which ontologies are encoded (Grau *et al.*, 2008). Many studies were found in the area of developing an environment for semantic web applications, such as the Protégé OWL plugin (Horridge *et al.*, 2004; Knublauch *et al.*, 2004). Protégé is currently the leading ontology development editor and environment. Protégé was developed at Stanford University and has already been through a number of versions and modifications (Gaševic, Djuric and Devedžic, 2006; Stanford University, 2005).

Although the development of protégé has intended for biomedical applications (Gennari *et al.*, 2003), the system is domain-independent and has been successfully used for many other application areas as well.

Protégé model is based on a simple yet flexible metamodel (Noy, Fergerson and Musen, 2000). Which consists on representing ontologies with classes, properties (slots), property characteristics, and instances (Knublauch *et al.*, 2004). An important strength of Protégé is that the Protégé metamodel itself is a Protégé ontology, with classes that represent classes, properties, and so on. For example, the default class in the Protégé base system is called: STANDARD-CLASS and has properties such as: NAME and: DIRECT-SUPERCLASSES. This structure of the metamodel enables easy extension and adaption to other representations (Noy *et al.*, 2001).

Gaševic *et al.* (2006) argue that the extreme popularity of OWL, is due to the important feature of its vocabulary in its extreme richness for describing relations among classes, properties, and individuals. For example, we can specify in OWL that a property is, Symmetric, the *InverseOf* another one, an *equivalentProperty* of another one, and Transitive; that a certain property has some specific cardinality, or *minCardinality*, or *maxCardinality*; and that a class is defined to be an *intersectionOf* or a *unionOf* some other classes, and that it is a *complementOf* another class (Gaševic, Djuric and Devedžic, 2006). This is important when developing the EIR Ontology. One of the main reasons for developing OntEIR is the need for a clear and understandable EIR framework, it is important to be able to define the classes and individuals as well as the relations between these classes and the individuals as clear as possible.

5.2.2.4 Building the EIR Ontology

Ontology was used to represent the EIR framework, for the reason that requirements can benefit from ontologies, because they facilitate the explicit modelling of the domain (Dobson and Sawyer, 2006). Being machine readable, in addition to facilitating the modelling of the domain, also allows the requirements traceability in the ontology, and the checking of consistency using an inference engine (Dobson and Sawyer, 2006).

The EIR Ontology includes classes, taxonomies and relationships. The taxonomical concept was reached and discussed earlier in section 5.2.1.2.4 of this chapter, terms and phrases were also adopted to describe relationships with other classes.

Noy and McGuinness (2001), argue that ontologies are formal description of concepts in a domain of discourse, these concepts can also be called classes, which have attributes and features described through defining their properties, these properties are called slots, which have also restrictions on them (facets). They also state that the set of instances of classes along with the ontology itself create what can be called a knowledge base, 'in reality there is a fine, line where the ontology ends, and the knowledge base begins' (Noy and McGuinness, 2001).

Building ontologies include (Noy and McGuinness, 2001):

- Defining classes in the ontology,
- Arranging the classes in a taxonomic (subclass–superclass) hierarchy,
- Defining slots and describing allowed values for these slots,
- Filling in the values for slots for instances.

Knowledge base can be created by defining individual instances for classes, and filling slots with value information and additional slot restrictions.

When it comes to building ontologies, Noy and McGuinness (2001) argue that there is no one correct way or methodology for doing that, but there are some fundamental rules in ontology design, that may assist in making design decisions:

- There is no one correct way to model a domain— there are always viable alternatives. The best solution almost always depends on the application that you have in mind and the extensions that you anticipate.
- Ontology development is necessarily an iterative process.
- Concepts in the ontology should be close to objects (physical or logical) and relationships in your domain of interest. These are most likely to be nouns (objects) or verbs (relationships) in sentences that describe your domain.

It should be noted that the ontology development it an iterative process; after it is developed, it is revised and refined to evolve the ontology and fill in the details.

The process of building ontologies according to Noy and McGuiness (2000):

Step 1. Determine the domain and scope of the ontology

Step 2. Consider re-using existing ontologies

Step 3. Enumerate important terms in the ontology

Step 4. Define the classes and the class hierarchy

Step 5. Define the properties of classes—slots

Step 6. Define the facets of the slots

Step 7. Create instances

5.3 The EIR Ontology- OntEIR

The OntEIR was developed using Protégé 3.4.1, which uses the OWL. The basic concepts and classes were based upon the components of EIR and the original arguments of categorisation, and elicitation discussed in Section 5.2.1.

The development of OntEIR was mainly based on the 7-step process, described by Noy and McGuiness (2001).

A. Determine the domain and scope of the ontology: The domain and scope of OntEIR was determined and discussed in Section 5.2, in which the components and classifications of the requirements in OntEIR were examined in what will be the basis on which the OntEIR framework was built.

B. Define the classes and the class hierarchy: According to the definition of the domain in step 1, and the description of the EIR that was discussed in Section 5.2, the class hierarchy was developed as can be seen in Figure 5.11.

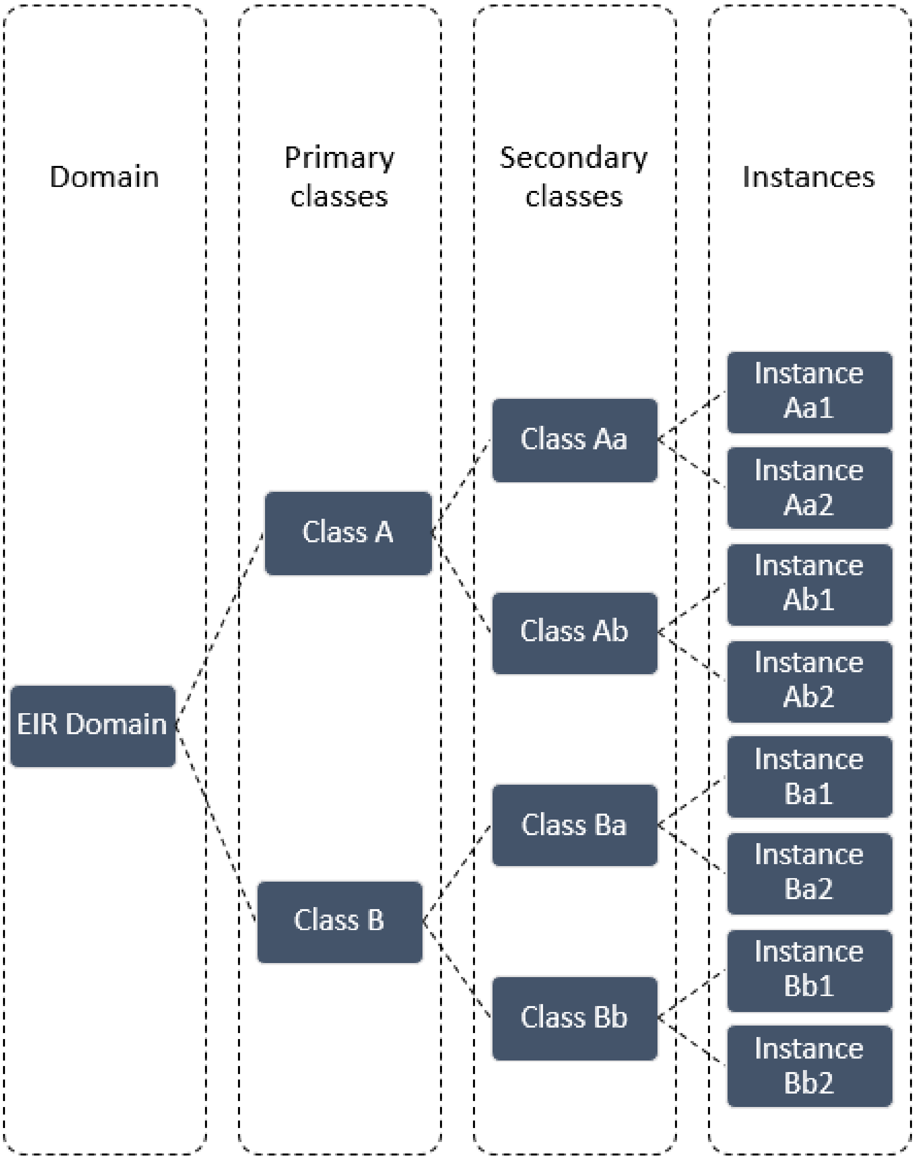


Figure 5.11: Class hierarchy concept in OntEIR

The class hierarchy shown in Figure 5.12 responds to the hierarchy concept described in Figure 5.11, and the initial OntEIR framework development stages discussed in Section 5.2.

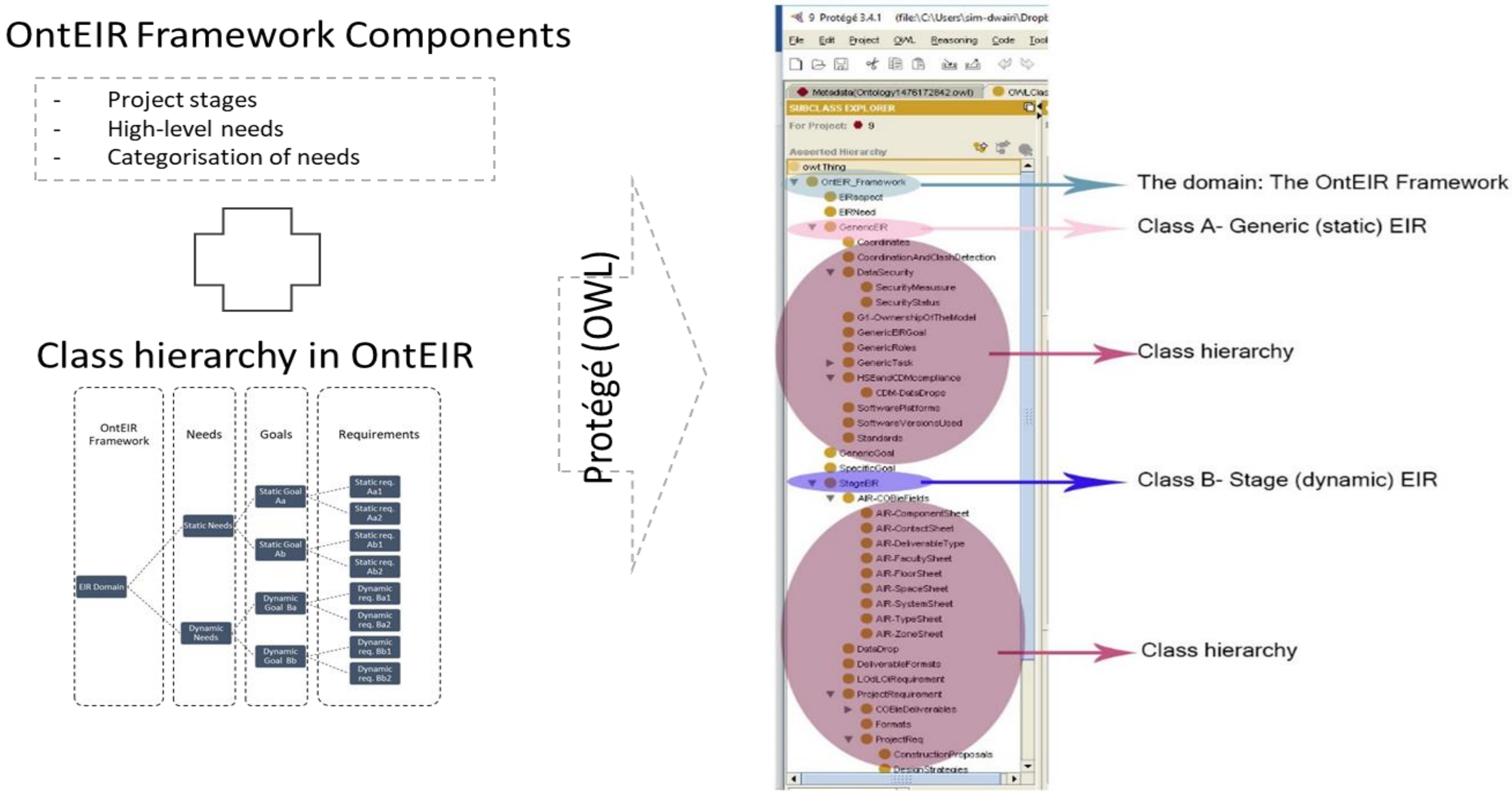


Figure 5.12: How the Class Hierarchy in the EIR Ontology responds to the OntEIR Framework and the Hierarchy of Goals

The last leaf in the class hierarchy is called instance, each class has a group of instances that are assigned to that class according to the properties and definition of that class.

Figure 5.13 is an example of a class hierarchy in the OntEIR Ontology:

1. The domain which is EIR has 2 main classes: Generic EIR (that represents the Static Needs), and the Stage EIR (that represents the dynamic needs), for this example a generic requirement was chosen.
2. The Generic EIR consists of a group of sub-classes which are: roles, tasks, coordinates, communication and clash detection, and ownership of the model, data security and AIM delivery strategy, each with their own set of sub-classes or instances. For this example, the class 'Task' was chosen.
3. The sub-class 'Task' also consists of a group of sub-sub-classes numbered from 1 to 7, for this example, the class 'Task1-CDE' was chosen.
4. This is the last class of the hierarchy. This sub-class consists of a group of responsibilities as instances. Instances share relations with other instances in another classes.
5. In this particular example, the instances share relations with other instances in the 'Role' class. These relations were defined as: 'is the responsibility of', 'is authorised by', 'is consulted by' and 'is informed by'.

Classes are linked together by relations that link their instances, those relations are called "properties", and they are verbs that describe the relation between the two individuals. Figure 5.14 shows the list of properties used in the OntEIR framework.

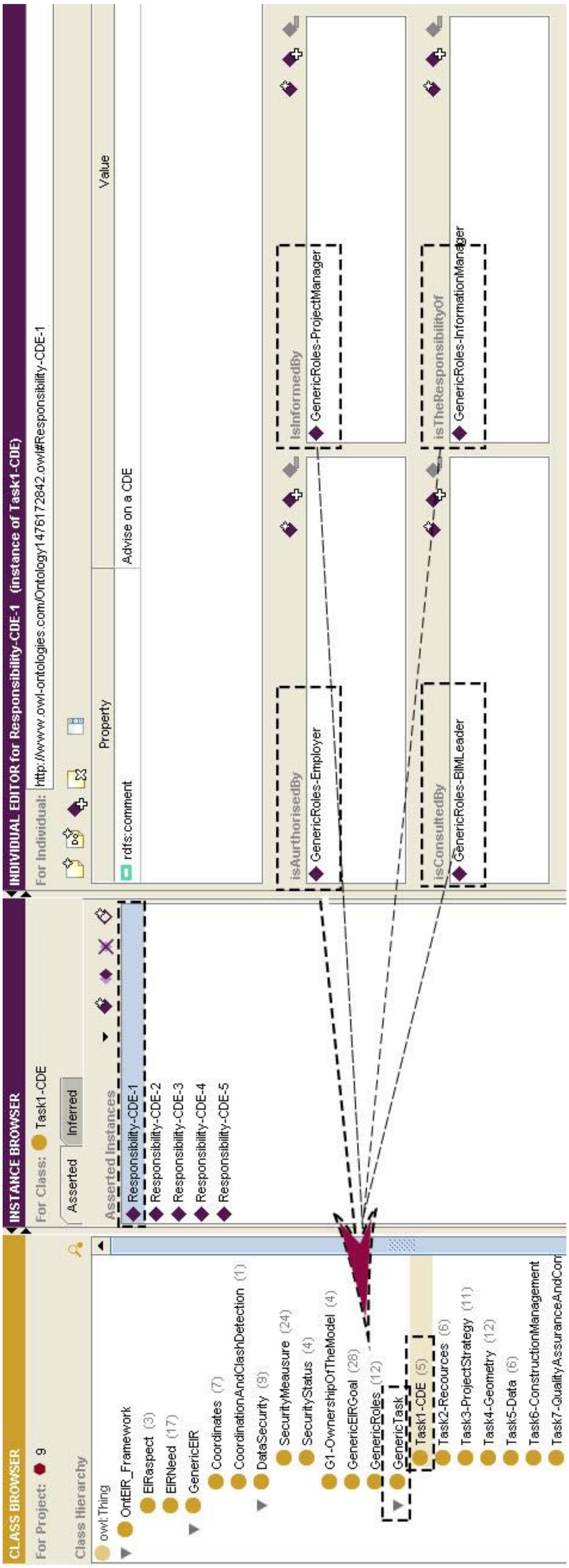


Figure 5.13 Screenshot of the EIR Ontology

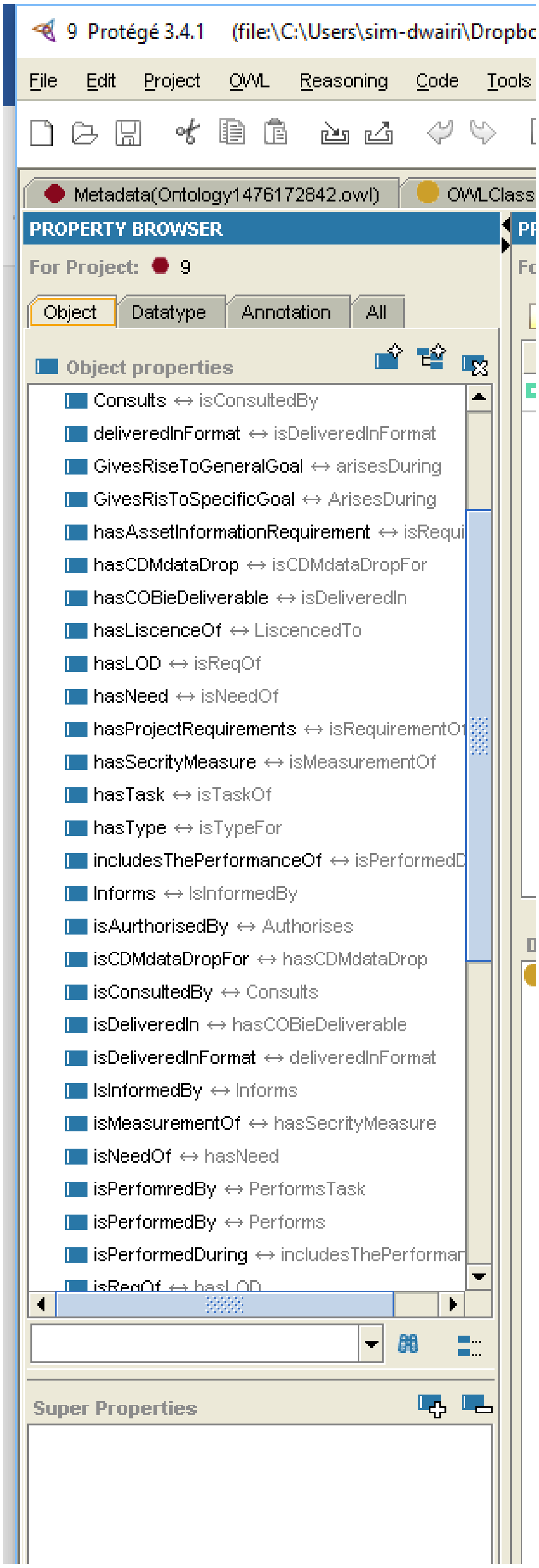


Figure 5.14: List of object properties in OntEIR

5.4 The OntEIR Framework

At the end of the initial OntEIR framework, the EIR ontology, included: 2 main classes (classification), 22 sub classes (Needs), 53 sub-sub classes (Goals), 395 Individuals (requirements) and 59 properties. Table 5.5 below shows an example of the components of the OntEIR framework, the complete list of the OntEIR classes, sub-classes and individuals are found in Appendix B.

Table 5.5: List of Classes and Individuals on the OntEIR Framework

Main class (Classification)	**Sub Class 1 (Need)**	**Sub Class 2 (Goal)**	**Individual (requirement)**
Stage EIR	Project requirements	Overall Form and content	Maintenance Access
			Space Planning
			Surveys
			Building and Site Sections
			Specifications
			Site and Context
			External Form and Appearance
			internal layouts
			Fire
			Physical Security
			Disabled Access
		Elements Materials and Components	Building
			MEP Systems
			Structural
			Specifications
		Performance	5DCostAnalysis
			4DProgrammingAnalysis
			Acoustic Analysis
			Building

			MEP systems
			Regulations Compliance Analysis
			Structural
			Thermal Simulations
			Services Commissioning
			Sustainability Analysis
		Design Strategies	Disabled Access
			Fire
			Maintenance Access
			Physical Security
		Construction Proposals	Phasing
			Site Access Site Set-up
			Site Set-up
		Health and Safety	Design Construction
			Construction
			Design
			Operation

At the end, the complete map of the classes, instances and the relations that connect them form the OntEIR Framework. Figure 5.15 represents the initial OntEIR framework, which was the basis of the first iteration of the evaluation process, discussed in the Chapter 6.

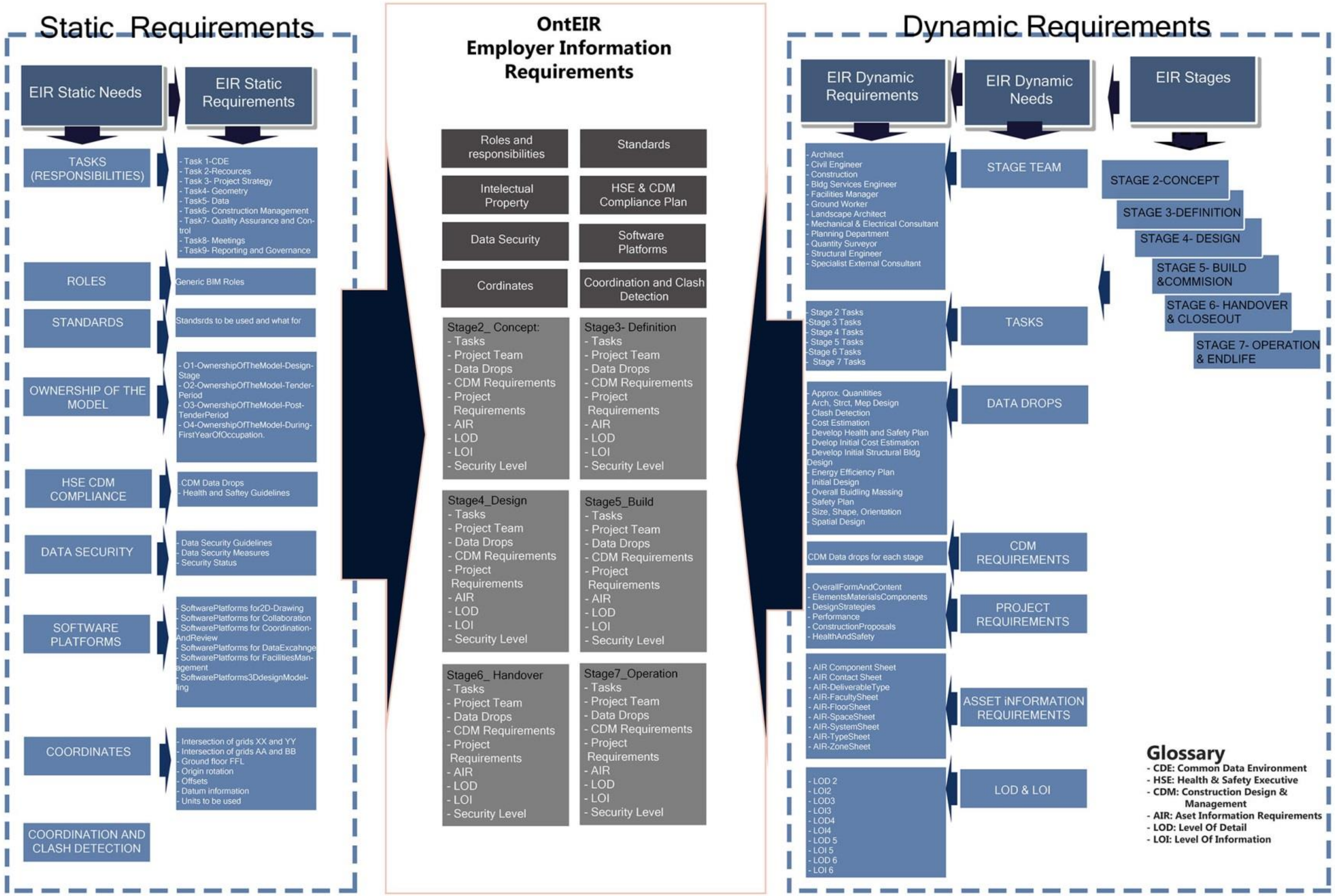


Figure 5.15: The Initial OntEIR Framework

5.5 Chapter Summary

In this chapter the initial Ontology Framework for defining EIRs (OntEIR) was introduced and described. This framework defines and describes the information requirements needed throughout the project lifecycle for a full and complete information model to be delivered at the end of the BIM project. Two major components make up this framework: high level needs, and project stages.

The high-level needs are broken down into goals then further broken down until reaching requirements. Needs are put into two divisions according to a new categorisation system presented in this chapter: static and dynamic, based on the nature of those needs and the relation they have with other aspects of the framework.

The OntEIR framework expands the current practices in EIR definition to include the project lifecycle and tracking of the information development during its different stages. It enables the client to easily trace their requirement and involve the relative stakeholder during the definition of the requirements.

The expected benefits of OntEIR are to contribute towards the definition of better-quality information requirements, which are more complete and correct. This could contribute to the waste reduction and improve of the quality of the built facilities. The framework is subjected to validation with experienced domain experts in EIR, to see if it manages to fulfil its intended aim, as will be discussed in the next chapter.

Chapter 6 Findings and Discussion of Framework Validation

6.1 The Validation Process

As part of the development process, the framework would have to go through an evaluation stage. According to Scriven (1967), evaluation is the process of assessing the value, worth or significance of objects based on a set of criteria. Davidson (2005) argues the importance to start the evaluation process with a clear understanding of the purpose of this evaluation. This study depends on Scriven's logic of evaluation, that starts by identifying the objects to be evaluated, which precedes the establishment of the criteria for the value of the object (Scriven, 1967). Valid conclusions can only be reached after determining the performance of the objects in relation to criteria of value.

The agenda for achieving the objectives of this logic considers at high importance the stakeholders' views and needs in a valid evaluation (Bryson, Patton and Bowman, 2011). This study carried out the following tasks to achieve a logical evaluation of the Framework:

1- Determine the purpose of the evaluation;
2- Seek stakeholders' involvement in the process, to build an understanding of the area from multiple views;
3- Develop the list of evaluation criteria;
4- Determine the performance of the framework according to the evaluation criteria identified;
5- Analyse the results and produce an evaluation outcome.

The evaluation of the OntEIR framework was conducted after an extensive literature review of the current practices in EIR (standards, and toolkits). After the literature review was completed, a phenomenological study could be performed. The phenomenological approach sets out to uncover the common meaning of the "clients' requirements" and "Employer Information Requirements" (EIR) and reach a deep understanding of the subject through and from the experiences of different individuals (Creswell, 2013). For the researcher to reach the best understanding based on the experiences of other individuals, they must put aside all previous experience they might obtain about the subject and start with a fresh perspective.

Chapter 5 previously discussed and described the OntEIR framework, and the methodology involved. The next step is the validation of the framework with domain experts and experienced stakeholders in BIM requirements and EIR.

The first part of this chapter (Sections 6.2, 6.3, 6.4, 6.5) discusses the procedure and the selection of participants, in addition to the validation criteria of this iteration, and then the results and analysis if findings.

While the second part (Section 6.6) is revisiting the initial framework that was validated, and updating it based on the analysis and findings reached in the section before.

6.2 OntEIR Framework Validation Process

This chapter discusses the validation of the OntEIR framework which is an application of the OntEIR Ontology. According to Brank *et al.,* (2005), validating the ontology application is an evaluation approach of the ontology itself.

Even though there are several different validation approaches of ontologies, validation through application approach was chosen to validate OntEIR due to the fact that it is validated by experts in construction and not IT. It would be easier to convey the ontology when working with different disciplines when it is done through application. It is sometimes argued that the best way for evaluating an ontology is the application for which it has been created (Leclere et al, 2002).
There are other approaches that could be used to validate the ontology. According to Tartir *et al.* (2010), these approaches include:

- Evolution-based approach: this method is mainly used to track the improvements done on ontologies that changed due to evolving. When ontologies change over time and more knowledge is added, it is important to track these changes to make sure that the quality of the ontology didn't decrease and no invalid changes have occurred.

- Logical-based (rule-based) approach: this method is used to evaluate the rules used to built the ontology to make sure there are no conflicts present (Arpinar *et al*., 2006).

- Metric-based (Feature-based) approach: this technique offers a quantitative validation of the ontology quality. By scanning the classes and properties, this technique gathers statistics about the knowledge presented in the ontology, and may lead to inputting some information that wasn't included in the ontology (Tartir *et al.,* 2010, Arpinar *et al.,* 2006).

A representation or application of the ontology was validated in this part of the research. This representation holds knowledge about the domain which are the needs and requirements needed to produce a complete and full EIR. Validating the application of the ontology is a validation of the ontology itself, because the quality and correctness of the ontology have direct impacts on the quality and correctness of the application (Tan *et al.,* 2017). This validation offers both a qualitative and quantitative outcome to decide whether the ontology was able to meet its designed goals.

The OntEIR framework validation process went through a two-stage iteration process:

- Iteration 1 was to validate the initial OntEIR framework and use the results to update and develop OntEIR.
- Iteration 2 validated and evaluated the updated and the final OntEIR framework, which was developed into an online tool.

This section of the validation process deals with Iteration 1, in which the initial OntEIR framework was validated and updated.

6.2.1 Interviews and Survey Procedure

This mixed research method of the study aims at exploring the OntEIR framework, in developing and producing complete and successful EIR. For the validation of the OntEIR framework, semi-structured interviews and a survey were conducted using a questionnaire (which can be found in Appendix B). The process of the interview started with a presentation of the OntEIR framework in terms of concepts and components, followed by a detailed look at the framework itself. The presentation was followed by a discussion with the interviewees about the framework, and notes were taken as guidelines for the development of the framework.

The number of interviewees in the same session varied from 1 to 7 participants, and they were selected according to certain criteria:

6.2.2 Selection of Participants for Interviews

The selection of subjects for the study, is considered by many researchers the most important step in the entire process, because it directly affects the quality of the results reached (Taylor and Judd, 1989). For this study, and as in other qualitative interviews, participants were chosen according to their depth of knowledge and experience about the phenomenon under investigation (Robson, 2002; Denscombe, 2014).

Participants were chosen based on having a good understanding of EIR and BIM. Construction professionals in facility and BIM management roles in addition to academics that had an extensive experience in BIM and EIRs in the construction industry are most likely to provide useful input and feedbacks in interviews and questionnaires, which were the main criteria in selecting the participants in the validation of the OntEIR framework.

Twenty participants were selected for the OntEIR framework validation for both interviews and survey. Details of the selected participants are shown in Appendix H.

Figure 6.1 below illustrates the professions of the number of participants involved in the survey:

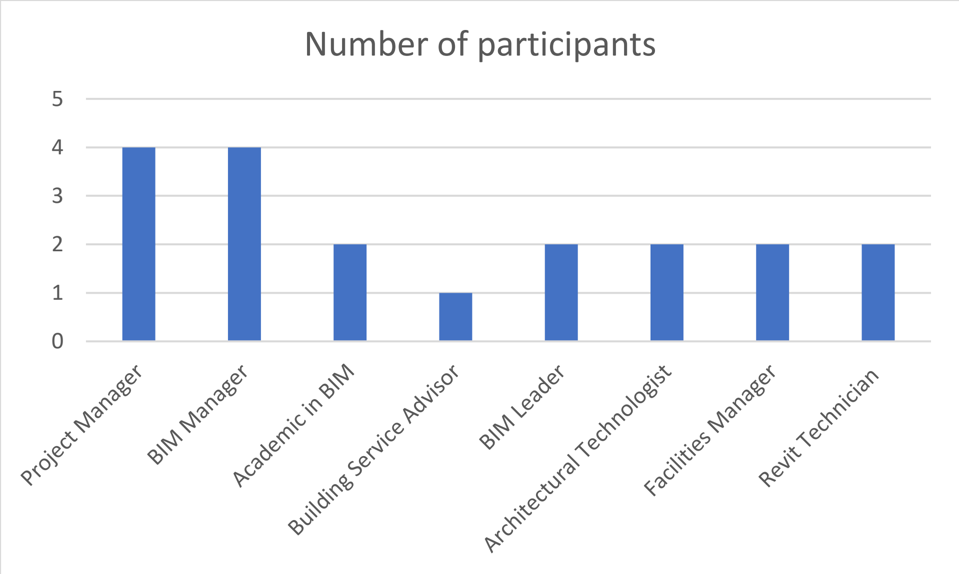


Figure 6.1: Participants in the OntEIR Framework Validation Process

6.2.3 Validation Criteria

The validation criteria are aimed at evaluating the OntEIR framework in terms of:

1- The categorisation of the Employer Information Requirements into static and dynamic;

2- Comprehensiveness of the framework in its ability to produce a full and complete EIR;

3- The understandability of the framework for BIM clients who want to get the whole benefit of the BIM process;

4- Recommendations for the update and further improvement of the framework.

The survey, which could be found in Appendix C, included 26 questions in total that were designed to cover these four criteria. The surveys recorded the feedback of the participants. The feedback sheet contained 26 Likert-scale and open-ended questions, which include:

- 9 Likert-scale questions, in which the categories of ratings include: 0 (Strongly disagree), 1 (Disagree), 2 (Neutral), 3 (Agree), 4 (Highly Agree) and 5 (Strongly agree); and

- 17 open ended questions in which the participant would have more freedom in answering the questions.

6.3 Findings & Analysis

Twenty participants responded to the survey, which consists of 100% of the target. The validation process was designed to obtain feedback and pointers for the update of the framework. As mentioned in Section 6.2 all participants have experience and good knowledge in BIM requirements, and specifically in EIRs and BEPs. Participants attended a semi-instructed interview which consisted of a presentation and discussion of the framework, followed by the 26-question survey. The aim of this validation is to check if the framework managed to achieve the aims set for it, and to validate the new categorisation system for the requirements.

6.3.1 Descriptive Statistics

For the analysis of the validation process, the descriptive statistics were used as an analysis technique. According to Denscombe (2014), Descriptive statistics are often used to uncover the patterns, distributions and peculiarities within a data sample. For data of a univariate type, frequency distributions were considered appropriate (Naoum, 2012). Measures of central tendency were used to identify mean response points with respect to the Likert-scales (Denscombe, 2014).

6.3.2 Relative Importance Index

After identifying the mean response for each question, the Relative Importance Index (RII) formula is applied to support the mean value analysis and rank the criteria that have been validated from strongest to weakest.

The RII will is applied on the ranks that represent very high in the Likert scale (4 and 5), which will allow the identification of the strongest criteria (the one with the highest RII). This will assist the researcher to identify the weaknesses of the framework and ranking its features from strongest to weakest, which will allow for more concentrated development attention on the weakest features for update and improvement of the framework.

According to Babatunde *et al.,* (2010) the formula for the RII is:

$$RII = \sum_{1}^{5} \left(\frac{Ni \times Ki}{Rh \times n} \right)$$

Where:

Ni: Number of respondents choosing rating points 4 and 5 on the Likert scale (Highly agree)

Ki: Rating points used (in this case it will be (4+5)/2=4.5)

n: total number of respondents

Rh: the highest number in the ranking order

6.4 Validation Criteria Results and Analysis

6.4.1 Criteria 1: Categorisation of Requirements and Distinction between Needs and Requirements

This section of the research was to evaluate and validate the concept of categorisation of the needs and requirements into static and dynamic, and the reasoning behind it.

This section was divided into 3 sub-sections:

- The concept of the categorisation into static and dynamic;
- Clarity of the distinction between the 2 categories, and their justification;
- The level of needs in each type, and recommendations for adding new needs or eliminating any of the existing.

The 3 sub-sections were represented with a question regarding a specific aspect of OntEIR, and together covers the idea of the categorising of the requirements introduced in OntEIR:

Question: Do you agree that the categorisation between static and dynamic requirements is right for EIR?

This question was to check whether having two types of requirements (Static and Dynamic) is justified. (Static requirements are the requirements that are defined at the beginning of a project and do not change according to the stage. Dynamic requirements are the requirements that change and develop according to the stage the project is in).

Answers for this question are shown in Table 6.2.

Table 6.1: Categorisation of Requirements

Mean ratings: 0≤mean≤1.5=disagree, 1.5<mean<2.5= Slightly Agree/ 2.5<mean<3.5= Agree/ 3.5≤mean= Highly Agree					
Mean	S.D	Degree of agreement			
		Disagree	Slightly agree	Agree	Highly Agree
4.20	0.93				✓

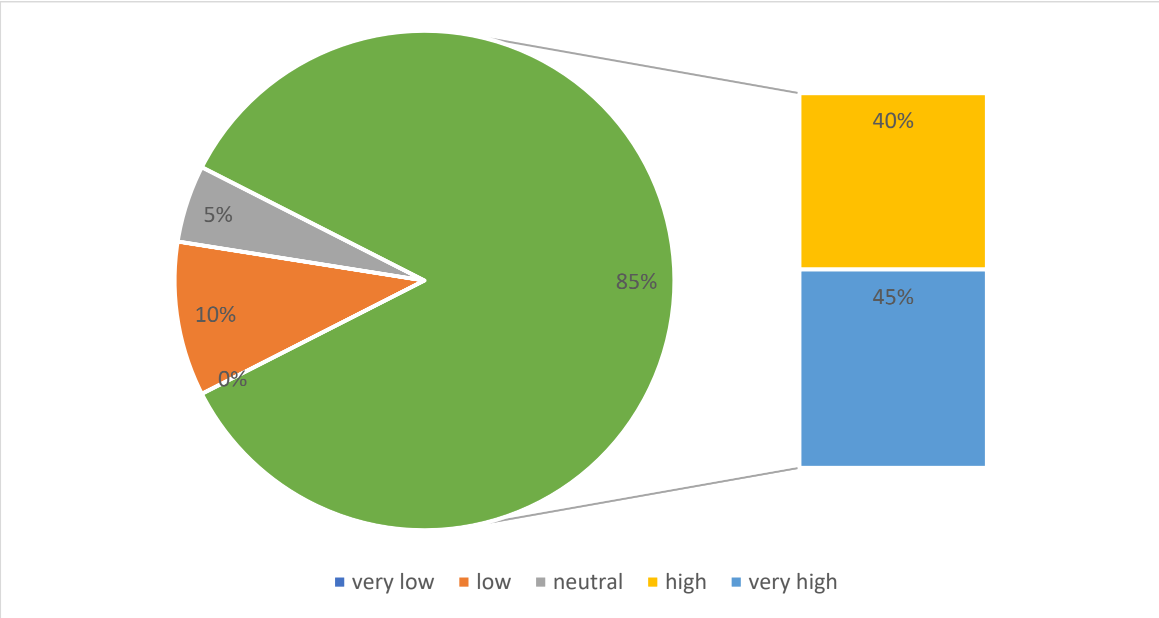


Figure 6.2: Categorisation of Requirements

Results showed that 85% of the participants agreed (high or very high on the Likert scale) with the categorisation of requirements into "static" and "dynamic", and that it is more understandable and made more sense for them, which would make EIR clearer for inexperienced users as well.

In addition to facilitating the understanding of the requirements for the users, the categorisation of the requirements was proposed to also enable the filtering of requirements in a way that would allow stakeholders to access just the information they need for task at hand.

RII for this question was: 0.765, this means that this criterion is strong in terms of responses.

<u>Question: Do static requirements contain the right level of needs?</u>

This question was to check the completeness of the static needs.

Table 6.2: Level of Static Needs

Mean ratings: 0≤mean≤1.5=disagree, 1.5<mean<2.5= Slightly Agree/ 2.5<mean<3.5= Agree/ 3.5≤mean= Highly Agree					
Mean	S.D	Degree of agreement			
		Disagree	Slightly agree	Agree	Highly Agree
3.60	0.66				✓

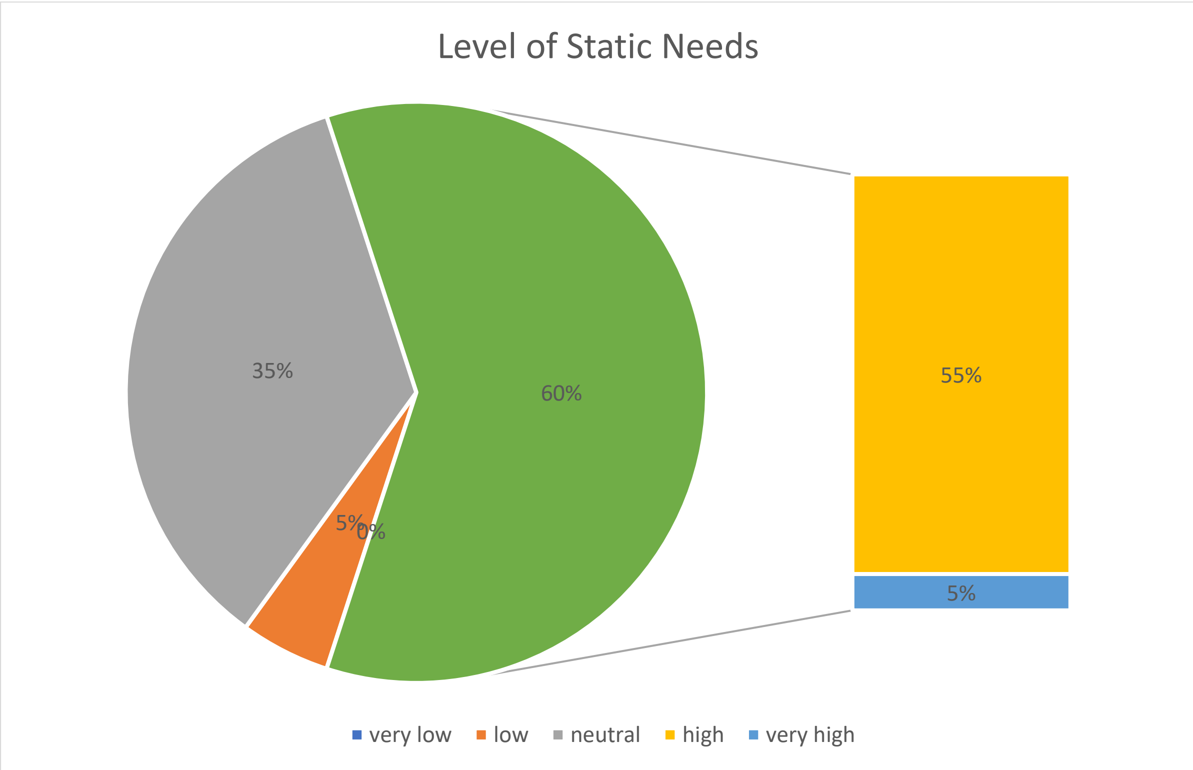


Figure 6.3: Level of Static Needs

In terms of needs covered by the static category 60% of the participants agreed that it is able cover the needs required for a complete EIR. Comments for further improvements included the ability to add client specific requirements.

The RII for this criterion or question was 0.54, which is not a high score, this means improvements have to be made on the level of static needs. This will also be evident in the answers to the open-ended questions and ways to improve, discussed later in Section 6.4.5.

<u>Question: Does the static section contain the right level of requirements?</u>

This question is to check the completeness of the static requirements.

Table 6.3: Level of Static Requirements

Mean ratings: 0≤mean≤1.5=disagree, 1.5<mean<2.5= Slightly Agree/ 2.5<mean<3.5= Agree/ 3.5≤mean= Highly Agree					
Mean	S.D	Degree of agreement			
		Disagree	Slightly agree	Agree	Highly Agree
3.55	0.67				✓

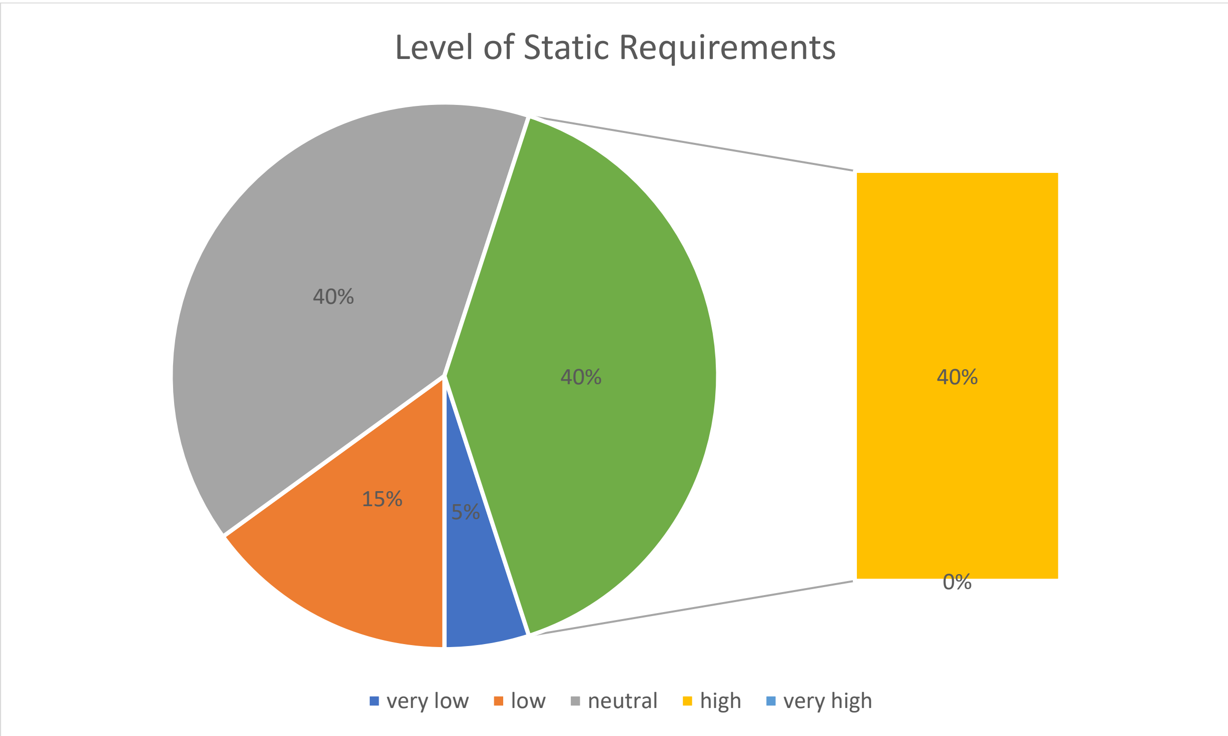


Figure 6.4: Level of Static Requirements

In terms of the requirements covered by the static section, results showed that none of the participants highly agreed that it covers the right level of requirements, 40% agreed that it did, and 40% were neutral. RII for this question was 0.36, which is very low. This compliments the previous question on the level of static needs in the framework. The level of static needs and requirements should be considered for update and improvement, as will be seen in Section 6.4.5.

<u>Question: In the dynamic Section, how well is the dynamic requirements' distinction between needs and requirements justified?</u>

This question is to measure how clear the distinction is between "dynamic needs" and "dynamic requirements" and if it complemented the understandability of the EIR.

Table 6.4: Distinction between Static and Dynamic Needs

Mean ratings: 0≤mean≤1.5=disagree, 1.5<mean<2.5= Slightly Agree/ 2.5<mean<3.5= Agree/ 3.5≤mean= Highly Agree					
Mean	S.D	Degree of agreement			
		Disagree	Slightly agree	Agree	Highly Agree
3.65	0.57				✓

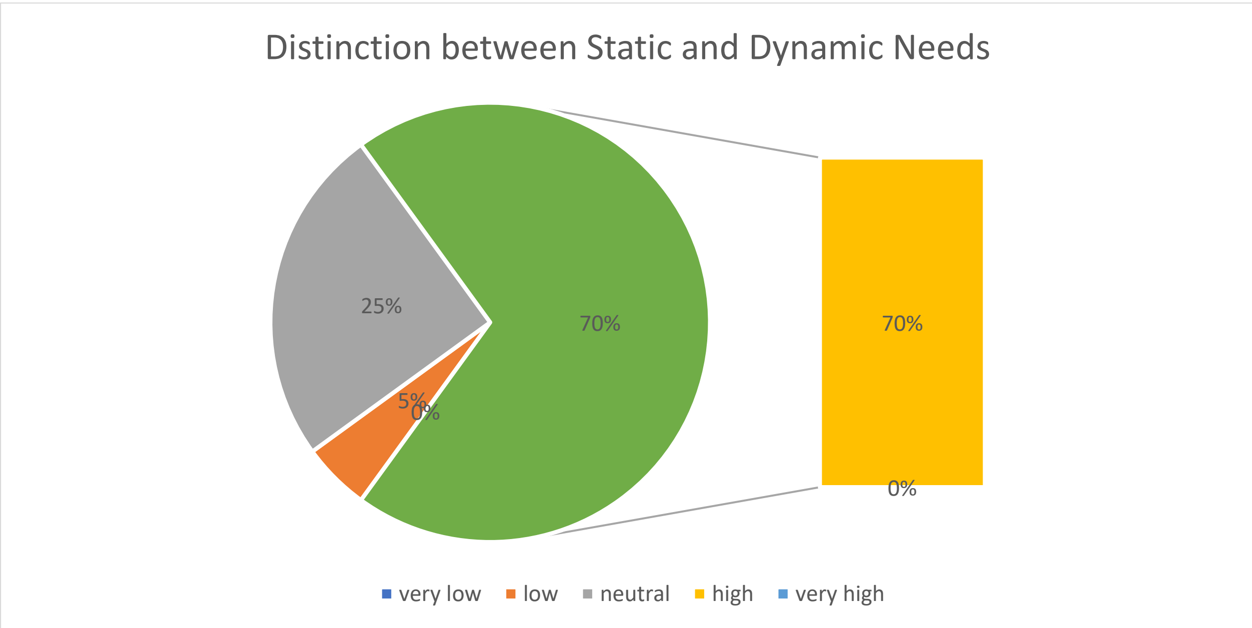


Figure 6.5: Distinction between Static and Dynamic Needs

Although the mean for this question was high, none of the participants rated the distinction between needs and requirements to be very high, and 70% though it was high, RII for this question was 0.63, which means that still some update should take place on the dynamic needs and requirements and will be discussed I Section 6.4.5 later in this Chapter.

<u>Question: Does the dynamic section contain the right level of needs?</u>

This question is to check the completeness of the Dynamic needs.

Table 6.5: Level of Dynamic Needs

Mean ratings: 0≤mean≤1.5=disagree, 1.5<mean<2.5= Slightly Agree/ 2.5<mean<3.5= Agree/ 3.5≤mean= Highly Agree					
Mean	S.D	Degree of agreement			
		Disagree	Slightly agree	Agree	Highly Agree
3.95	0.74				✓

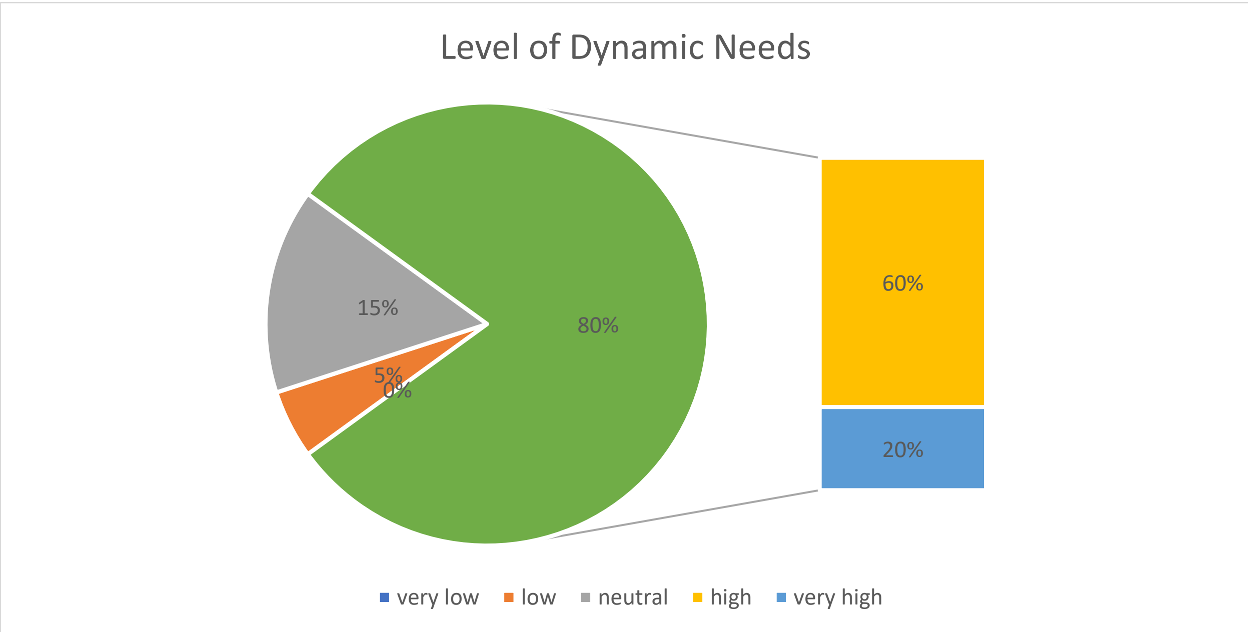


Figure 6.6: Level of Dynamic Needs

The completeness of the dynamic section in terms of containing the right level of needs, scored high in the responds, where 80% of the participants responded that it highly covers the needs. RII for this question scored 0.72

The categorisation of requirements has received high scores in the framework due to the lack of understandability and clarity current practices have to offer in the same field such as the PAS 1192-2:2013 (Ashworth, Tucker and Druhmann, 2017). OntEIR offers an understandable and make sense to the user. It relates directly to the project and is understand by all levels.

6.4.2 Criteria 2: Framework Comprehensiveness

Questions regarding this criterion were set to evaluate to what extent does the full OntEIR framework able to be all-inclusive to all requirements and aspects needed to produce a full and complete EIR, which in turn will be the basis on which a clear and full BEP is produced.

This criterion included the questions:

<u>Question: How comprehensive is the OntEIR framework in defining the requirements for EIR?</u>

This question is to measure the comprehensiveness of the overall framework in covering the appropriate level of requirements needed to create a full EIR.

Table 6.6: Overall Comprehensiveness of OntEIR

Mean ratings: 0≤mean≤1.5=disagree, 1.5<mean<2.5= Slightly Agree/ 2.5<mean<3.5= Agree/ 3.5≤mean= Highly Agree					
Mean	S.D	Degree of agreement			
		Disagree	Slightly agree	Agree	Highly Agree
3.90	0.70				✓

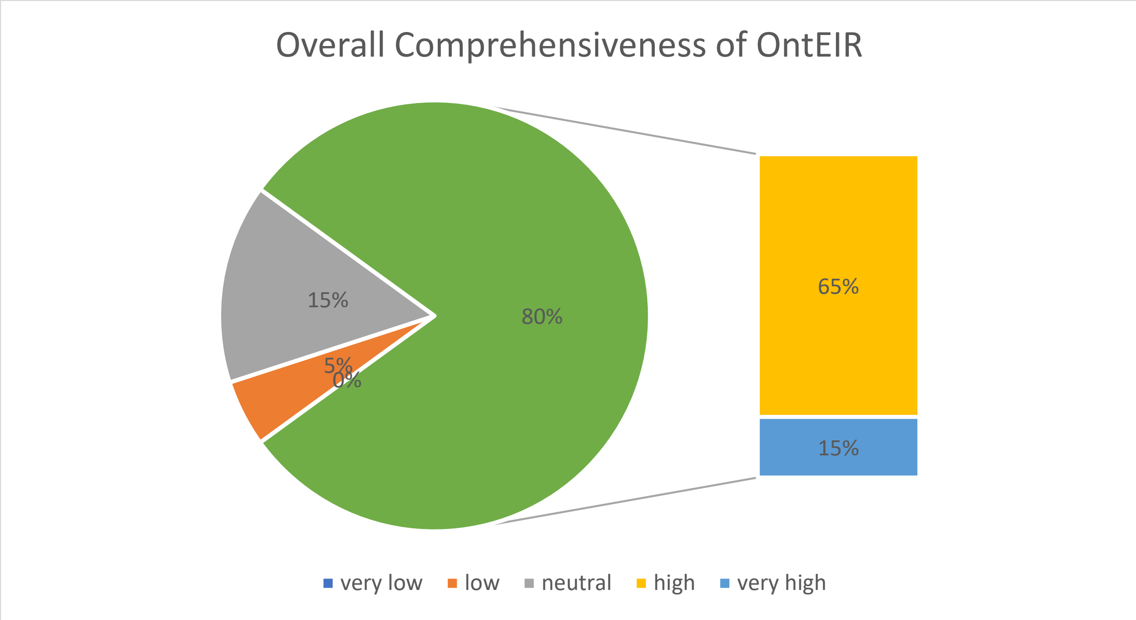


Figure 6.7: Overall Comprehensiveness of OntEIR

For this question, respondents rated the comprehensiveness of the framework to be high in terms of obtaining the level of requirements to create a complete EIR, as seen in Figure 6.7. RII for this question scored 0.72, which means that the comprehensiveness of the framework is one of its strong features.

Comprehensiveness and completeness of the framework is essential for the development of a proper EIR, that is why this validation for the initial framework was conducted with industry professionals. Open ended questions were provided at the end of the questionnaire for participants to include any comments that provide benefit for the update of the final framework, that will be examined in Section 6.6 to come, and adds to the comprehensiveness of it. Results of the open-ended questions included some requirements that were not fully covered in the Static needs (as seen from the answers in Section 6.4.1) and are essential for the complete comprehensiveness of the framework. those requirements will be discussed in detail in Section 6.4.5.

6.4.3 Criteria 3: The understandability of the framework especially for clients

This section is to evaluate how easy it is to understand the OntEIR framework, and the usability for all types of users, especially inexperienced users. It focuses on the concept of breaking needs into requirements, as discussed in Chapter 5 previously, and if it was justified and understood.

<u>Question: In the Static Section, how well is the static requirements' distinction between needs and requirements justified?</u>

This question was to measure how clear the distinction was between "static needs" and "static requirements" and if it complemented the understandability of the EIR.

Table 6.7: Distinction Between Needs and Requirements

Mean ratings: 0≤mean≤1.5=disagree, 1.5<mean<2.5= Slightly Agree/ 2.5<mean<3.5= Agree/ 3.5≤mean= Highly Agree					
Mean	S.D	Degree of agreement			
		Disagree	Slightly agree	Agree	Highly Agree
3.15	0.85			✓	

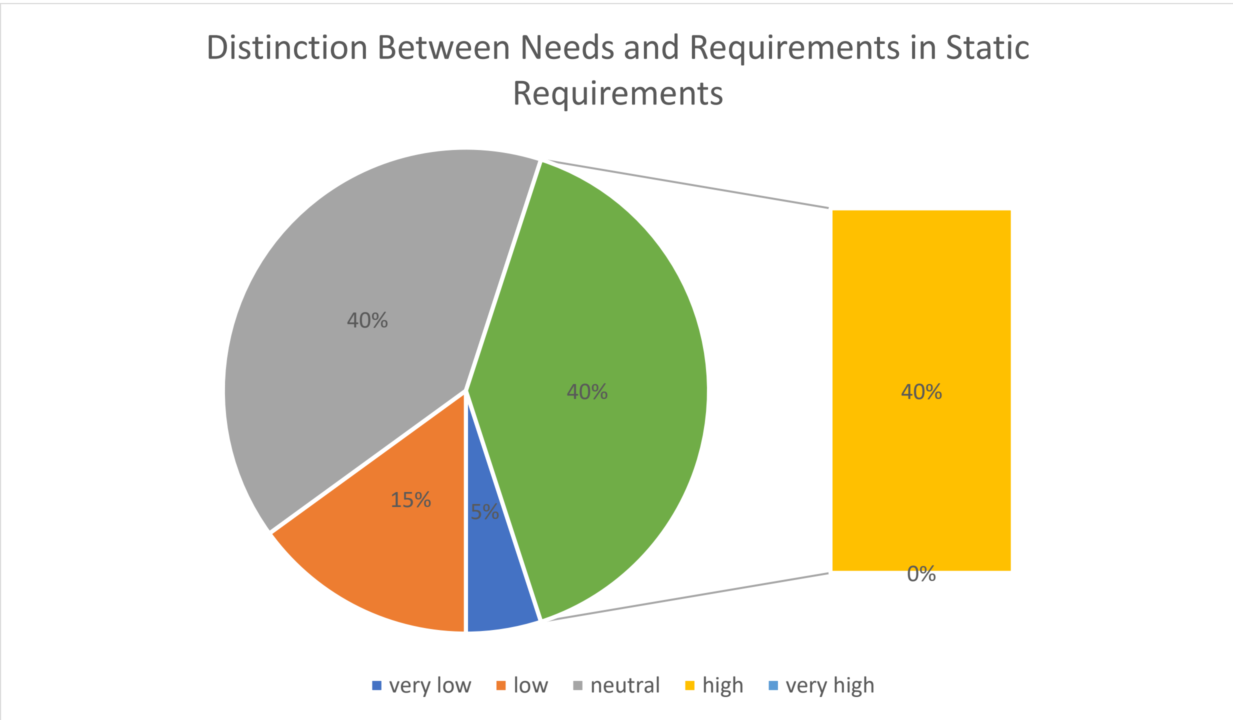


Figure 6.8: Distinction Between Needs and Requirements in Static Requirements

For this question, none of the respondents thought that the distinction between needs and requirements in the static section is very clear, 40% thought it is clear, and 40% were neutral. RII for this question is 0.36, which is a low score. While the score was lower than ideal, this has little consequences on the overall success of the framework because initially the idea of the hierarchy from needs to requirements was introduced to facilitate the elicitation of requirements during the development of the tool.

<u>Question: In the dynamic Section, how well is the dynamic requirements' distinction between needs and requirements justified?</u>

This question is to measure how clear the distinction is between "dynamic needs" and "dynamic requirements" and if it complemented the understandability of the EIR.

As discussed in Section 3.2.1 about the importance of a defining a proper EIR and the struggle clients face with current practices, leaving the industry with only 20% of clients that know how to develop a proper EIR (NBS, 2017), in parallel with a study conducted by Ashworth et al., (2017) in which clients expresses like "walking in a midfield" when trying to understand all the BIM guidance and standards when preparing their EIR, the issue of understandability is very important for clients that are trying to develop a proper EIR.

Table 6.8: Distinction Between Needs and Requirements

Mean ratings: 0≤mean≤1.5=disagree, 1.5<mean<2.5= Slightly Agree/ 2.5<mean<3.5= Agree/ 3.5≤mean= Highly Agree					
Mean	S.D	Degree of agreement			
		Disagree	Slightly agree	Agree	Highly Agree
3.65	0.57				✓

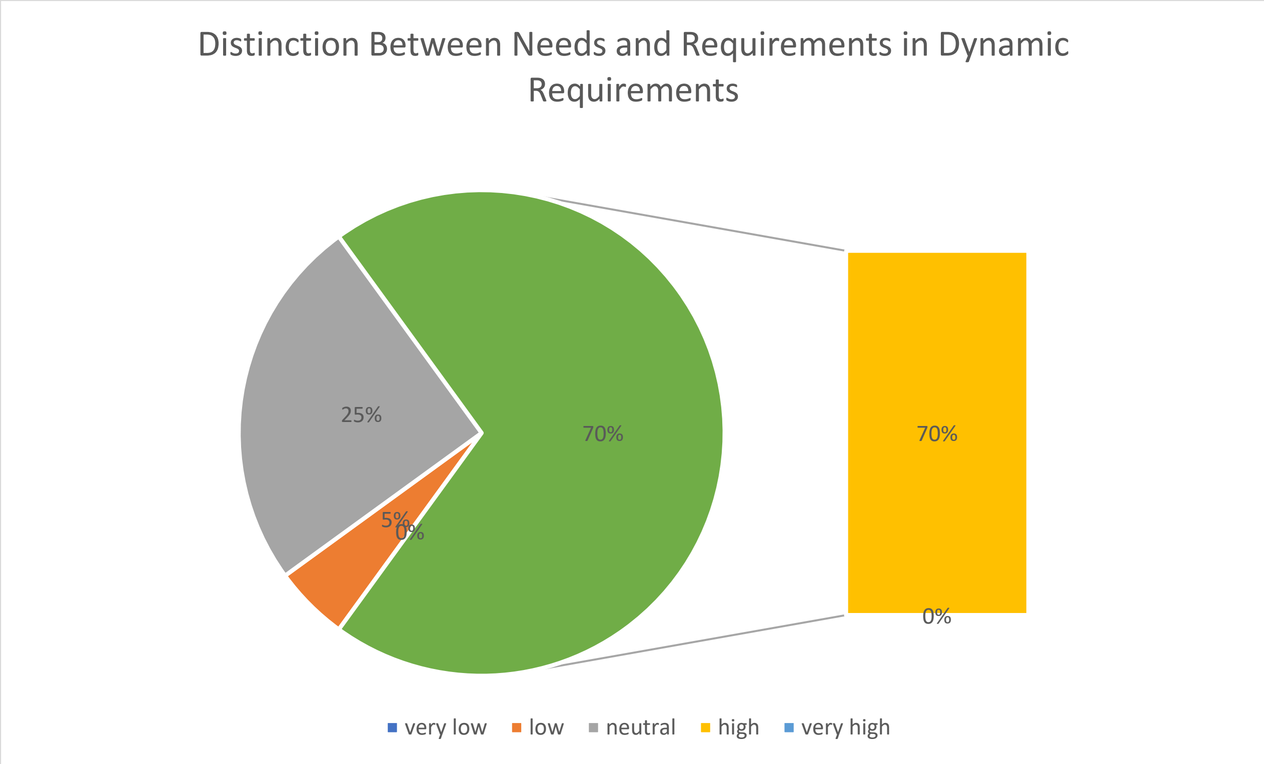


Figure 6.9: Distinction Between Needs and Requirements in Dynamic Requirements

For the dynamic section, none of the participants responded that the distinction between the needs and requirements are "highly" justified, while 70% only agreed with the distinction. RII for this question= 0.63. the distinction between the needs and requirements in the dynamic section had a higher RII than its equivalent in the Static section was due to it being less complicated. But also, this feature has little consequences on the overall success of the framework, because it was presented originally to facilitate the elicitation of requirements.

6.4.4 Initial Framework Focus Group

The first focus group conducted for this study was aimed at discussing the initial OntEIR framework. this focus group took place at Airbus in Filton, Bristol. Nine experts attended this focus group, details of the roles attending are shown in Table 6.9; for confidentiality reasons names of the attendants were replaced with ID numbers:

Table 6.9: Participants in the Airbus Focus Group-Ids and Roles

Participant ID	Role
FG1	Facilities Management
FG2	Facilities Management
FG3	Facilities Manager and Construction Project Manager
FG4	Facilities Processes and BIM Expert
FG5	Facilities Processes and BIM Expert
FG6	Construction Project Manager (facilities)
FG7	Client (Manufacturing facilities)
FG8	Construction Project Manager (Manufacturing facilities)
FG9	Client (Manufacturing facilities)

The roles chosen for this focus group was according to the involvement of this role with the information requirements provided by in the AIM. Therefore, since the framework and tool are aimed to specifying the Information Requirements for the client, it was considered fitting these roles to provide evaluation to determine how the framework can affect the identification of the EIR, of which they are involved. The process designed for the evaluation of the framework in this focus group is illustrated in Figure 6.10.

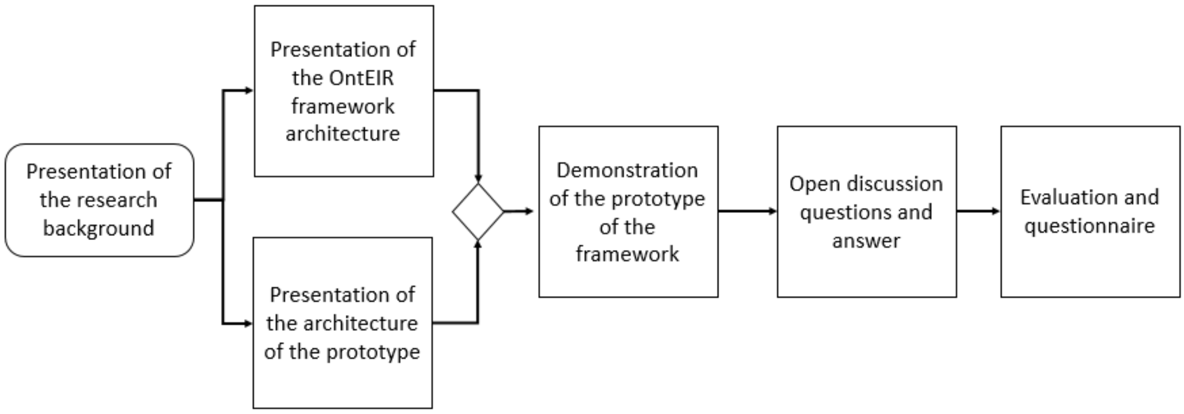


Figure 6.10: The Focus Group Evaluation Process

At the beginning, a power point presentation was presented by the researcher to outline the research and challenges facing the current practices in EIR. It also outlined the concepts of categorisation and the elicitation process used in the OntEIR framework. The OntEIR framework was then presented and all components discussed in detail. Then the architecture of the OntEIR prototype tool was presented with all its components and relations.

For this evaluation, a prototype of the OntEIR tool and its architecture was also presented as means of implementing the OntEIR framework. This was done by means of the following steps:

1- A demonstration of the web-based tool architecture and components. This was done through explaining to the participants the functionalities of the tool, the interface of the tool, the menu, and data entry.
2- A demonstration of how users log into the user interface, how to save and edit information and the relation between the different requirements in the tool.
3- After the presentation of the framework and the demonstration of the tool, the floor was open for discussion where the participants discussed freely and commented on the presentations. Questions and answers were also encouraged and made through the course of the discussion.

A quantitative approach was used to present the data which was then analysed and discussed. The questions/questionnaire was designed to capture both qualitative and quantitative data. Two types of evaluations were also conducted: formative and summative. Formative evaluation is applied to provide feedback for those who are trying to develop something (Gray, 2014), and the summative evaluation is applied to provide feedback on how effective a system is in achieving its aim. Therefore, the triangulation method was used for the collection of the evaluation, and presentation and analysis.

6.4.5 Recommendations for framework update and improving

Many things interfere with the analysis of the framework and the fields of improvement. In the previous sections the criteria for the framework validation were discussed and results to each question were presented. This section will discuss:

1) The open-end questions and notes from the interviews on how to improve the framework in terms of what requirements should be added in both the static and the dynamic categories, what requirements should be removed and general thoughts about the framework; and
2) The weaknesses of the framework in terms of the lowest point of the RII for each question and ways to improve in the framework update and tool which will be presented in the next section.

6.4.5.1 Discussing the Open-ended Questions and Interviews

In addition to the Likert questions which were analysed and discussed in the previous section, the questionnaire also contained open-ended questions, in which the participant could answer freely without restrictions about suggested areas of improvement for and updates of the framework. Also, interviews that were conducted with the participants prior to the survey, offered a rich source of qualitative data for the validation and update for the framework.

Table 6.10 below shows the areas of improvements and updates discussed.

Table 6.10: Areas of Improvements and Update of the Initial Framework

Question	**Remarks**
In the static section, what requirements should be added?	- CDE - Clash detection frequency - AIM delivery strategy
In the static section, what requirements should be removed?	All participants answered with "None"
In the dynamic section, what requirements should be added?	More detail in the Asset Information Requirements Classification system to be used should be specified (UniClass, NRM…)
In the dynamic section, what requirements should be removed?	All participants answered with "None"
Additional comments on the overall OntEIR framework?	RIBA stages would be more comprehensive to use in with the industry stakeholders instead of the PAS stages used.
Sample Quotes: - Looks like a very good approach and very useful - Seems like a very good and helpful framework in general - A very useful and well configured framework	
What do you think is the strongest feature of the OntEIR framework?	
Sample Quotes: - The comprehensive overview of BIM aspects - It focuses the users and guides them through the different aspects he/she needs to think of when developing the EIR.	

- That it incorporates the fact that during the stages we need the same things but at an increasing level of detail and maturity
- That one can decide which level of detail is needed in which stage, and in general the distinction between static and dynamic requirements.
- It allows for increasing or specific levels of detail depending on the various stages, which is more realistic.

6.4.5.2 Identifying the weakest features of the OntEIR framework and ways to improve

In this section, the criteria of the validation will be arranged according to their RII from weakest to strongest with discussion on how to improve. Table 6.11 discusses the strongest and the weakest features of the Framework and ways to improve

Table 6.11: Weakest to Strongest Criterion and Ways to Improve

Criterion	**Highly agree**	**Agree**	**RII**	**Discussion**
Categorisation of the requirements into static and dynamic	45%	40%	0.765 (high)	No action needed
	Strongest Feature			
Does the static section contain the right level of needs?	5%	55%	0.34 (low)	As seen in the interviews and open-ended questions discussed in the previous section, participants believe that there are still some static needs and requirements to be covered in the framework and tool. Those requirements include: CDE requirements, AIM requirements, communication requirements
	Weakest Feature			
Does the static section contain the right level of requirements?	0%	40%	0.36 (low)	

6.5 Discussion of Framework Validation

"OntEIR focuses on users and guides them through the different aspects they need to think of when developing an EIR" (Participant in the validation).

The OntEIR framework has been introduced in the construction industry, as a means to define better quality, in particular, more complete sets of Employer Information Requirements (EIR) for BIM projects. OntEIR adopted the categorisation of the requirements in the EIR, into two main high-level types of "static" and "dynamic" requirements. The categorisation of the requirements in OntEIR was based on the relations and links they have with the other requirements and the other parts of the OntEIR framework, such as the stages.

Based on the first iteration validation of the framework, and according to the criteria, it was found that pariticipants found that the OntEIR framework has done well regarding all criteria. The overwhelming majority percieved the framework to be understandable and clear. However, based on the comments given by the participants during both the surveys and interviews, update of the framework in terms of stages used, AIM delivery strategy, classification system to be used, where some of the participants prefer the use of UniClass or NRM, in addition to other comments regarding giving the user more involvement if defining the requirements.

According to the results and findings of Iteration 1, the update of the findings will maintain the categorisation system used (Static and Dynamic) due to the overall agreement of the participants with it. However, some modifications to other aspects of the framework had to go under work, to make it more comprehensove, complete and understandable for all types of users using the OntEIR framework.

6.6 Revisiting the OntEIR Framework

In light of the results and findings of the validation process, the OntEIR framework went through a number of modifications and updates. Results of the Framework validation showed that the majority of the participants (85%) agreed with the categorisation system (Static and Dynamic) presented in the framework.

Also, there was and overall satisfaction of the information presented in the framework and the requirements covered. However, and during the interviews conducted with the participants, and when analysing the open-ended questions in the survey, which allowed the participants to present their input on the framework, it has been found that an update and development of the tool was needed to make it more comprehensive and complete for the BIM users in the industry.

6.6.1 Update of the Static Needs and Requirements

After the analysis of the validation of the initial OntEIR framework, results and findings have shown that the there is a need for further covering of needs and requirements in the static section. Participants agreed on adding the "needs":

- Communication: Coordination and Clash Detection
- Asset Information Model (AIM) Delivery Strategy

Communication: Coordination and Clash Detection

Dubas and Paslawski (2017) argue that communication in BIM is crucial for the correct execution of the project, due to the need for information exchange between the stakeholders to achieve an obtained goal.

Park et al. (2013) discuss the problems that might negatively impact the construction quality and could be overcome by using proper communication strategies:

1- Data loss: which is due to the way information is stored and exchanged;
2- Workload; and
3- Revealing defects after they appear.

Communication in OntEIR is done at two levels: (1) communication between the parties involved in the delivery of the project which includes the data exchange, coordination of responsibilities and the clash detection; and (2) communication between the stakeholders and the client, in terms of exchange of information and the client decision points. It is important to mention that the communication of data is done through the CDE, which is the common single space agreed by all stakeholders involved in the project and is where all the data is stored and exchanged. Figure 6.11 below illustrates the level of communication covered by OntEIR.

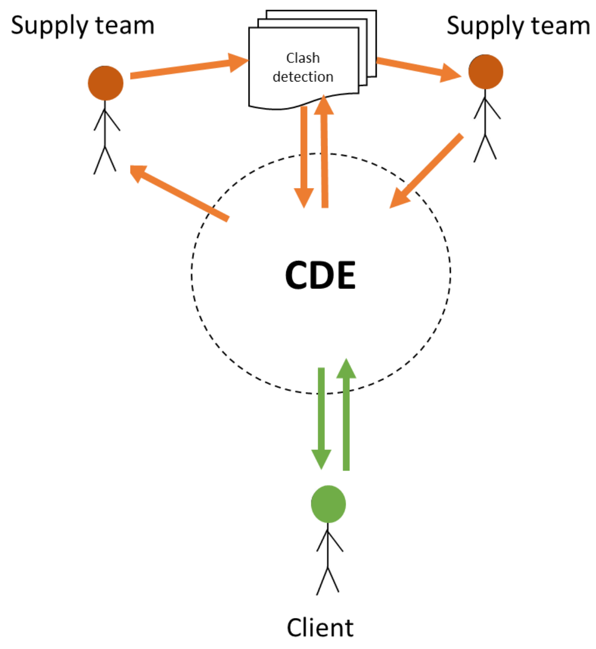


Figure 6.11: Communication involved in the BIM project

Thus, the requirements included in the “communication” needs include:

- CDE: in which the Common Data Environment is defined;
- Frequency of information exchange;
- Clash detection process;
- Clash resolution process;
- Clash detection responsibility;
- Other communication fields that the client feels should be defined.

Asset Information Model Delivery Strategy

In this need, the client defines the requirements of the AIM, which is the model expected to be delivered at the completion of the delivery phase. It includes the requirements needed for the model format, and how the information is transferred into an existing or proposed facility management system, in addition to the classification system to be used in the Asset Information Requirements (AIR) that would eventually make up the full model.

Consequently, the requirements included in this need are:

- Information exchange format;
- Standard classification system; and

- CAFM software.

6.6.2 Update of the Dynamic Needs and Requirements

During the validation of the initial OntEIR framework presented in Chapter 5, and validated in Chapter 6, results and findings have shown that the there is a need for further covering of needs and requirements in the dynamic section. Participants agreed updating and developing the following "needs":

- Project stages;
- Asset Information Requirements (AIR) and the COBie deliverables;
- Definition of LOD and LOI.

Project stages

In the first OntEIR framework, the stages involved in the dynamic stages were based upon the PAS 1192-2 (bsi. 2013) stages, which included:

- Stage 2: Concept
- Stage 3: Definition
- Stage 4: Design
- Stage 5: Build and Commission
- Stage 6: Handover and Closeout
- Stage 7: Operation and End life

According to the participants of the validation, the RIBA stages would be preferable to be used in EIRs. It is argued that the RIBA Plan of Work provides the most detailed definitions of what should be undertaken within a project stage and should probably be used as the starting point for defining the requirements for the projects.

Level of Definition (LOD) & Level of Information (LOI)

The initial OntEIR framework discussed the LOD & LOI as them being an important part of the development of the model throughout the stages, in fact, LOD and LOI play an integral part in defining the maturity and development of the model.

During Iteration 1 of the validation process, participants debated that there should be more definition for the LOD and the LOI in the OntEIR framework. This means the framework should define which level of detail and level of information definitions it adopts, due to the fact there are many definitions that would affect the maturity of the model.

Iteration 2 of the OntEIR framework validation adopted the PAS 1192-2 (bsi, 2013) definition for the LOD and the LOD of the model, but also giving the user the freedom to also chose their own definitions too, Table 6.12 shows the definitions of the LOD and the LOI used in the update of the OntEIR framework.

Table 6.12: Updating LOD and LOI in the OntEIR Framework

LOD	Definition	LOI	Definition
LOD 2 (Conceptual)	Graphical representation of element, dimensionally accurate.	**LOI 2**	Provide an outline description of the deliverable.
LOD 3 (Approximate Geometry)	The model element is graphically represented in the model as a generic system, object or assembly with approximate quantities, size, location, and orientation	**LOI 3**	Provide information relevant to the specific performance of the deliverable
LOD 4 (Precise Geometry)	The model element is graphically represented in the model as a specific system, object or assembly with accurate quantities, size, location, and orientation	**LOI 4**	Information to specify the completion (cleaning, testing, spares, training…) of the deliverable should also be provided in the associated specification.
LOD 5 (Fabrication)	The model element is graphically represented in the model as a specific system, object or assembly with accurate quantities, size, location, and orientation and with detailing fabrication	**LOI 5**	Provide information relevant to the specific child products of the deliverable to allow suitable products from manufacturers to be selected. Information covering the completion and execution of the

	assembly, and installation information		deliverable and its child products should also be provided.
LOD 6 (As Built)	The model element is a field verified representation accurate in terms of size, location, quantity, and orientation.	**LOI 6**	Provide information relevant to the specific child products of the deliverable to allow for purchasing. Information covering the completion and execution of the deliverable and its child products should also be provided.

6.6.3 The Final OntEIR

After conducting the validation process on the initial OntEIR framework presented in Chapter 5, and analysing the responses received from the participants during the interviews and the surveys, the update was conducted on the initial OntEIR framework, to reach the final form.

Figure 6.12 provides an overview of the final OntEIR framework, with the necessary modifications due to the points discussed in Sections 6.6.1 and 6.6.2.

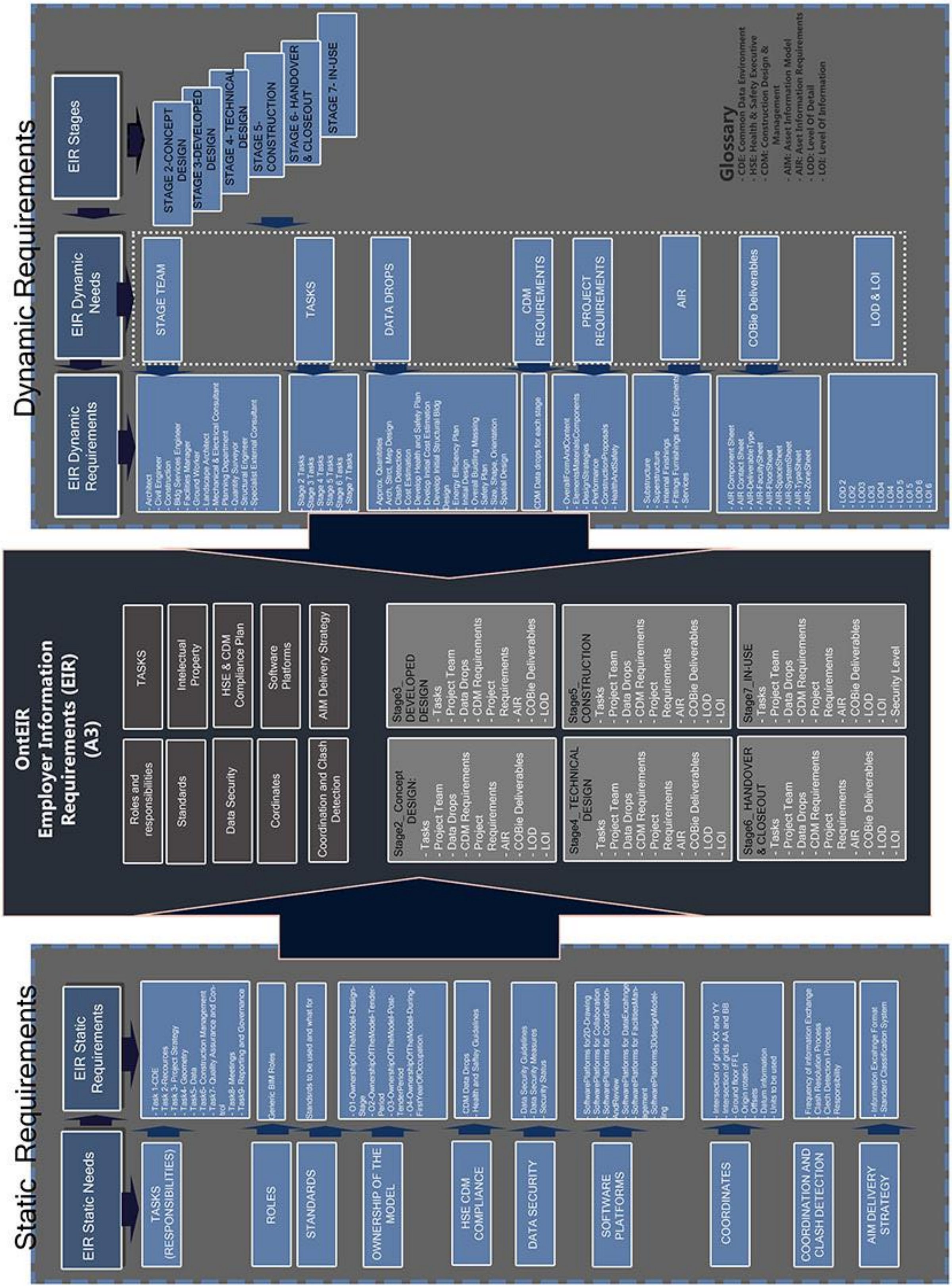


Figure 6.12: The Final OntEIR Framework

6.7 Chapter Summary

This chapter discussed two important steps in developing the final OntEIR Framework: the validation of the initial framework, and the update of the framework based on the analysis of results of this validation.

The validation process was conducted with experts in the industry through semi-structured interviews and a survey. The aim was to measure the framework according to certain validation criteria that aimed at testing the categorisation system used, the comprehensiveness of the framework and the clarity and legibility of the framework. Results showed that the overwhelming majority of the participants agreed with the new categorisation of the requirements into static and dynamic. And although results in the other criteria were positive, the framework still had room for update and improvements.

The update of the framework was conducted based on the answers for the open-ended questions in the survey, and the discussions that took place in the interviews and the focus groups.

At the end of this chapter, the final OntEIR Framework was presented which was and update of the framework presented in Chapter 5, based on the ideas and responds presented by the industry experts.

Chapter 7 The Development and Validation of the OntEIR Tool

7.1 Introduction

In the first section of this chapter (Section 7.2), the concept of the OntEIR tool is explained, how information for developing it was prepared, and how the tool functions were specified. Then the used technologies in developing and designing the tool were presented.

The second section demonstrates the tool by providing screen shots of the different tool functions and a description of each function (Section 7.3). Section 7.4 presents the validation of the tool using an online structured survey that was aimed at a population of professionals with different levels of experience in BIM and EIR. In addition to that a case study with a major contracting company in the UK, including a subsequent survey with participants, was used to compare OntEIR in terms of its completeness and comprehensiveness of the EIR developed in both cases. Section 7.5 concludes the chapter and provides a summary.

7.2 Developing the OntEIR Tool

The OntEIR Tool was developed as a way to assist clients in developing their EIR according to the OntEIR framework that was developed, discussed, validated and updated as explained previously.

Having a digital platform to define the client requirements has been shown to overcome many setbacks of the paper-based information process. As Dugar (2015) argues, the traditional way in using a paper-based process makes it difficult to access the information, understand or query, slow to produce or change, prone to errors that lead to a lot of duplicated efforts.

The OntEIR tool was developed for clients to enable them to define their information requirements as necessary for the BIM process, and as found in the AIM. OntEIR adopts a process that is easy to understand and thus allows for a more complete identification of requirements and better quality EIRs.

The OntEIR tool was developed based on the final OntEIR framework presented in section 6.6.3, applying a systematic process.

The development of the OntEIR tool could be summarised in the following steps:

1- Loading all the information and requirements found in the OntEIR framework into Microsoft Excel spreadsheets that can be subsequently implemented in an online tool.
2- Designing the OntEIR page in a way that it is divided into two types of requirements and needs: the general needs: that represent the static needs in the framework, and the stage needs that represent the dynamic needs.
3- Preparing the definitions for each need.
4- Defining the functional and non-functional requirements of the tool.
5- Choosing appropriate technology to develop the tool (the data base and the programming language).
6- Uploading the tool online.

The next sections will discuss these steps in detail:

7.2.1 Preparing the Excel Sheets

The first step in developing the OntEIR tool was the preparation of the Excel spreadsheets, which held all the information and generic requirements that will be presented in the tool.

As is the case in the framework, in which two types of needs are introduced: Static and Dynamic; the tool is divided into two parts: general requirements (which represent the static needs and requirements in the framework), and stage requirements (that represent the dynamic needs and requirements in the framework). The information in the Excel sheets included:

- The high-level needs;
- The requirements included in that need;
- The method of defining the requirement: by text, by choosing from a drop-down list, or by checking a box.

Table 7.1 shows the Excel sheets involved in the development of the tool and the information associated with them.

Table 7.1: Excel Sheets Prepared before the development of the tool

General requirements	
High-level Need	**Type of information input**
Project information	Text
Roles	Text and check box
Responsibilities	Check box and choose from drop down list
Project team role	Text and check box
Standards	Check box
Ownership of the model	Check box and choose from drop down list
Data security measures	Check box
Software platform	Text
coordinates	Text
Communication: coordination and clash detection	Text
AIM delivery strategy	Text
Stage requirements	
Stage definitions	Text
LOD and LOI definitions	Check box OR text
Data drops	Check box
Performed by	Drop down list
Data security status	Drop down list
Project requirements	Drop down list
LOD	Drop down list
LOI	Drop down list

Responsibility of	Drop down list
Delivery format	Drop down list
AIR	Drop down list
COBie	Drop down list
AIR responsibility	Drop down list

The complete set of the Excel sheets with all the needs, requirements, and methods of input can be found in Appendix D.

7.2.2 Specifying the Tool Requirements

The next step was to specify the requirements associated with the OntEIR tool and its performance. Those requirements should be able to specify what the tool will do, and how it will do it. Two high-level types of requirements had to be specified for the tool: non-functional requirements and functional requirements.

7.2.2.1 The OntEIR Tool Functional Requirements

The Functional Requirements Specification documents the operations and activities that a system must be able to perform. Functional Requirements in general should include:

- Descriptions of data to be entered into the system
- Descriptions of operations performed by each screen
- Descriptions of work-flows performed by the system
- Descriptions of system reports or other outputs
- Who can enter the data into the system?

The Functional Requirements Specification should be designed to be read by a general audience. Readers should understand the system, but no particular technical knowledge should be required to understand the document.

For the OntEIR tool, the functional requirements specified included:

1- The OntEIR tool shall provide a multi-phase-workflow form.

2- The OntEIR tool shall have an admin panel, which allows a declared admin to create and delete users.

3- The OntEIR tool shall allow users to view all their old submissions.

4- The OntEIR tool shall allow users to view the project information for each submission.

5- The OntEIR form shall be divided into stages.

6- The OntEIR tool shall display a consent letter for the user to accept before allowing the use of the form.

7- The OntEIR tool shall allow imports and exports of excel and PDF formats.

8- The OntEIR tool shall allow users to save, submit and re-visit to edit the form, download in CSV and pdf formats the empty form or their submissions, and delete their submissions.

7.2.2.2 The OntEIR Tool Non-Functional Requirements

This type of requirements describes “how” the software would do what it does. For example: software performance requirements, external interface requirements, design constraints, and software quality attributes.

For the OntEIR tool, the list of non-functional requirements included:

1- **Authentication:** The OntEIR tool shall enable only authorised users to access the form, i.e. those registered by the administrator.

2- **Authorization levels**: the OntEIR tool allows two authorisation levels; the administrator and the user:

- Admin role: the OntEIR tool shall allow the administrator to create, delete users, in addition to all user role privileges.
- User role: the OntEIR tool shall allow the users to only create, save, submit a new form; or view, edit or delete their old submission(s).

The Admin role should not be able to edit users’ submissions; the Admin should only be able to delete, view and download reports.

3- **Reporting Requirements:** OntEIR tool shall track the time required to complete the form and give the ability to download user submission in different formats.

4- **Historical Data**: the OntEIR tool shall store user submissions, and give the user the ability to edit, view and delete his/her submissions.

5**- Legal or Regulatory Requirements:** OntEIR users shall accept terms and conditions before being able to use the form.

7.2.3 Used Technologies

It is important to point out that the researcher did not develop the tool herself, it was outsourced under her guidance, and discussions with the programmer resulted in the selection of the enumerated choices. Even though the tool was developed by an outsourced programmer, the researcher was driving the development of the software to implement the OntEIR framework in a working software tool for the research purposes.

For the OntEIR tool to be developed, three main things had to be addressed:

1- Choosing the appropriate database;
2- Choosing the programming language;
3- Uploading the tool on a website server.

7.2.3.1 Choosing the Appropriate Database

The OntEIR Tool was developed as a web-based tool, to make it more accessible for the different users and be disseminated to end users more quickly. The first necessary step in doing this is to identify the database that will be used. A Database is essential for the tool for the following reasons (Fan, 2010; Han, Song and Song, 2011):

- High concurrency of reading and writing with low latency;
- Efficient storage of large volumes of data and access requirements;
- High scalability and high availability;
- Lower management and operational costs.

It is essential that the appropriate type of Database be used, and for the OntEIR tool, the non-relational (NoSQL) database was used. The main advantages of NoSQL databases are the following:

1) They allow for quick data reading and writing;

2) They support mass storage;

3) They are easy to expand; and

4) They are low cost (Han *et al.*, 2011).

For the OntEIR tool, form inputs were expected to have many nested data and users are expected to add new fields. This would mean that the structures would have different schemas. Therefore, a non-relational (NoSQL) data base was more convenient to use. And for that the Mongo Data Base was chosen for OntEIR.

The MongoDB is a non-relational data base (MongoDB., 2018), the features it has made it the best candidate for OntEIR:

I) It is a non-relational database, which features the richest and most like the relational database;

2) It supports complex data types: MongoDB supports JSON data structures to store complex data types (MongoDB., 2018);

3) It offers a powerful query language: it allows most of the functions like query in single-table of relational databases, and also supports index search.

4) High-speed access to mass data: when the data exceeds 50GB, MongoDB access speed is 10 times faster than that of MySQL. Because of these characteristics of MongoDB, many projects with increasing data are considering MongoDB (MongoDB., 2018).

7.2.3.2 Programming

There are two types of communications involved in the OntEIR tool process, the backend and the frontend.

The frontend development:

Definition: Front end development manages everything that users visually see first in their browser or application. Frontend developers are responsible for the look and feel of a site.

For the OntEIR tool:

- The frontend programming language used was JavaS (JAVA, 2018);
- The layout used was based on Thymleaf (Thymleaf., 2018);
- The following plugins/Libraries were used: jQuery, jQuery steps, Chosen, Bootstrap, html2canvas, sweetalert2, json.human.js, jquery.serializeJSON.

The backend development:

Definition: Back end development refers to the server side of an application and everything that communicates between the database and the browser.

- Framework: Spring
- Application Server: Tomcat
- Database: Mongo DB

7.2.3.3 Uploading the OntEIR Tool on a Website Server

For the purpose of uploading the OntEIR tool onto a website server an existing server hosted by the University of the West of England was used, i.e. the “hbim.org”. The OntEIR programme was uploaded on this website after transforming it into an .HTML language using “Thymeleaf”.

“Thymeleaf is a Java library. It is an XML/XHTML/HTML5 template engine able to apply a set of transformations to template files in order to display data and/or text produced by your applications”. (Thymeleaf Tutorial, 2017). The tool now was ready to be used, as will be demonstrated in the next sections.

7.3 Demonstration of the OntEIR Tool

The OntEIR online tool, was developed based on the technologies and tools explained in section 7.2, and the validation points raised by the participants in chapter 6.

Before programming the OntEIR tool, all data were emptied in Microsoft Excel, as shown in the Excel spreadsheets in Appendix D. The spreadsheets included the needs and requirements for both the Static requirements and the Dynamic requirements.

The information structure contained in the Excel spreadsheets were then implemented using JAVA to visualise it in the OntEIR tool.

The interface for the tool differs depending on whether one requests access as user or admin. Usernames and passwords should be defined by the admin for them to access the tool, which was done for validation reasons that will be explained in iteration 2 of the validation process later.

In the following the development of a full EIR using OntEIR is presented step by step.

In the main menu page, shown in Figure 7.2, the user sees two types of requirements, on either side of the page: General Requirements, which represent the static requirements in the OntEIR framework, and Stage Requirements, which represent the dynamic requirements in the framework.

For each page of the tool, there are three options:

- Previous page
- Next page
- Submit/save (This allows the user to save the work for later use or submit it when completed.)

Before clicking any of the needs, it shows them in grey colour, as seen in Figure 7.1. When they are active they are shown in navy colour, and when they have been completed they turn into dark blue colour. This allows users to visually keep track of their progress.

The next sections will illustrate each of the selections in detail.

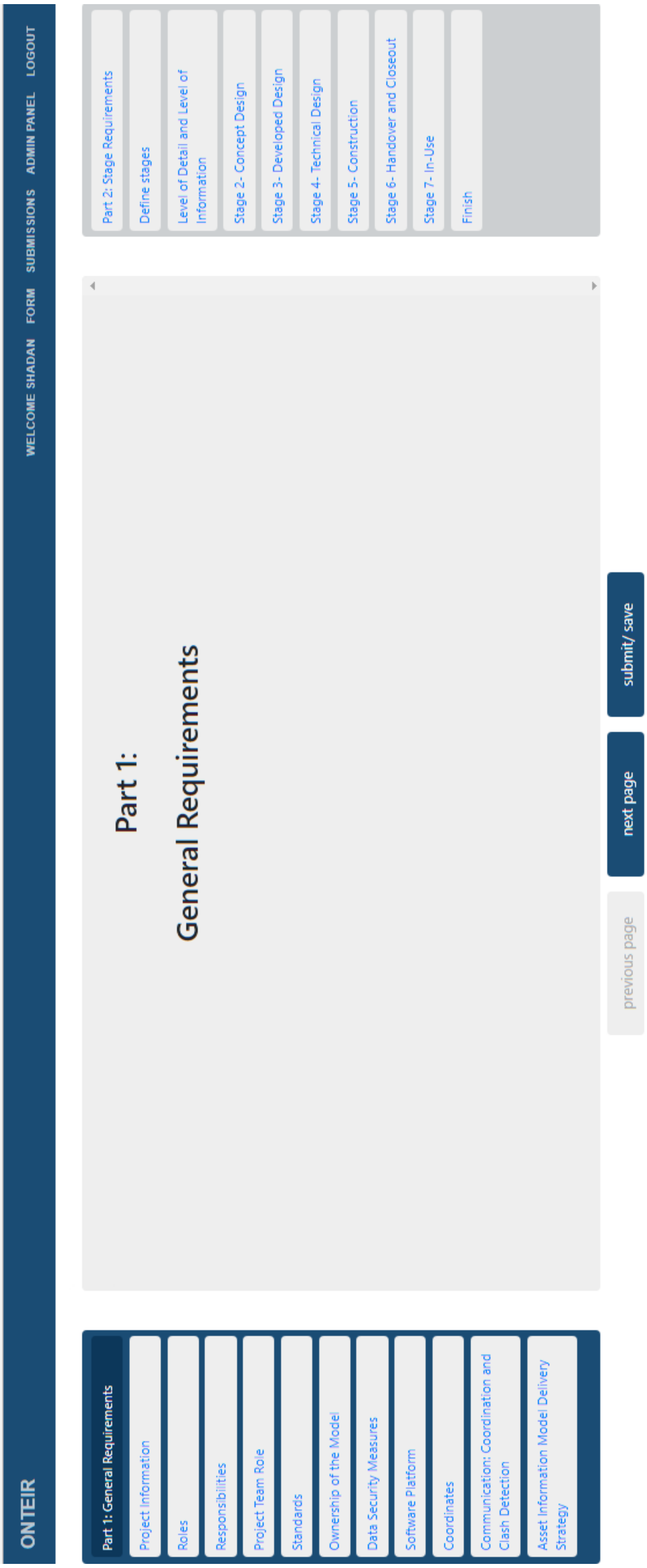


Figure 7.1: OntEIR Interface – The Main Menu

7.3.1 The General Requirements

As mentioned above, the general requirements represent the static requirements in the framework, and include the following needs:

- Project information;
- Roles;
- Responsibilities;
- Project team role;
- Standards;
- Ownership of the Model;
- Data Security Measures;
- Software Platform;
- Coordinates;
- Communication: Coordination & Clash Detection;
- Asset Information Model Delivery Strategy.

The definition of each of the needs and what is expected from the user, is shown when hovering over the need with the mouse, as seen in the screenshot in Figure 7.2.

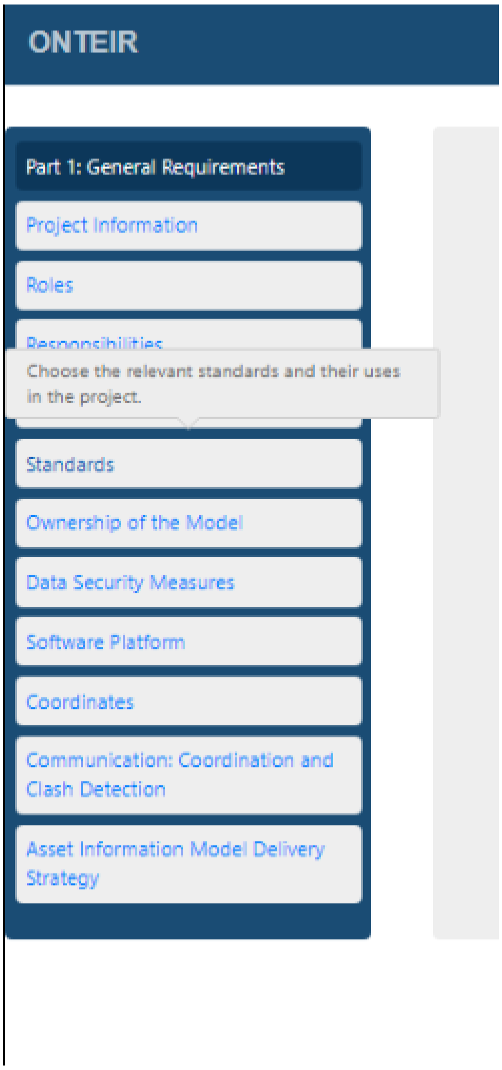


Figure 7.2: Definitions of Needs when hovering with mouse

1-Project information:

This tab allows the user to list general information about the project, which include:

- Project number
- Project name
- Project address
- Client name
- Contact details
- Design start date

- Construction start date
- Completion date
- Handover date
- Short project description
- Add New Button: this button will allow the user to add any other relevant information that is not listed in the tool

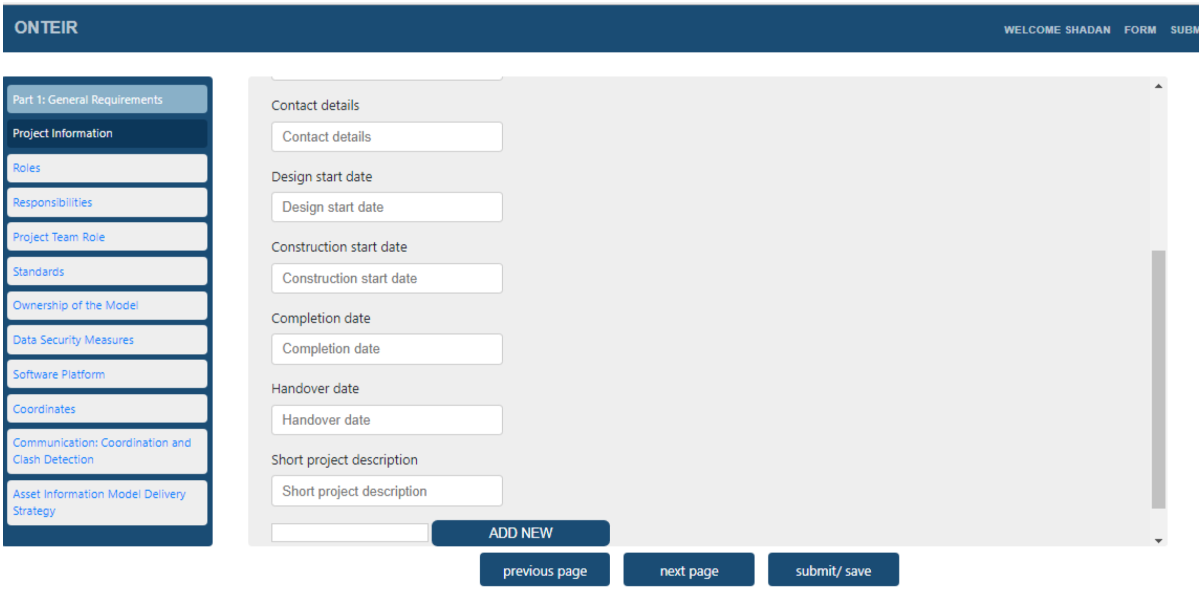


Figure 7.3: Project Information Need - OntEIR Tool

2-Roles

In which the general roles and names associated are listed. To use a certain role to be involved in the project, the user would have to check the box beside it, as seen in Table 7.2 and Figure 7.4.

Table 7.2: Roles in OntEIR

Role
Employer
BIM Leader

Information Manager
Lead Designer
Design Team
Main Contractor
Specialist Contractor
Project Manager
Facilities Manager
CDM
Cost Manager
Add Role...

3-Responsibilities:

This section includes the responsibilities associated with the roles defined previously. Responsibilities include tasks for each of these roles, as shown in Table 7.3 and Figure 7.5.

Table 7.3: Responsibilities in OntEIR

Responsibilities
Task1: CDE
Task2: Resources
Task3: Project Strategy
Task4: Geometry
Task5: Data

Task6: Construction Management
Task7: Quality Assurance and Control
Task8: Meetings
Task9: Reporting and Governance

For each of these tasks, the user should define which role is responsible, consulted by, informed by, and approved by, as seen in the screen shot in Figure 7.5.

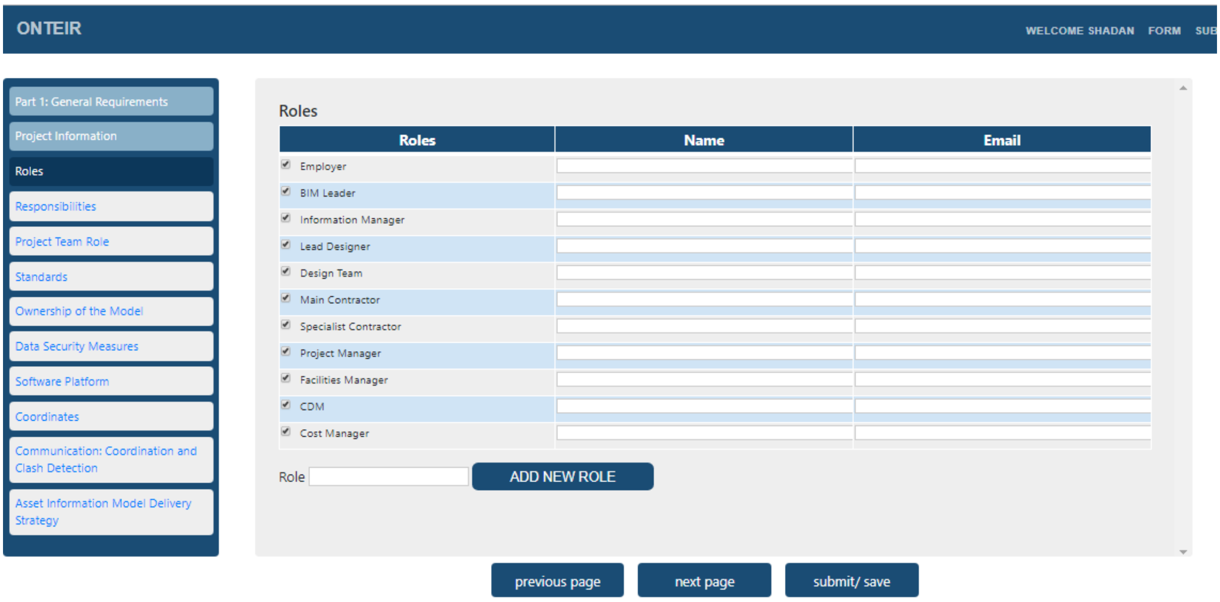


Figure 7.4: Roles Tab-OntEIR Tool

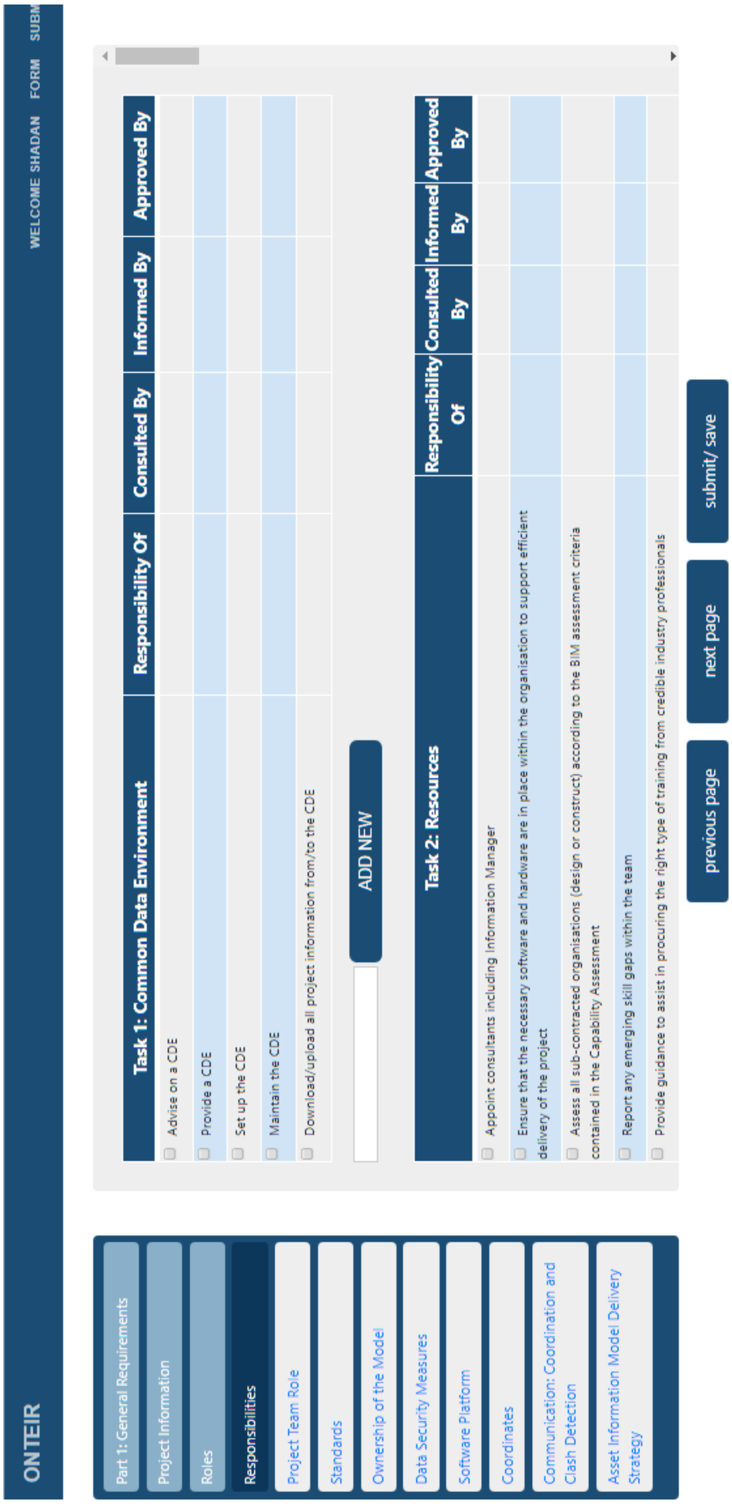


Figure 7.5: Responsibilities Tab-OntEIR Tool

4-Project team roles

This tab lists the roles that will be involved in the delivery of the project, and the name and email associated. Roles include the following (Table 7.4 and Figure 7.6).

Table 7.4: List of the Roles in the OntEIR Tool

Project team role
Architect
Civil
SE
MEP
Building Service Engineer
FMA
Ground Worker
Planning Department
add role…

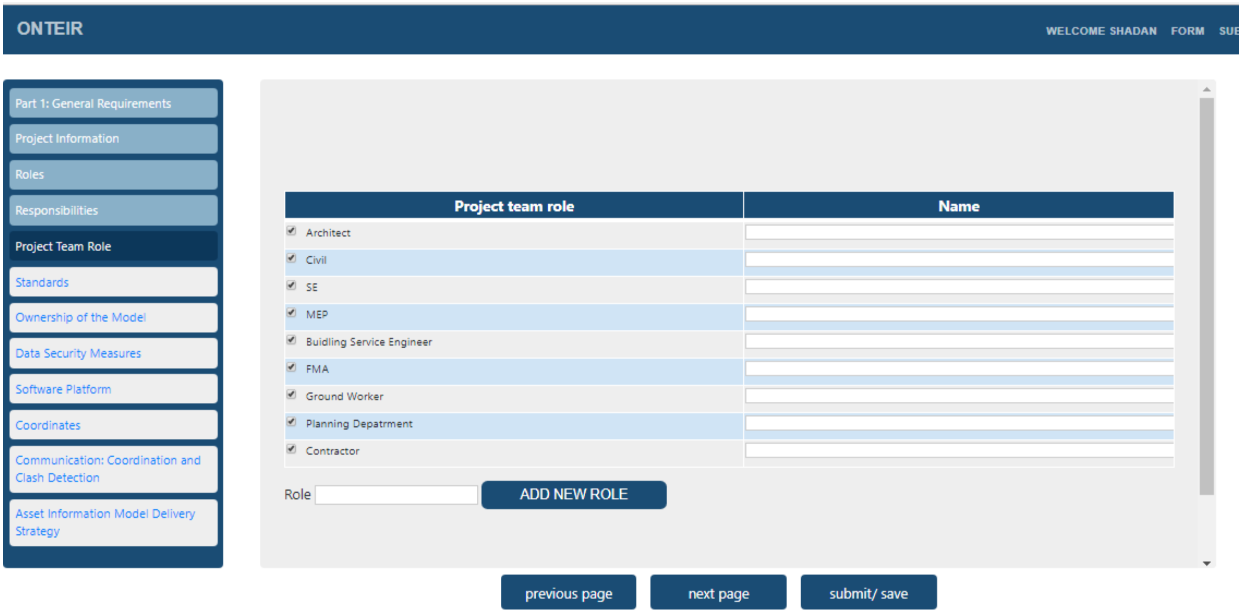


Figure 7.6: Project Team Role- OntEIR Tool

5-Standards

This section includes the standards that will be used in the project, and the definition of each standard. The boxes checked will be used in the project, and the user can add any other standards to be used in the project.

Figure 7.7 provides a screenshot of the standards tab from the OntEIR tool:

6-Ownership of the model:

In this tab, the user would define who owns the model at different stages if the project, and who would it be licenced to, as shown in Figure 7.8.

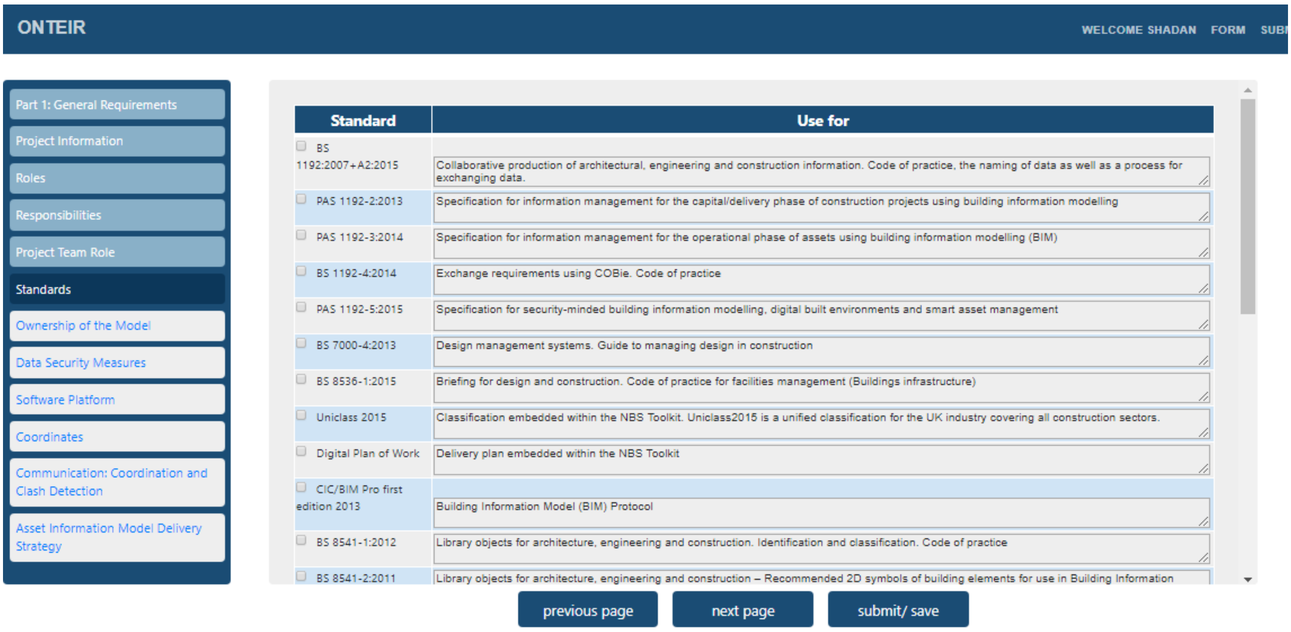


Figure 7.7: Standards Tab form the OntEIR Tool

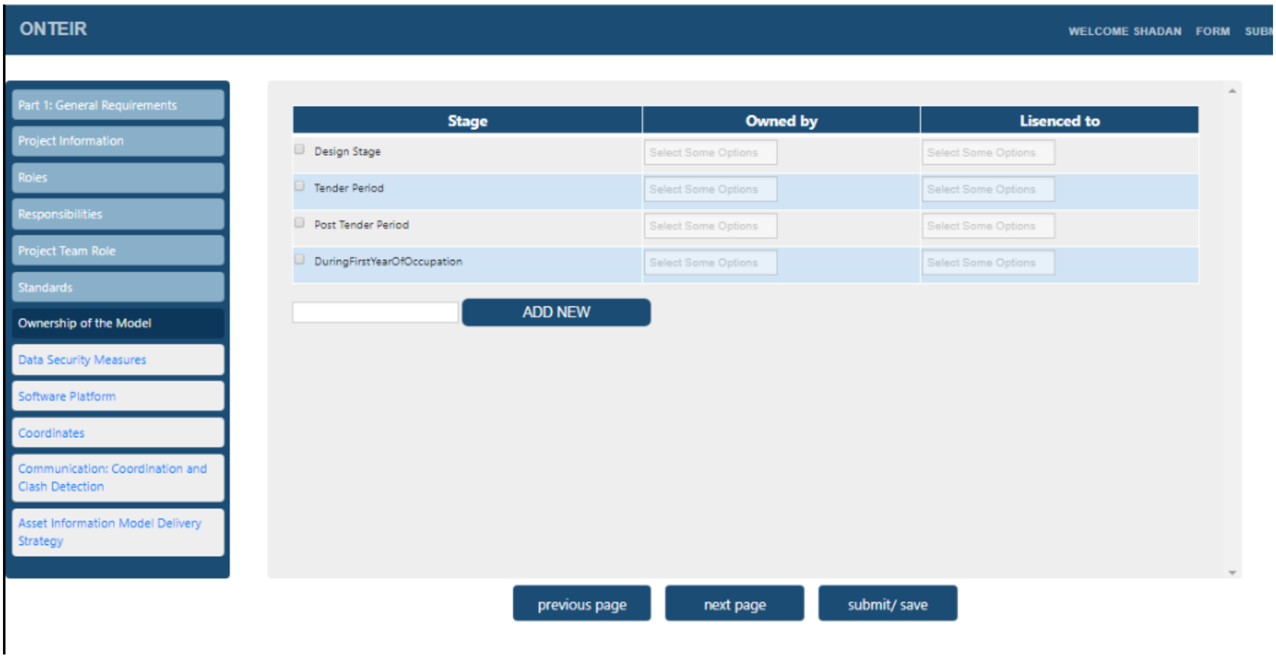


Figure 7.8: Ownership of Model Tab-OntEIR Tool

7- Data security measures

The clients define the measures that they want the suppliers to use to protect the data. The main items are shown in Table 7.5:

Table 7.5: Data Security Measures in the OntEIR Tool

Home and mobile working
User education and awareness
Incident management
Information risk management regime
Managing user privileges
Secure configuration
Malware protection
Network security

Figure 7.9 provides a screenshot of the Data security measures tab of the OntEIR tool.

8- Software Platform:

During this tab, the client defines the software to be used for the different technical needs for the project, and the versions to be used, as shown in Figure 7.10.

9- Coordinates:

The client should also define the coordinates to be used in the project. Those coordinates should be outlined in the EIR. The requirements in the coordinates tab in the OntEIR tool are shown in the screenshot in Figure 7.11

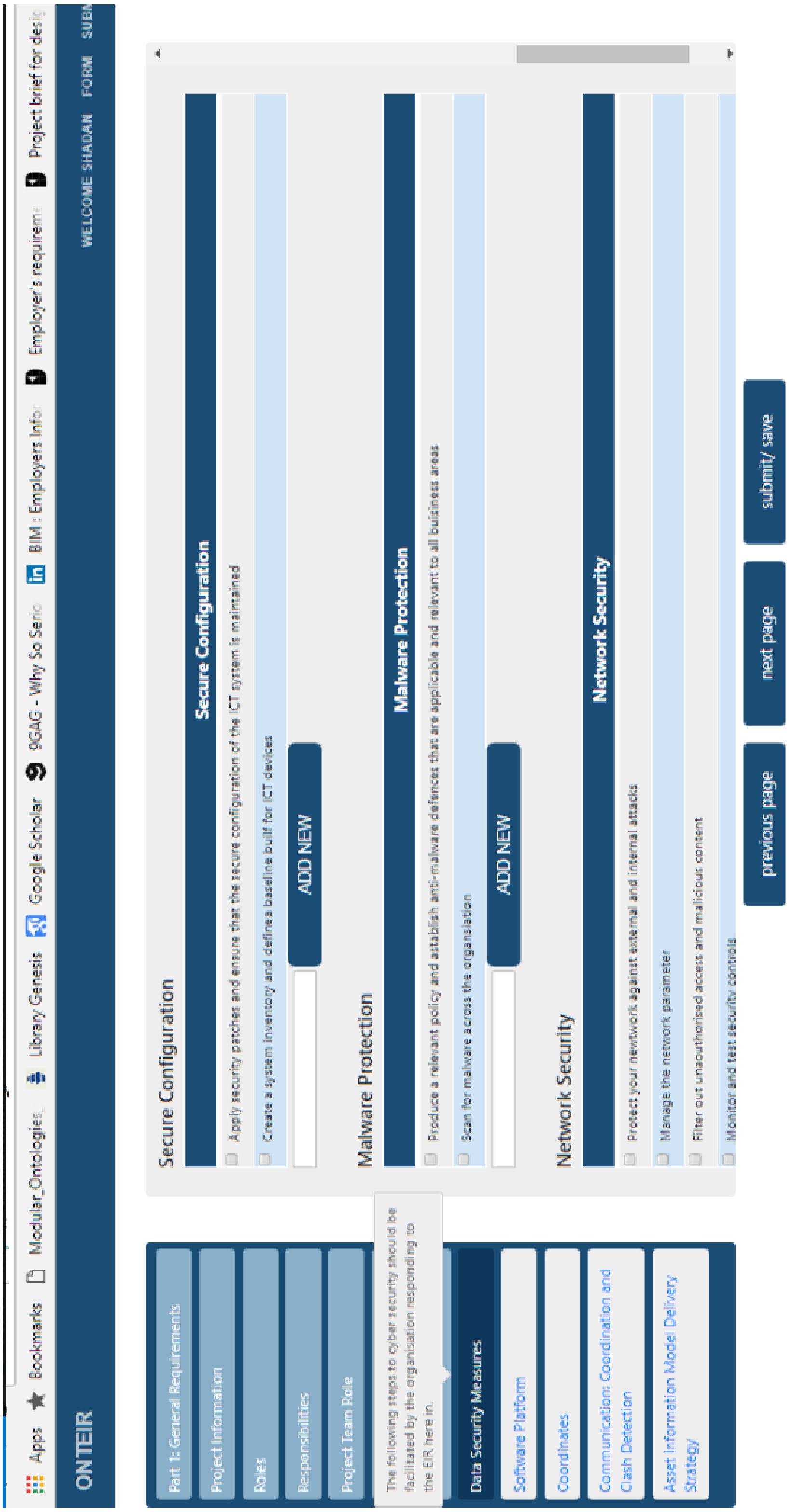


Figure 7.9: Data Security Measures- OntEIR Tool

Figure 7.10: Software Platforms - OntEIR Tool

Figure 7.11: Coordinates Tab-OntEIR Tool

10- Communication: coordination and clash detection

This tab outlines the communication process involved in the BIM project and explained in Section 6.6.1. Figure 7.12 depicts a screenshot of the corresponding view in OntEIR tool.

11- Asset Information Model Delivery Strategy

During this tab, the user defines the strategy involved in the delivery of the AIM, as explained in section 6.6.1 previously. Figure 7.13 is a screenshot for the AIM delivery strategy tab in the OntEIR tool.

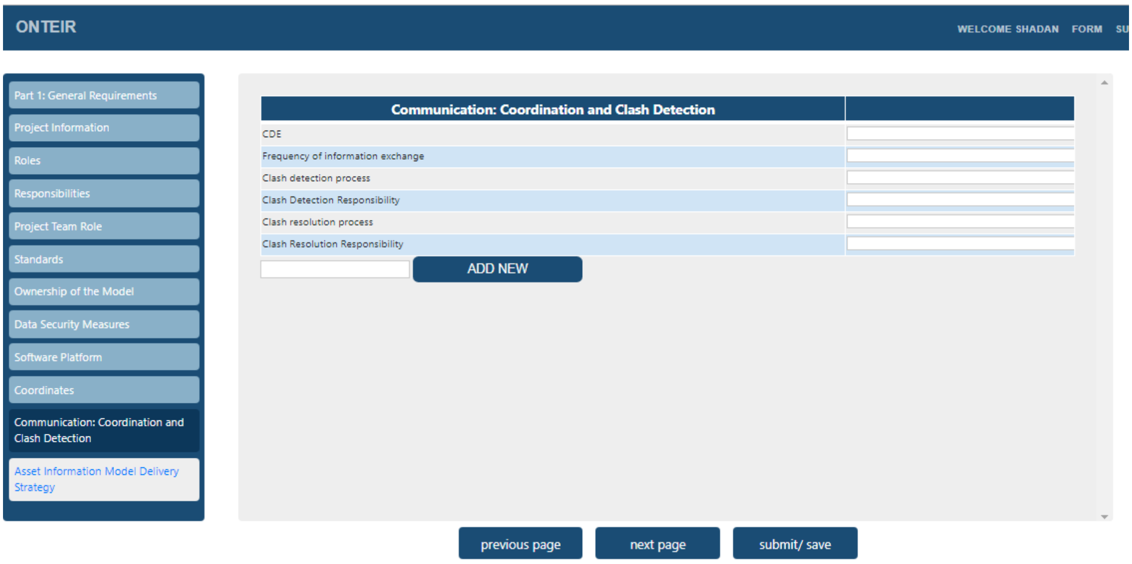


Figure 7.12: Communication Tab-OntEIR Tool

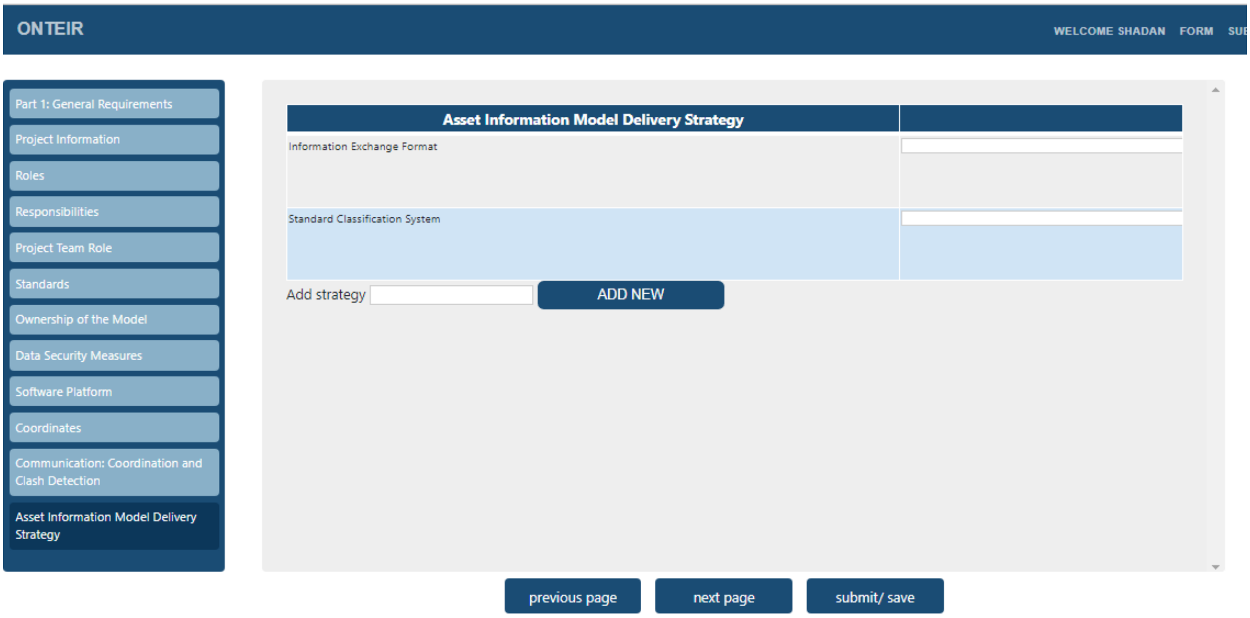


Figure 7.13: AIM Delivery Strategy Tab-OntEIR Tool

7.3.2 Stage Requirements

Stage requirements represent the dynamic requirements in the OntEIR framework discussed on Section 7.3. This section includes the stages of the project, based on the RIBA plan of work, as discussed in Section 6.6.2.

Define Stages and LOD & LOI

Requirements of the stage section start with defining the stages in terms of start date and finish date of the stage, and the definition of the LOD and LOI to be used in the project deliveries. After that each tab represents a stage, and each of these stages include requirements that should be defined, as shown in the screen shots in Figures 7.14, 7.15 and 7.16.

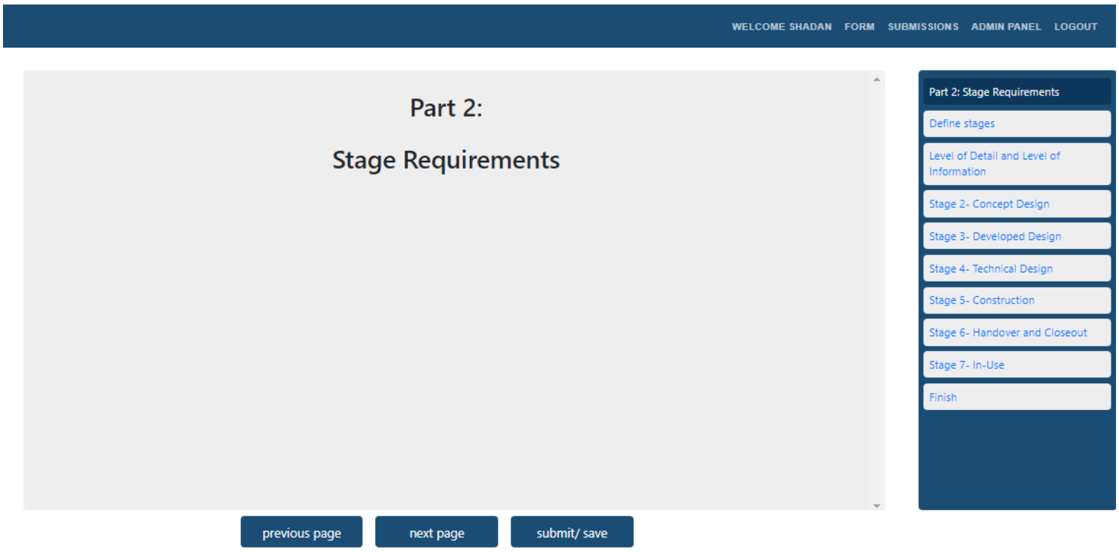


Figure 7.14: Stage Requirements - OntEIR Tool

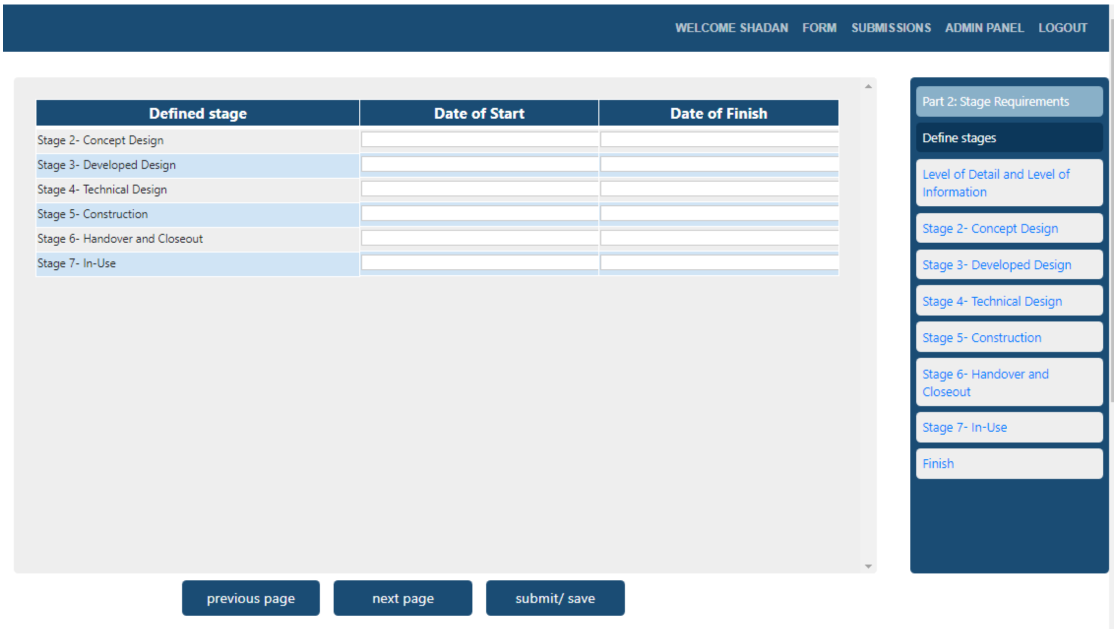


Figure 7.15: Stages Definitions Tab - OntEIR Tool

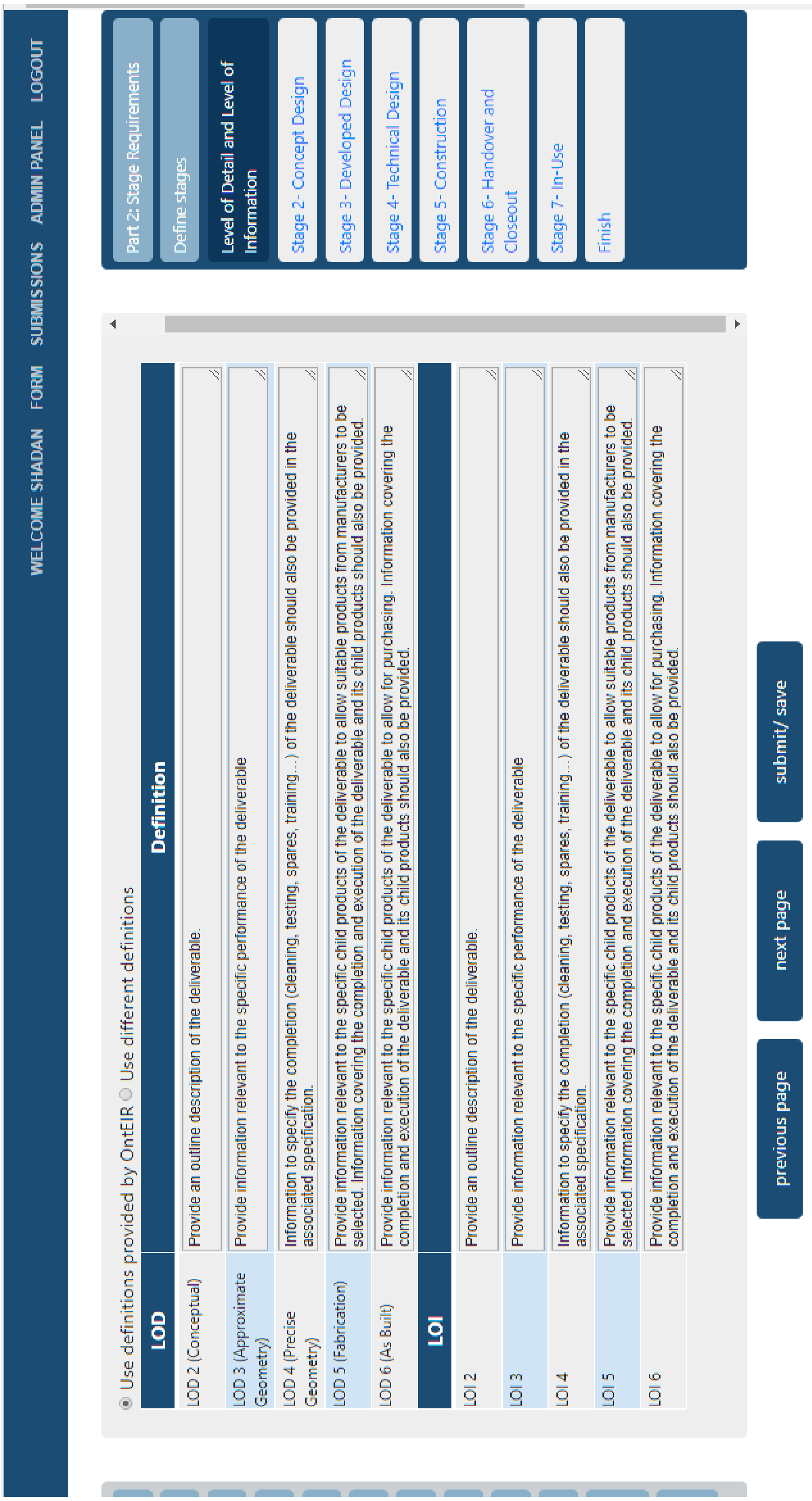


Figure 7.16: LOD & LOI Definitions Tab - OntEIR Tool

Stages requirements

The next step after defining the beginning and end of each stage, and the definitions of the LOD and LOIs, is the definition of the requirements for each stage.

For each stage, the following requirements should be outlined in detail, as listed in Table 7.6.

Table 7.6: Requirements that are Defined for every Stage in OntEIR

Requirements for each stage
Data drops
CDM drops
Performed by
Security status
Project requirements
Asset Information Requirements
COBie
AIR responsibility

Data drops

According to the Cabinet Office (2012), data drops help captures and check clients' requirements throughout the lifecycle of buildings. Data drops are the data requirements for key stages of building lifecycle development which are aligned with RIBA Plan of Work Stages (RIBA, 2013).

The importance of having a clear data drop for every stage that is allows the client to check and validate the project's compliance with the brief and the EIR. And also, to check if projects are still within the time and budget scale set.

In OntEIR, the data drops are pre-defined for each stage according as proposed in the PAS 1192-2 (2013). The user has the option to use the data drops define, by checking the box, or not using them, by not checking the box beside it. Also, the user has the option to add new data drops, as seen in the screenshot in Figure 7.17.

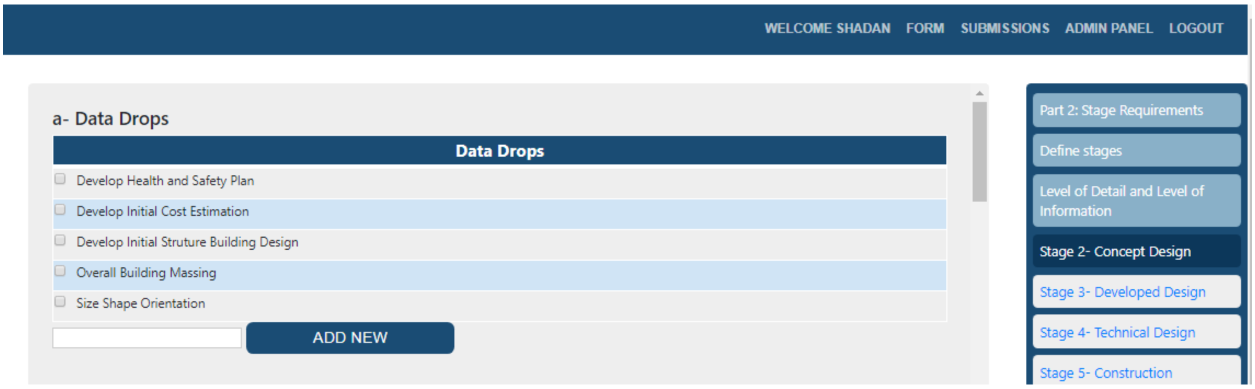


Figure 7.17: Data Drops - OntEIR Tool

CDM Data drops

According to the Construction Design and Managements Regulation (CDM, 2015), data drops for health and safety during construction should also be stated in EIRs before the beginning of the project, to ensure the safety of all involved in the project construction.

OntEIR pre-defines the CDM data drops, which users can choose to include in their EIR, in addition to give the option to add any new drops, as shown in the screen shot taken from the OntEIR tool in Figure 7.18

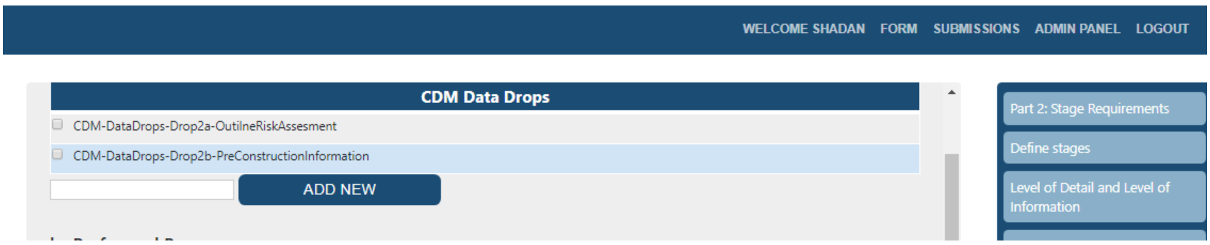


Figure 7.18: CDM Data Drops-OntEIR Tool

Data Security:

In this option the user is asked to choose from a group of Security status for each stage, the options are, as seen in Figure 7.19:

- IL1: Not protectively marked
- IL2: Protected
- IL3: Restricted

- IL4: Confidential

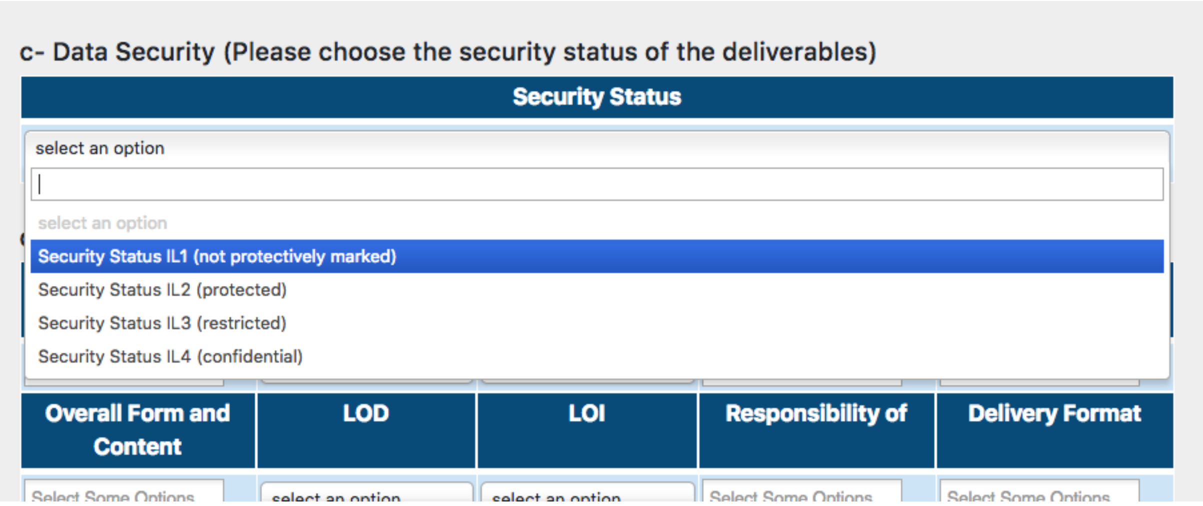


Figure 7.19: Data Security- OntEIR Tool

Project Requirements:

In this option the user is required to define the project requirements to create a complete MIDP. For each of the main requirement: elements materials and components, overall form and content, performance, design strategies, construction proposals and health and safety, there is a group of sub-requirements that have to be defined. And for each project requirement in each stage, the user will have to define the LOD and LOI, in addition to the role that is responsible for the delivery of that requirement and the delivery format, from which the user will one or more choose from the list: 2D PDF, 2D DWG, Documentation, BIM Model, as shown in Figure 7.20.

Figure 7.20: Project Requirements-OntEIR tool

Asset Information Requirements

For this need, the user chooses the AIR that he/she wants included in the COBie sheet. There is a group of requirements and sub requirements the user can choose from, as seen in Figure 7.21.

COBie:

In this option, the user chooses the information that is associated to the AIR in the COBie sheet. As seen in Figure 7.22, in this option, the user chooses the requirement, in addition to the Type of this requirement: Geometric or Non-Geometric.

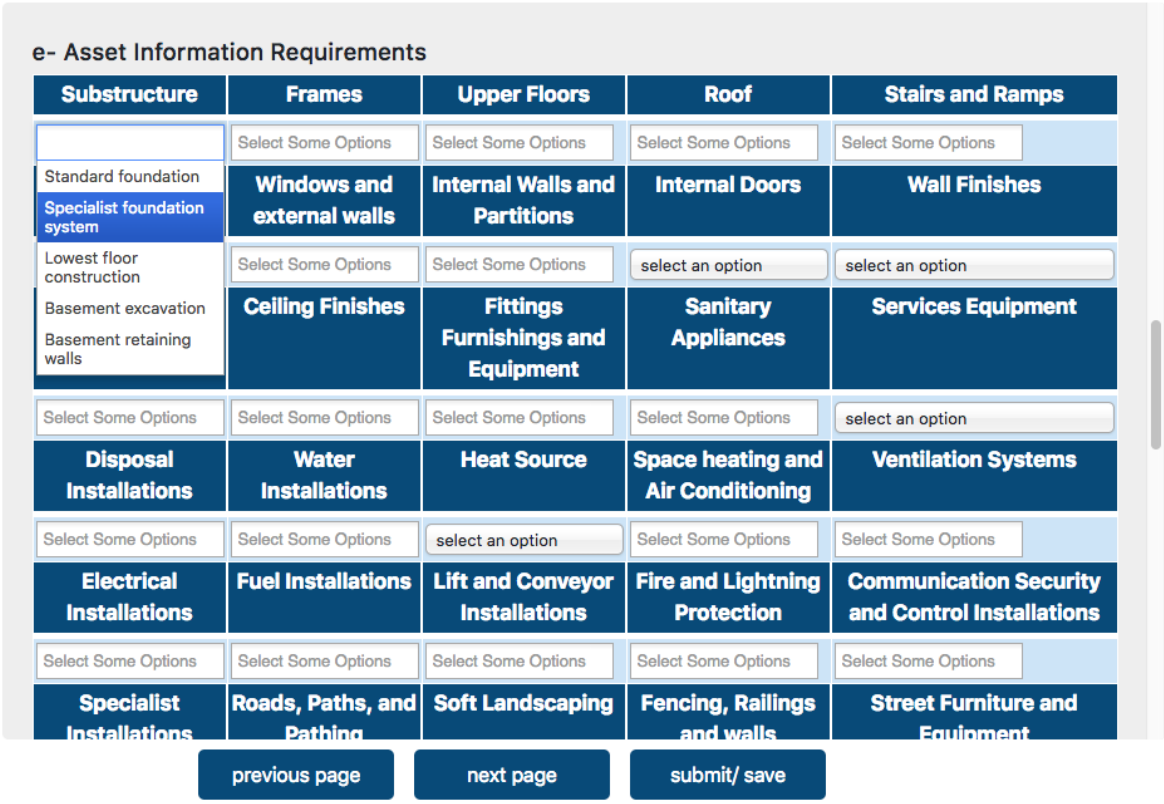


Figure 7.21: AIR- OntEIR Tool

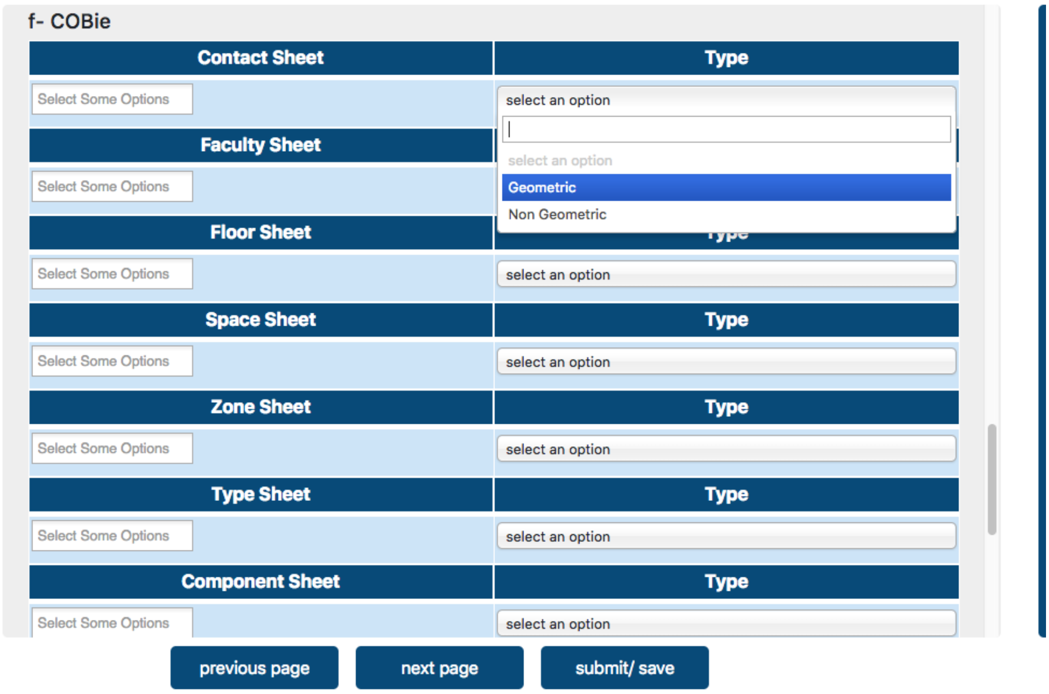


Figure 7.22: COBie Requirements-OntEIR Tool

7.3.3 Submitting, Saving, and Editing

Users of the OntEIR tool can either save their work before it is finished or submit it when done. This will allow the users to edit their work before printing as seen in Figure 7.23

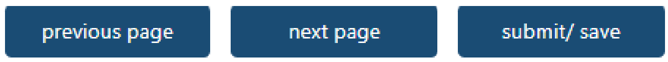


Figure 7.23: Submitting, Saving and Editing - OntEIR Tool

Submitted and saved work could be found in the submissions tab on top of the page, shown in Figure 7.24. This will then open a page for all submissions.

Figure 7.24: Submissions Tab - OntEIR Tool

The preview button will take the user to a table with all the information locked in when filling in the requirements (Figure 7.25).

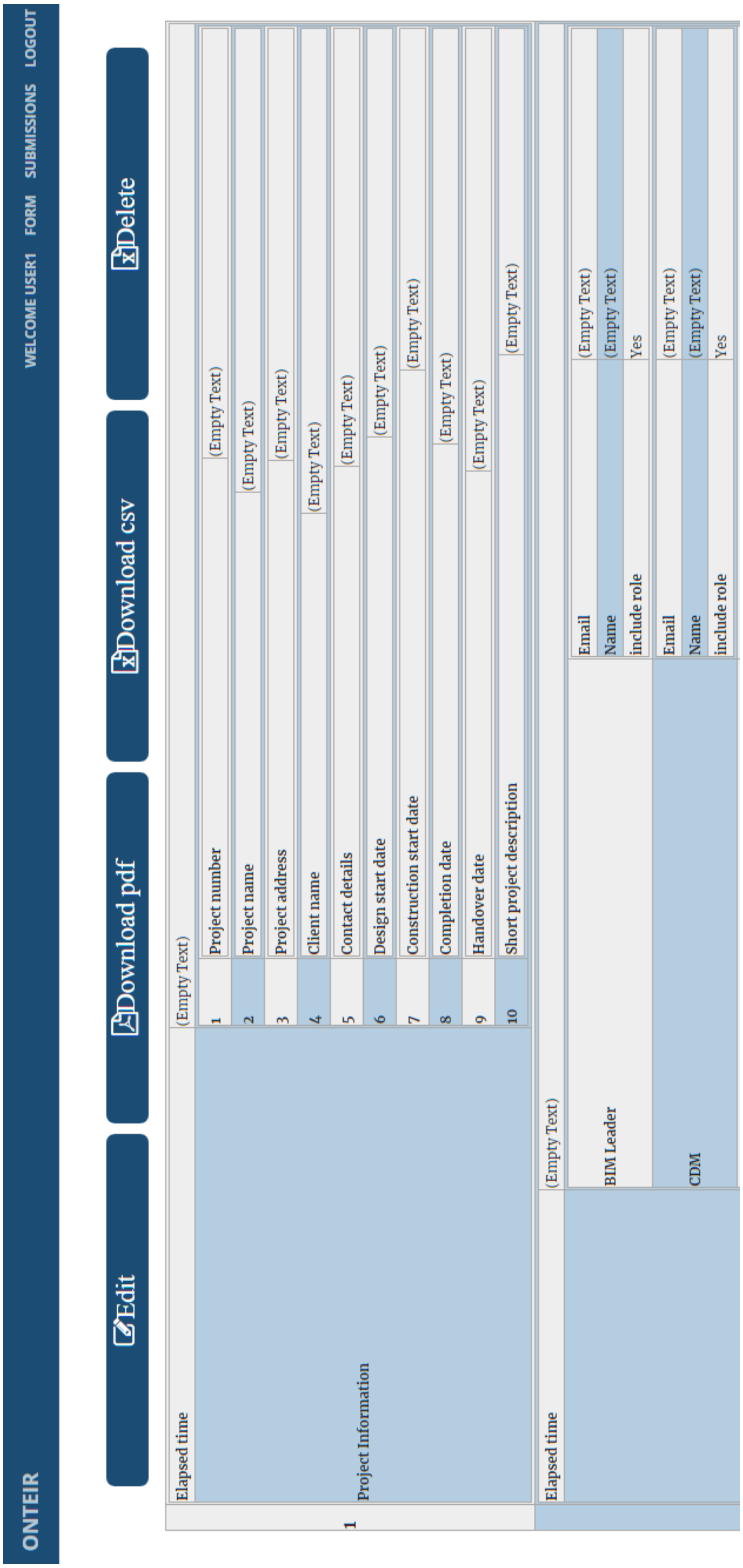


Figure 7.25: Preview Tab - OntEIR Tool

The user has the options to edit, download as PDF, download as CSV, or delete the form, as shown in the top of the screen on Figure 7.25.

Edit: The edit button allows the user to go back to the OntEIR form and edit any of the information previously input into the tool.

Download as PDF: This converts the file into a PDF format.

Download as CSV: This option converts all the data into an excel format and exports the information into an excel sheet.

Delete: This option is to delete the form and all the data associated.

The admin rights: The admin panel is similar to the user panel shown previously, however it has some additions that are only given with admin rights. The submissions tab in the admin panel hold all the information and forms that have been submitted and saved by all the users.

Figure 7.26: Admin Panel - OntEIR Tool

Also, the admin has the right to add users and give them usernames and passwords using the admin tab, as Shown in Figure 7.27.

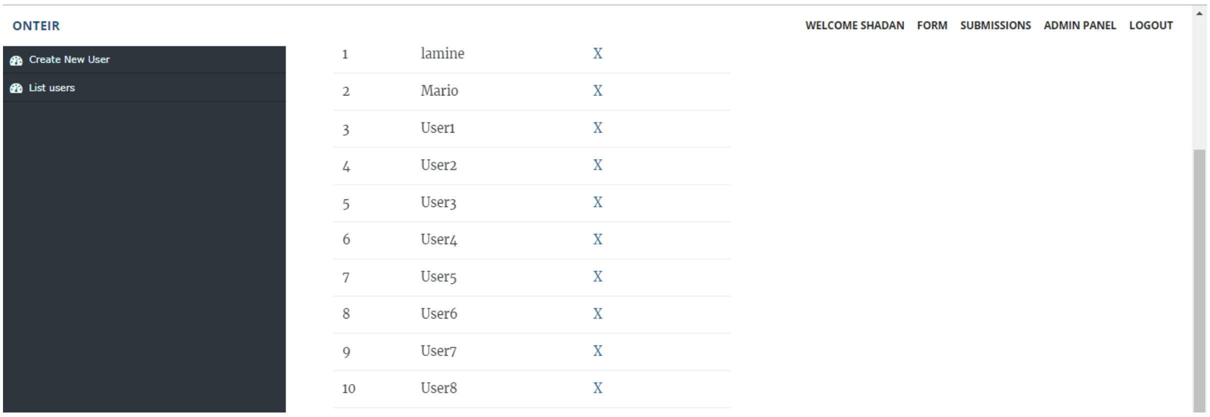


Figure 7.27: List of Users - OntEIR Tool

The next section discusses the validation and evaluation of the OntEIR Tool

7.4 Validation of the OntEIR Tool

Chapter 6 described the first of two iterations of the validation process, in which the OntEIR framework was validated with domain experts. According to the findings of Iteration 1, the framework was updated, and the tool was developed. The validation process explained in the next section was designed to validate the OntEIR Tool.

7.4.1 Validation Criteria

This validation process discusses the OntEIR tool, in terms of:

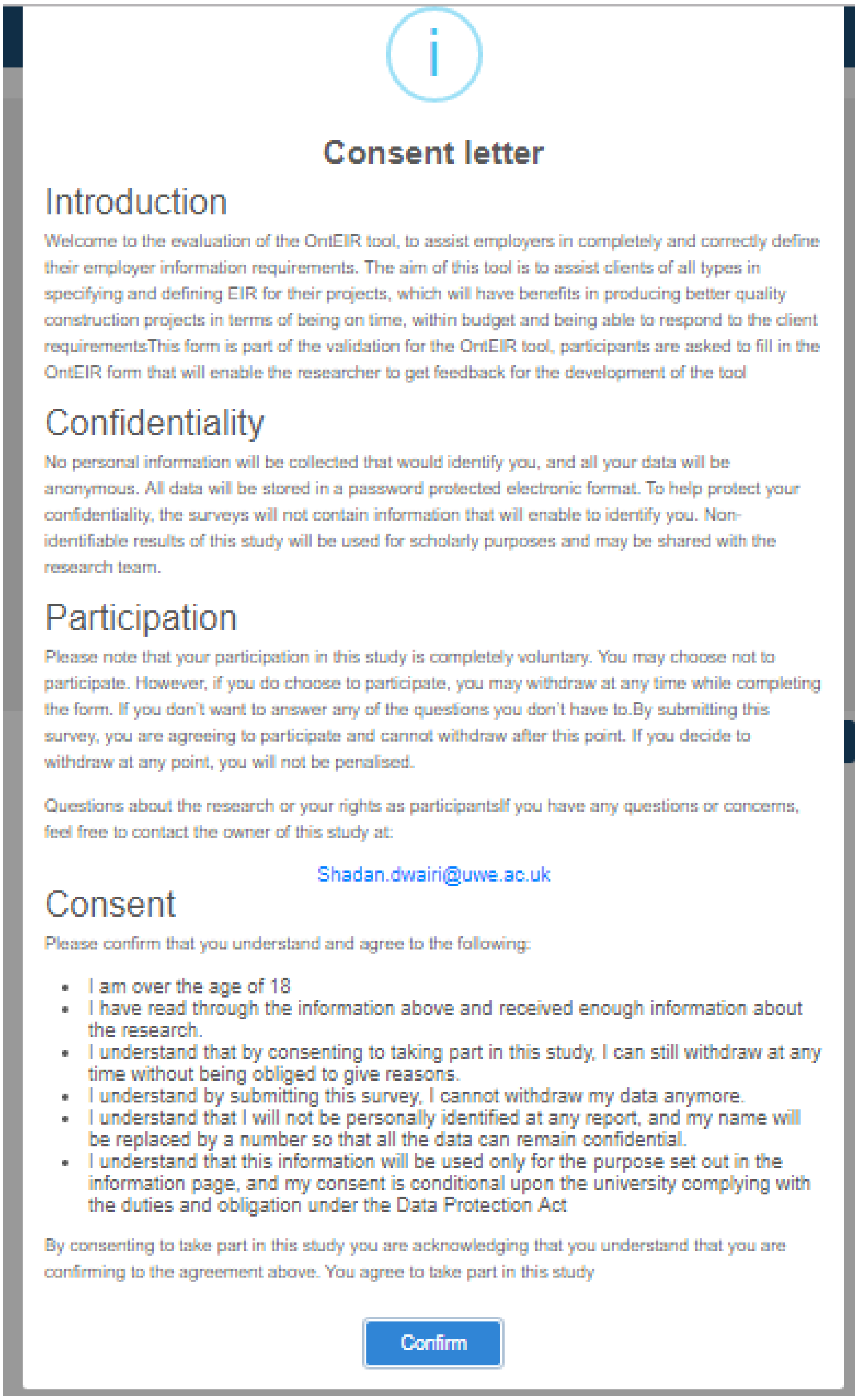
- Its Graphical User interface;
- The effect the tool has on users in terms of understanding the EIR;
- If the tool was able to provide the appropriate level of information to complete a full EIR;
- How likely it is that the user uses the tool again or recommends it.

More specifically, the questions discussed:

- The quality of information;
- The appropriateness of the level of information;
- The ease of use of the tool;
- Aesthetics of the tool and the interface;
- The ability of the tool to improve the users' understanding of the EIR;
- The ability of the tool to produce a complete and full EIR;
- The ability to specify requirements for specific projects; and
- The likelihood of using the tool in the future or recommending it to others.

7.4.2 Validation Procedure

As explained in section 7.3.1.3 the admin on the OntEIR tool has the ability to add users for the tool, with their own username and password. After identifying the participants for the validation, usernames were created for them along with their passwords. They were asked to test the tool and then fill in the online questionnaire, which is found in Appendix F and to which they were provided the link. It is important to mention that ethical considerations were also considered the validation of the OntEIR Tool, and before starting both the tool and the questionnaire, participants were asked to sign the consent form shown in Figure 7.28.



Consent letter

Introduction

Welcome to the evaluation of the OntEIR tool, to assist employers in completely and correctly define their employer information requirements. The aim of this tool is to assist clients of all types in specifying and defining EIR for their projects, which will have benefits in producing better quality construction projects in terms of being on time, within budget and being able to respond to the client requirementsThis form is part of the validation for the OntEIR tool, participants are asked to fill in the OntEIR form that will enable the researcher to get feedback for the development of the tool

Confidentiality

No personal information will be collected that would identify you, and all your data will be anonymous. All data will be stored in a password protected electronic format. To help protect your confidentiality, the surveys will not contain information that will enable to identify you. Non-identifiable results of this study will be used for scholarly purposes and may be shared with the research team.

Participation

Please note that your participation in this study is completely voluntary. You may choose not to participate. However, if you do choose to participate, you may withdraw at any time while completing the form. If you don't want to answer any of the questions you don't have to.By submitting this survey, you are agreeing to participate and cannot withdraw after this point. If you decide to withdraw at any point, you will not be penalised.

Questions about the research or your rights as participantsIf you have any questions or concerns, feel free to contact the owner of this study at:

Shadan.dwairi@uwe.ac.uk

Consent

Please confirm that you understand and agree to the following:

- I am over the age of 18
- I have read through the information above and received enough information about the research.
- I understand that by consenting to taking part in this study, I can still withdraw at any time without being obliged to give reasons.
- I understand by submitting this survey, I cannot withdraw my data anymore.
- I understand that I will not be personally identified at any report, and my name will be replaced by a number so that all the data can remain confidential.
- I understand that this information will be used only for the purpose set out in the information page, and my consent is conditional upon the university complying with the duties and obligation under the Data Protection Act

By consenting to take part in this study you are acknowledging that you understand that you are confirming to the agreement above. You agree to take part in this study

Confirm

Figure 7.28: Consent Letter-OntEIR Tool

7.4.3 Selection of Participants

Unlike the first iteration of the validation process explained in Chapter 6, it was not required from all participants in this iteration to have extensive knowledge and experience in BIM and EIR. Participants would however need to have some level of experience in building construction and its typical requirements.

190 participants were selected and contacted for the survey. Participants were selected based on their experience in BIM and EIR and their role. Both major contracting companies with extensive knowledge in BIM, and less experienced stakeholders were identified through connections or via LinkedIn and were contacted, and the link to the OntEIR tool, along with the username and password assigned for them. 51 of the participants completed the questionnaire.

Participants included the roles of: Project manager, BIM Developer, Supplier, BIM Specialist, BIM Manager, BIM Coordinator, BIM Consultant, BIM Advisor, Building Services, Client Representatives and BIM Directors.

Also, this survey included 3 types of experiences:

1- Experience 1: < 5 years: 22 participants
2- Experience 2: 3 years $\leq$ experience $<$ 5 years: 11 participants
3- Experience 3: < 3 years: 18 participants

Figure 7.29 shows the percentage of experience levels of the participants in the study.

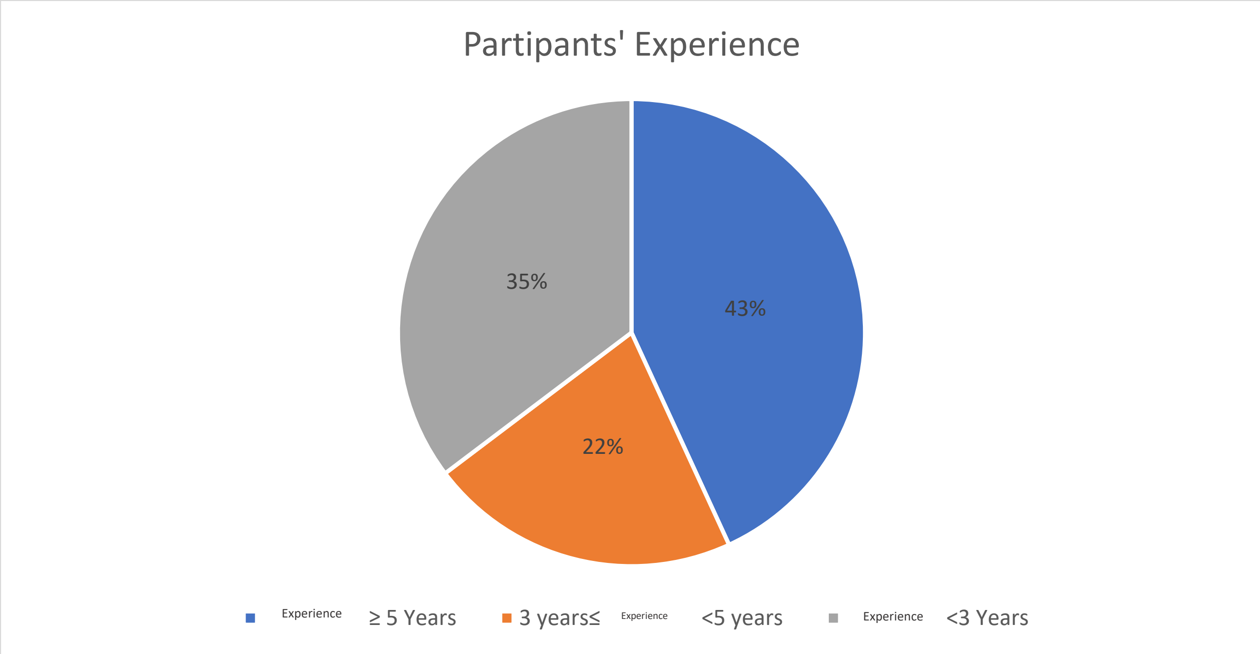


Figure 7.29: Participants' Experiences

The relation between role and experiences of the participants are shown in Figure 7.30 that shows that the highest number of participants are highly experienced BIM Consultants, and inexperienced clients or client representatives.

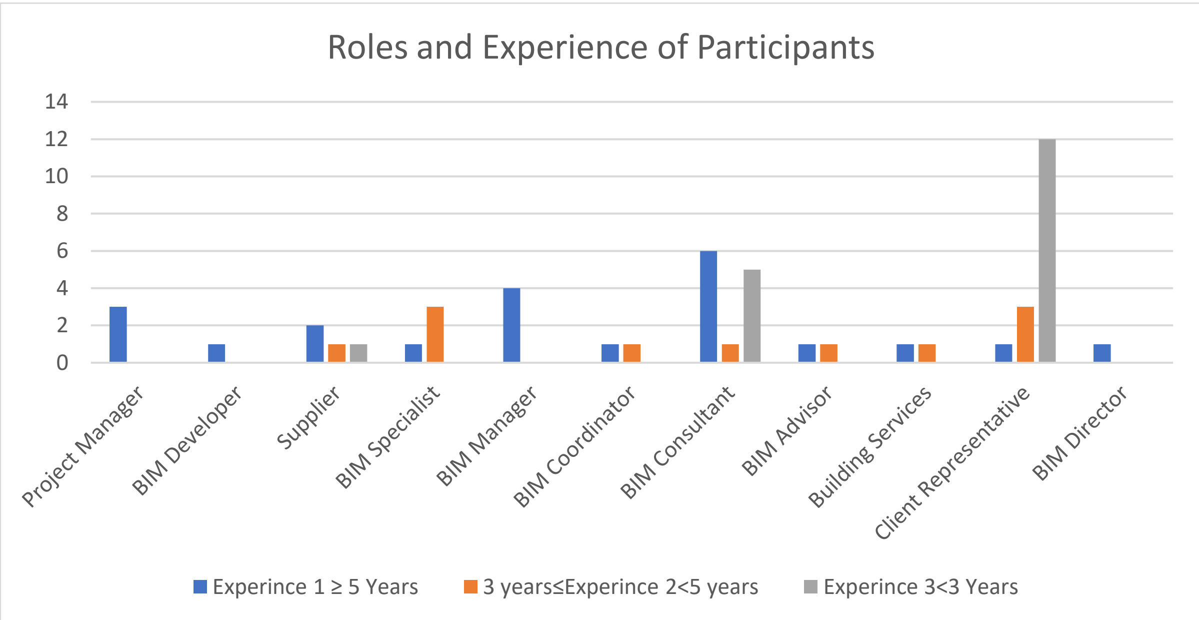


Figure 7.30: Relation between Roles and Experiences of Participants

Details of the participants in the survey are found in Appendix E

7.4.4 Findings and Analysis

Findings of the validation process were based upon the validation criteria explained in Section 7.4.1.

7.4.4.1 The Graphical User Interface and Ease of Use

In any web-based technology, the Graphical User Interface (GUI) plays a significant role in contributing to the success of a system as well as enhancing the interaction between a system and its users. According to Kung et al. (2008), the GUI says a lot about the tool in terms of: how it is and its appearance, in addition to the impression it creates, and the input/output data and the impression it makes. A good GUI plays an important role in enhancing the interaction between the user and the tool, which will lead to the success of the tool. Hu et al. (1999) also argue that GUI are important because it where the knowledge and information are visualised and represented and communicated between users.

OntEIR was validated according to the first validation criteria on the user interface. Questions included the following:

Question: How is your first impression of the tool in terms of Graphical User Interface (GUI)?

In this question, participants were asked to validate the GUI by giving their first impressions of the tool. The findings presented in Figure 7.31 showed that the majority of the participants, which represent 57% rated it to be “Good” or “Excellent” and 41% considered it to be “Average”. Only 2% gave it the rating of “Poor”, and no respondents saw it as “Terrible”.

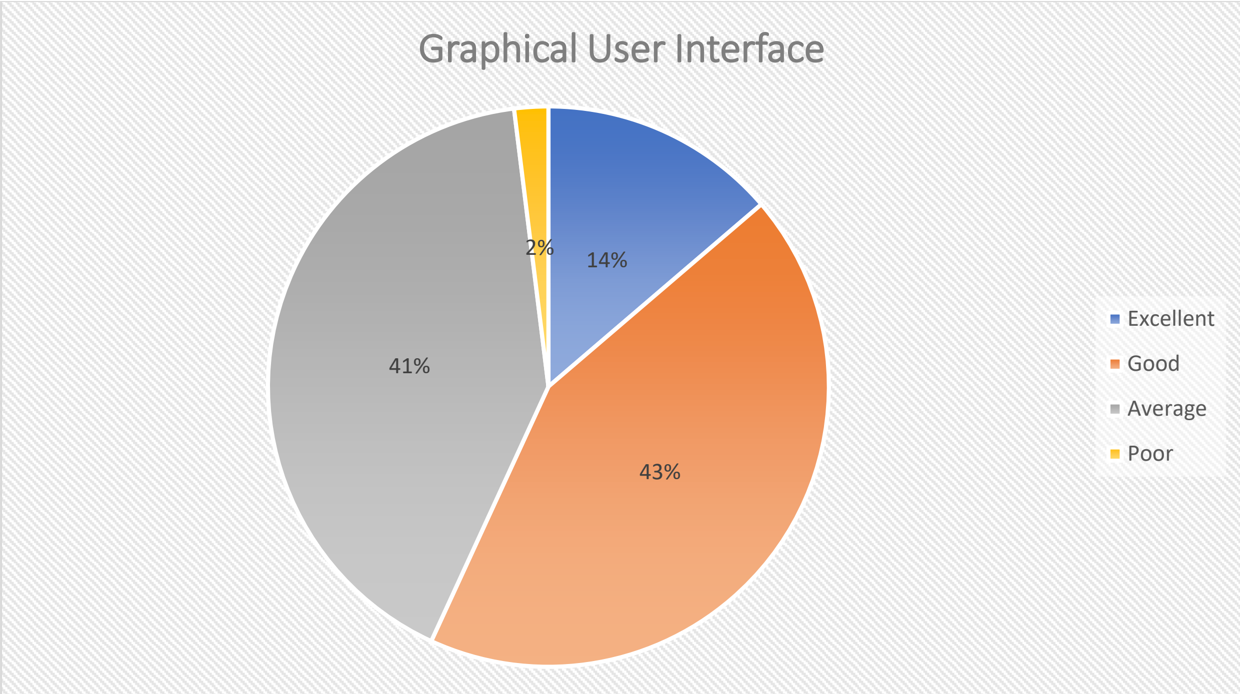


Figure.7.31: Graphical User Interface

Figure 7.32 shows how the answers were divides between the three groups of experience.

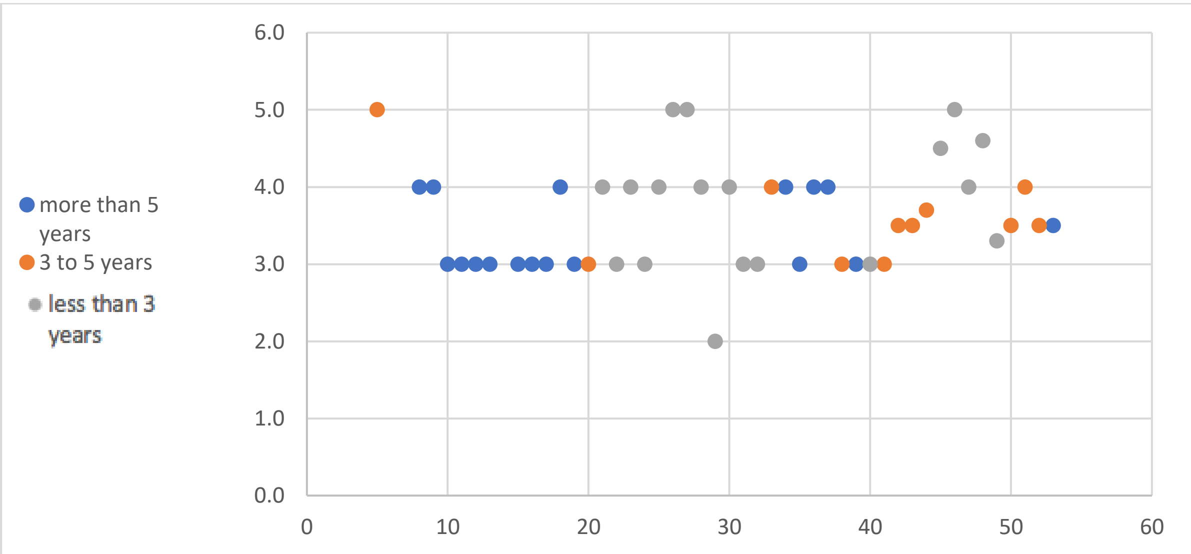


Figure 7.32: Graphical User Interface Scatter Chart

As mentioned in Section 7.4.3, participants were categorized into three groups based on their relevant experience. Table 7.7 shows the responds those three groups to the question.

From Figure 7.32 it could be seen that most of the answers were in the 3 and 4 zone, and the highest grade for the GUI was given by the least experienced participants. This could be due to the fact that the more experienced participants probably have used the already available, commercial tools in the industry that have of course more sophisticated graphic presentations than OntEIR, given that OntEIR is a research tool prototype that was developed with limited resources and time.

This could also be seen in Table 7.7 that shows the mean of the answers for each of the groups involved in the study.

Table 7.7: Means of Responses for the Different Groups

GUI								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
5 years or more	22	3.568	.6600	.1407	3.276	3.861	3.0	5.0
3 to 5 years	11	3.609	.5839	.1760	3.217	4.001	3.0	5.0
less than 3 years	18	3.800	.8534	.2011	3.376	4.224	2.0	5.0
Total	51	3.659	.7142	.1000	3.458	3.860	2.0	5.0

According to SPSS, the question received the total mean of 3.65 and the results of the mean for each group are also shown in the table. The next test conducted was to measure the significance of the means, as described in Section 4.4.3, if the significance was more than 0.05, this means that there is no significant difference how the members of the three groups have responded and the differences are irrelevant to the study.

Table 7.8 shows the differences between the means in the different groups for this question, and the significance of each.

Table 7.8: Significance test

(I) experience	(J) experience	Mean Difference (I-J)	Std. Error	Sig.
5 years or more	3 to 5 years	-.0409	.2662	.987
	less than 3 years	-.2318	.2291	.573
3 to 5 years	5 years or more	.0409	.2662	.987
	less than 3 years	-.1909	.2758	.769
less than 3 years	5 years or more	.2318	.2291	.573
	3 to 5 years	.1909	.2758	.769

It could be seen from the above table, that the significance level higher than .05 which means that the difference between the groups is irrelevant.

Having a mean of 3.65 is considered high, but still indicates that there is some work that has to be done on the GUI of the tool to make it more attractive and readable to the users. As discussed before the GUI is an important issue in tools because the role it plays in enhancing the interaction between the user and the tool. Some participants recommended the user of graphics in enhance this experience.

Question: How easy was it to select and define a certain requirement in the tool?

The ease of use feature is another feature that was taken into consideration when designing OntEIR. According to Thomas-Alvarez et al., (2013), Ease of use is an important feature that should be considered when designing software in general (Thomas-Alvarez and Mahdjoubi, 2013). In this question, respondents were asked to rate how easy it was to select and define requirements in the tool. Results showed that 55% of the users saw it as “Very easy”, 29% rated it as “Extremely easy”, and 16% gave it a rating of “Moderately easy’. No respondents rated it as “Slightly easy” or “Extremely difficult”.

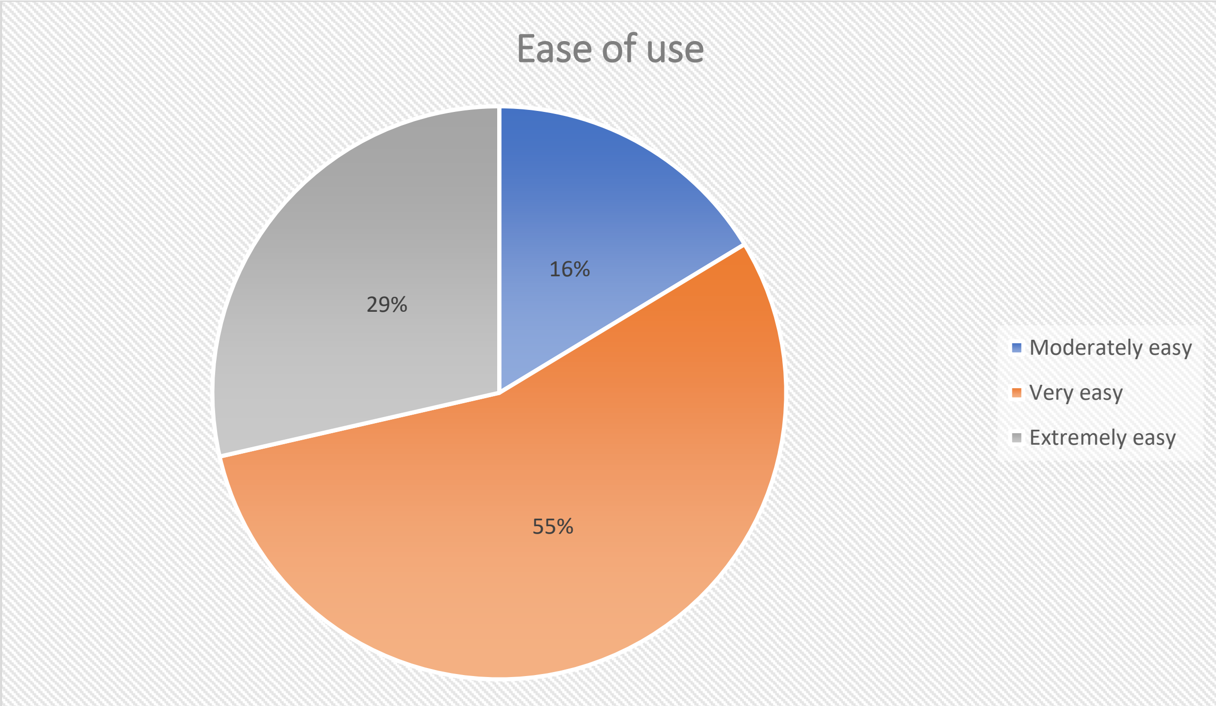


Figure 7.33: Ease of Use

Having a tool that easy to understand and use is an important issue that affects its success regardless of the type of user and their experience. Answers for this question by all 51 participants are shown in Figure 7.34 which provides a scatter chart. It is important in this question to see how the experienced participants answered given that they have more experience in the industry and in the current practices (tools) in EIR.

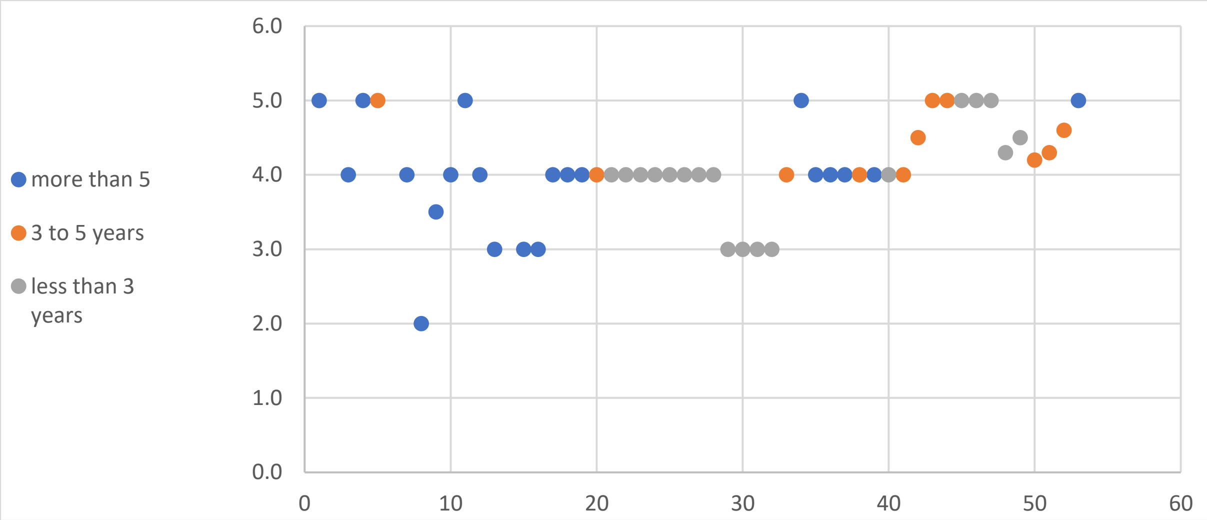


Figure 7.34: Ease of Use Scatter Chart

Responses according to the experience of participants are summarised in Table 7.9

Table 7.9: Means of Responses for the Different Groups

easy to define								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
5 years or more	22	3.977	.7634	.1628	3.639	4.316	2.0	5.0
3 to 5 years	11	4.418	.4262	.1285	4.132	4.704	4.0	5.0
less than 3 years	18	3.989	.6570	.1549	3.662	4.316	3.0	5.0
Total	51	4.076	.6787	.0950	3.886	4.267	2.0	5.0

From Table 7.9 it could be seen that the mean for this question was high (4.06) with participants with the experience between 3 and 5 years being the highest. Table 7.10 helped to analyse whether there is any significance how the three categories of participants have responded that is worth expanding on.

Table 7.10: Significance test

(I) experience	(J) experience	Mean Difference (I-J)	Std. Error	Sig.
5 years or more	3 to 5 years	-.4409	.2465	.184
	less than 3 years	-.0116	.2122	.998
3 to 5 years	5 years or more	.4409	.2465	.184
	less than 3 years	.4293	.2555	.223
less than 3 years	5 years or more	.0116	.2122	.998
	3 to 5 years	-.4293	.2555	.223

Table 7.10 indicates that there does not seem to be a correlation between the experiences of the participants and their answers.

Discussion: For this question, the mean for all categories was high. The total mean of all the participants was 4.076, which is very high. The OntEIR tool makes is easy for the user to define a certain requirement, and the function of changing colour of the need, once the requirements are defined inside that need makes the tracking of the defined needs versus the undefined need easier. Also, having a definition for each need (set of requirements) helps the users in guiding them about the nature of the answer.

Question: How straightforward is the tool?

This question was to measure how successful the tool's approach was in guiding the user in defining the requirements needed to produce the EIR, and the amount of ambiguity the users faced.

Of the 51 participants, as Figure 7.35 shows: 58% rated the tool to be "very straightforward" along with 24% who rated it as "Extremely Straightforward" and 18% who gave it a rating of

“Moderately Straightforward”. None of the participants rated the tool to be slightly or not straightforward at all.

Figure 7.36 shows the responds of all the 51 participants in a scatter chart, which gives indication of where the majority of responds are placed.

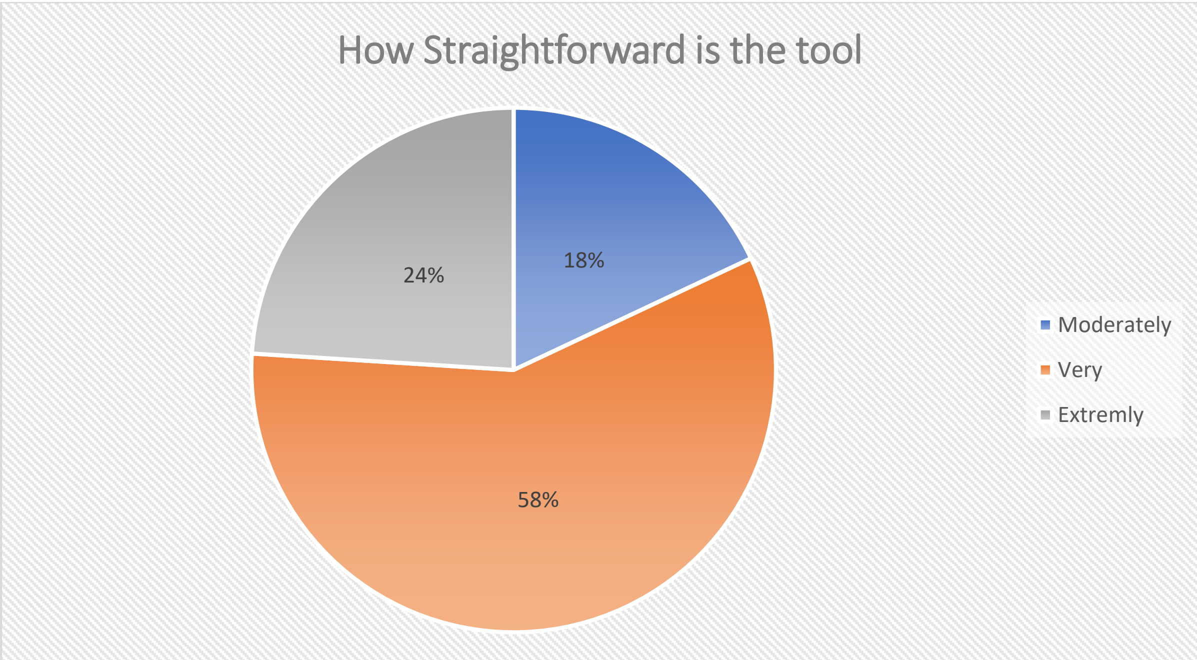


Figure 7.35: Being Straightforward

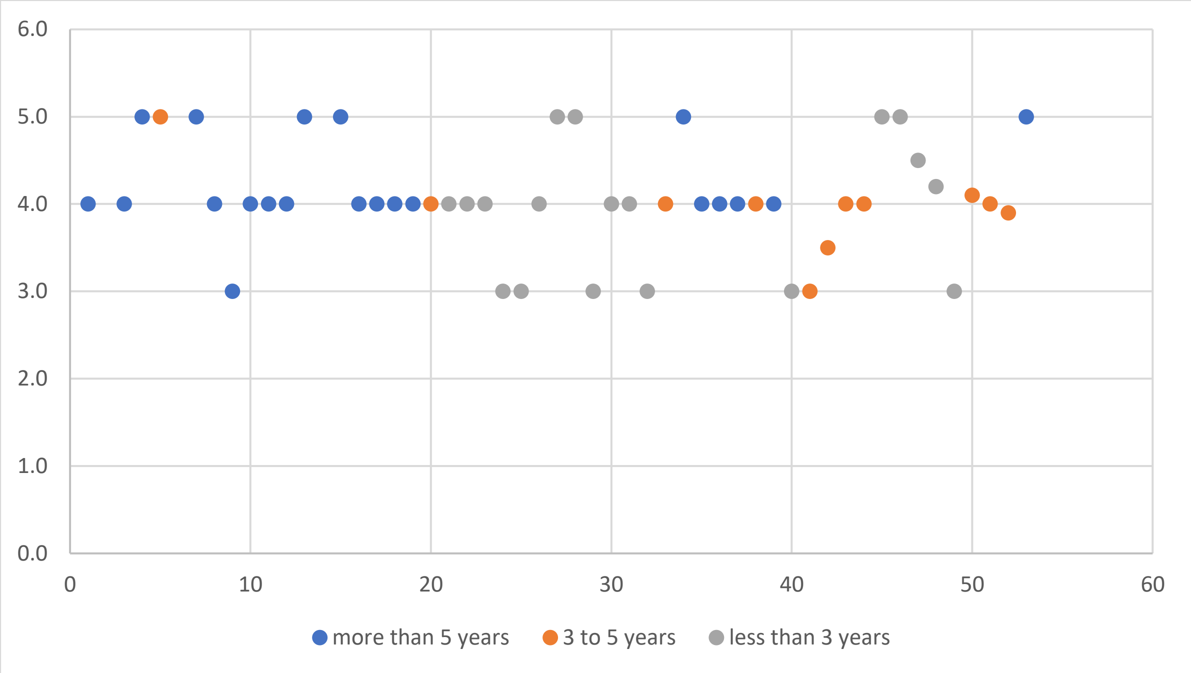


Figure.7.36: Being Straightforward Scatter Chart

This question could be considered as a continuation for Question 2 about the easiness of the use of the tool and could be one of the reasons why the participants considered the tool to be easy, because it was straight forward in defining requirements. This could be also seen from the high mean this question received from the participants, shown in Table 7.11.

Table 7.11: Means of Responses for the Different Groups

straightforward								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min.	Max.
					Lower Bound	Upper Bound		
5 years or more	22	4.227	.5284	.1127	3.993	4.462	3.0	5.0
3 to 5 years	11	3.955	.4741	.1429	3.636	4.273	3.0	5.0
less than 3 years	18	3.928	.7744	.1825	3.543	4.313	3.0	5.0
Total	51	4.063	.6222	.0871	3.888	4.238	3.0	5.0

Again, for this question, significance was tested between the three different groups of experience and results showed that there is no significant difference how the members of the three groups have responded, as seen in Table 7.12.

Table 7.12: Significance test

(I) experience	(J) experience	Mean Difference (I-J)	Std. Error	Sig.
5 years or more	3 to 5 years	.2727	.2281	.461
	less than 3 years	.2995	.1963	.288
3 to 5 years	5 years or more	-.2727	.2281	.461
	less than 3 years	.0268	.2363	.993
less than 3 years	5 years or more	-.2995	.1963	.288
	3 to 5 years	-.0268	.2363	.993

Discussion: One of the aims of this tool was to tackle the problem of ambiguity and being 'overwhelmed' that users suffer from when using existing standards and tools when they are trying to define their EIRs, as discussed in Section 3.4. The results of the analysis of this question have proven the tool was perceived as straightforward and clear to the users. The classification system, the definitions, the easiness of choosing a requirement, have all participated in making this tool an easy to understand, easy to use and therefore straightforward tool, as perceived by all types of users at the three levels of experience.

7.4.4.2 Understandability of the EIR

The second criterion tested by this validation was the extent to which OntEIR enhanced the understandability of EIR. Experienced participants would answer based on their experience and comparison with other EIR current practices, while inexperienced participants will answer based on their current understanding of the tool and EIR. Both answers are very important for the evaluation and further update and development of the tool.

The first thing that was measured in terms of understandability was the classification of requirements in the tool, between the general and stage requirements.

Question: How clear was the classification and transition between general (static) requirements and stage (dynamic) requirements?

The Static and Dynamic categorisation system of requirements in the OntEIR Framework and Tool is one of the contributions of this study. It is important to test how well received this categorisation not only in the framework, which was discussed in Chapter 6, but also in the application of this categorisation in the tool. For this question, 40% of the participants gave the tool a rating of "Extremely Clear", another 40% rated it as "Very Clear" and 20% said it was "Moderately Clear". No participants gave the rating of "Slightly Clear" or "Not Clear", as seen in Figure 7.37.

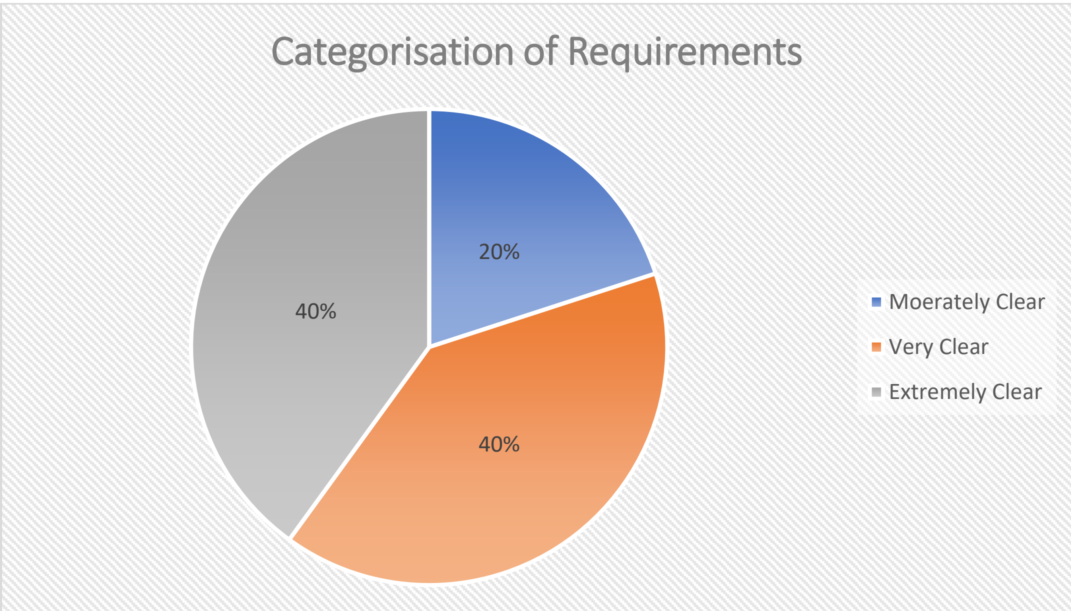


Figure 7.37: Categorisation of Requirements

Figure 7.38 demonstrates the responses for this question with a clear distinction between the different experiences involved in the study. It is important to consider each of the groups' perception about the categorisation system of the framework and tool.

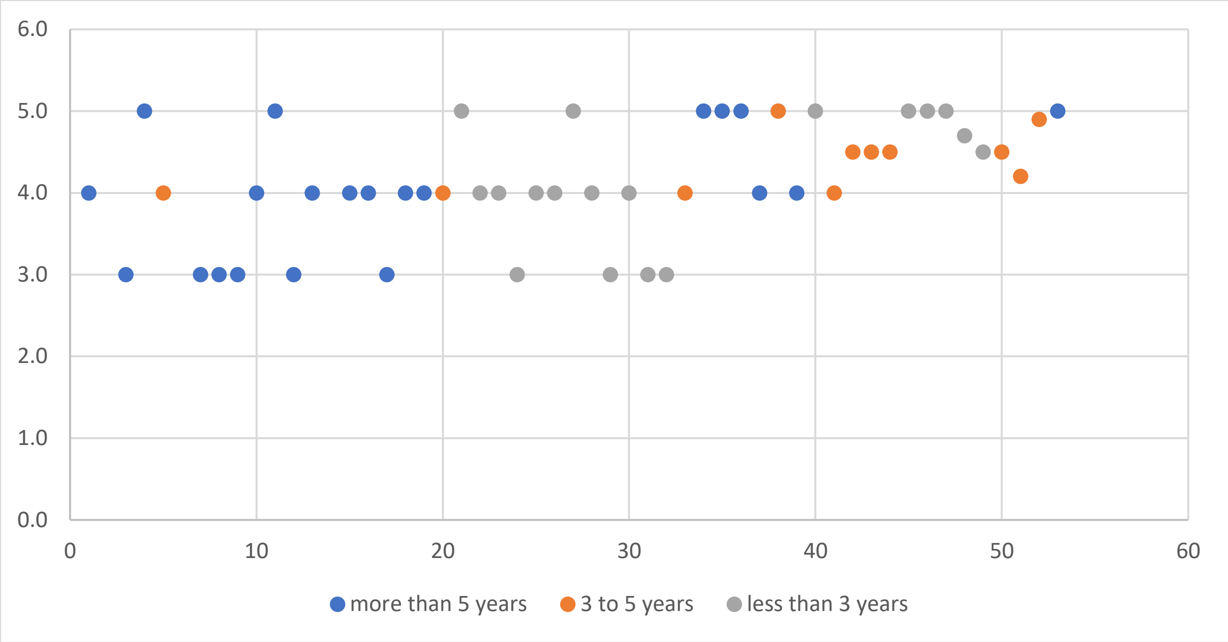


Figure 7.38: Categorisation of Requirements Scatter Chart

Table 7.13 shows the different mean of responses for the different groups of experiences. It can be seen that the total mean for this question being 4.12, being very high, as well as the means for each group, which ranges between 3.995 and 4.373.

Table 7.13: Means of Responses for the Different Groups

clear static and dynamic								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
5 years or more	22	3.955	.7854	.1675	3.606	4.303	3.0	5.0
3 to 5 years	11	4.373	.3636	.1096	4.128	4.617	4.0	5.0
less	18	4.178	.7735	.1823	3.793	4.562	3.0	5.0
Total	51	4.124	.7185	.1006	3.921	4.326	3.0	5.0

Again, as seen in Table 7.14, the significance of answers between the different groups was higher than 0.05 in all cases, i.e. there is no significant difference how the members of the three groups have responded.

Table 7.14: Significance test

(I) experience	(J) experience	Mean Difference (I-J)	Std. Error	Sig.
5 years or more	3 to 5 years	-.4182	.2635	.261
	less than 3 years	-.2232	.2268	.590
3 to 5 years	5 years or more	.4182	.2635	.261
	less than 3 years	.1949	.2731	.757
less than 3 years	5 years or more	.2232	.2268	.590
	3 to 5 years	-.1949	.2731	.757

Discussion: the categorisation concept in the OntEIR tool (into general and stage) was discussed and validated in Chapter 6 in the OntEIR Framework (as static and dynamic). In both cases, the categorisation has been accepted and considered a strong feature of both the framework and tool, for what it has to offer in increasing clarity and understandability of the requirement and its role in the project.

7.4.4.3 Quality of the Information Provided

The quality of information provided is measured to find out how useful the product is (Edwards *et al.*, 2014). According to Grudzień *et al.,* (2016) the quality of information generally depends on the sources of providers, and on whether or not the information has been validated.

Question: How would you rate the quality of the information presented?

This was to measure the quality of information presented in the tool itself, and if it was perceived as sufficient to prepare a proper EIR document.

Participants were asked the question of how they would rate the quality of the information presented. As seen in Figure 7.39, 60% of the participants regarded the information to be "Highly useful", 12% considered it to be "Extremely useful", 26% of the participants rated it as "Moderately useful" and 2% gave it a rating of "Slightly useful". None of the participants rated the quality to "Not useful".

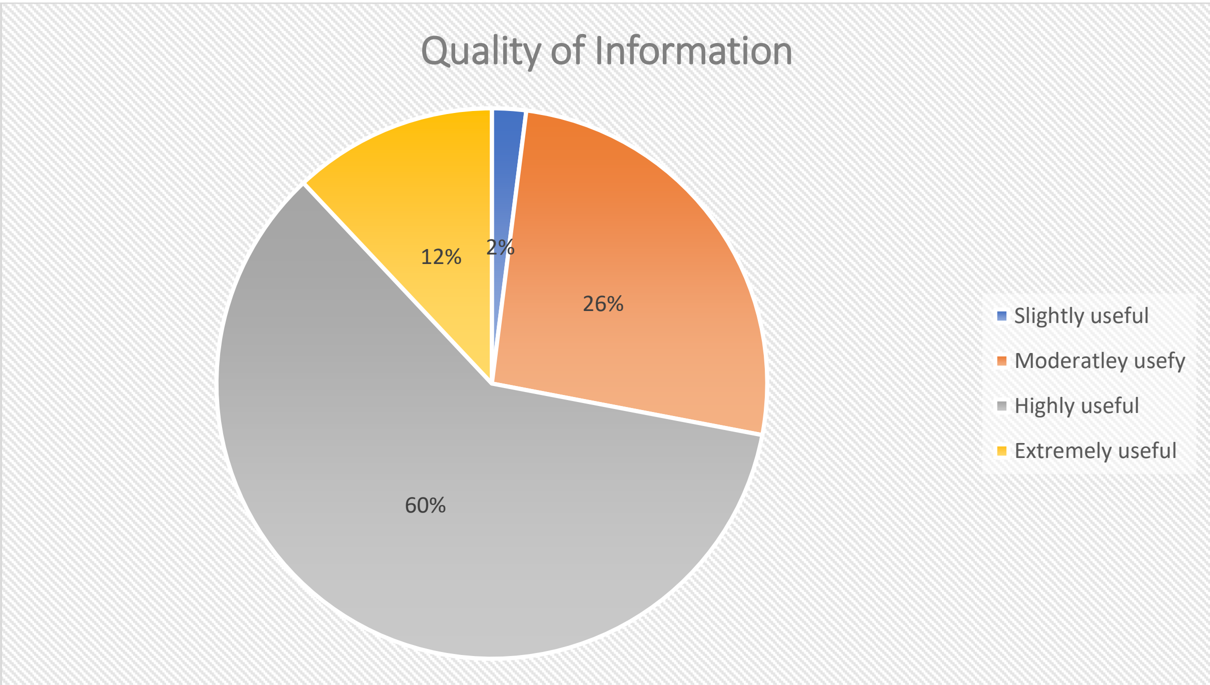


Figure.7.39: Quality of Information

Figure 7.40 represents the answers of all the participants in the questionnaire of all groups of experience.

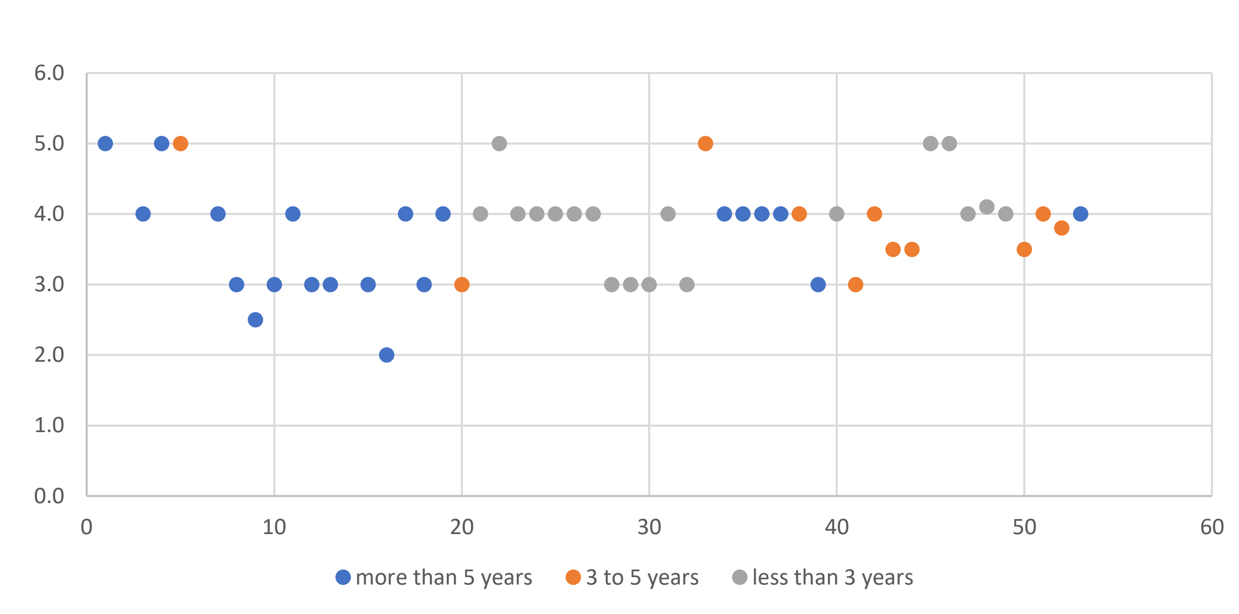


Figure.7.40: Quality of Information Scatter Chart

Experience in this question plays a role in the answer. Highly experienced participants may have a better understanding of what information the EIR should contain. Means of the answers for the different groups is shown in Table 7.15

Table 7.15: Means of Responses for the Different Groups

quality of information								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
5 years or more	22	3.523	.8234	.1756	3.158	3.888	2.0	5.0
3 to 5 years	11	4.009	.3700	.1116	3.761	4.258	3.5	5.0
less than 3 years	18	3.950	.6401	.1509	3.632	4.268	3.0	5.0
Total	51	3.778	.7089	.0993	3.579	3.978	2.0	5.0

The total mean of the answers to this question was 3.778. Table 7.16 shows the difference between means of the three groups and significance.

Table 7.16: Significance test

(I) experience	(J) experience	Mean Difference (I-J)	Std. Error	Sig.
5 years or more	3 to 5 years	-.4864	.2532	.144
	less than 3 years	-.4273	.2179	.133
3 to 5 years	5 years or more	.4864	.2532	.144
	less than 3 years	.0591	.2624	.972
less than 3 years	5 years or more	.4273	.2179	.133
	3 to 5 years	-.0591	.2624	.972

Comprehensiveness and Completeness

Question: to what extent does the tool provide you with the appropriate level of information to develop a full and complete EIR?

The level of information provided by OntEIR refers to how appropriate the amount and level of information is presented and organised, and to what extend does this information allows the user to developing complete EIRs.

From Figure 7.41, it can be seen that an overwhelming 70% of the participants regarded the level of information to be “Extremely Good” or “Good”, 28% rated it as “Neither Good nor Poor”, and the remaining 2% gave it a rating of “Somewhat Poor”. None of the participants regarded the level of information to be “Extremely Poor”.

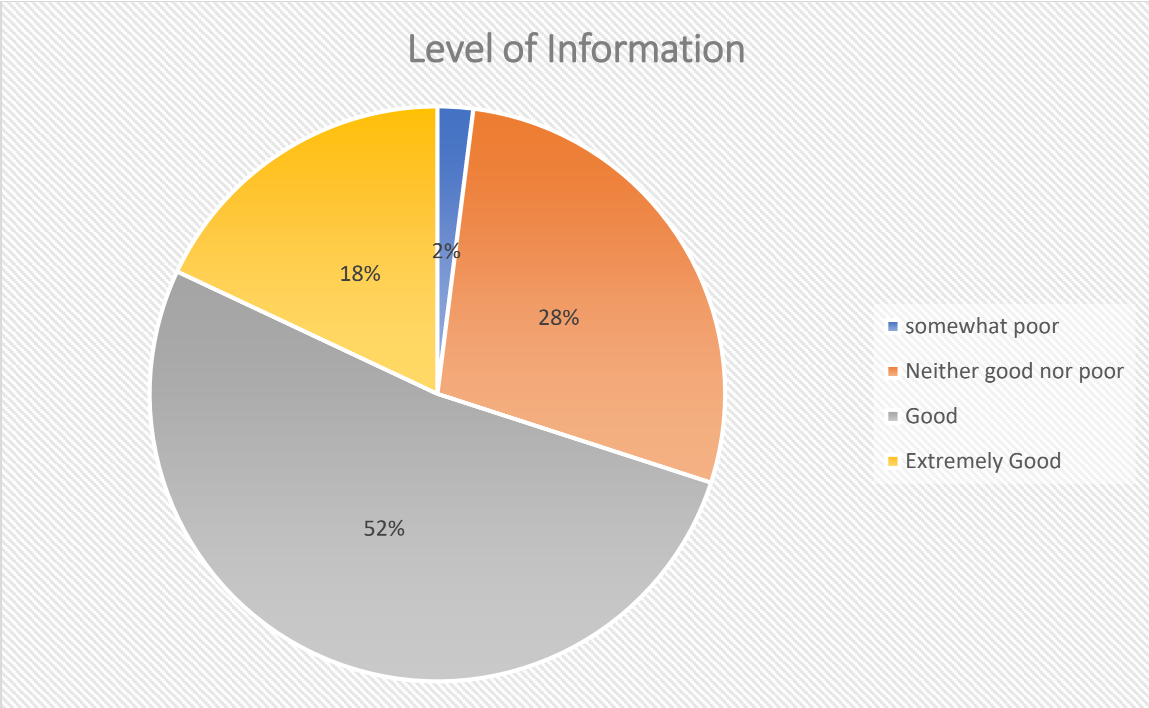


Figure 7.41: Level of Information

It can also be seen from Figure 7.42 and Table 7.17 that even though the means for the different groups of experience are very close, there is still a correlation between the two: the higher the experience the lower the mean. Many of the experienced participants have provided comments in the comment box about this matter that will be discussed in Section 7.4.4.5.

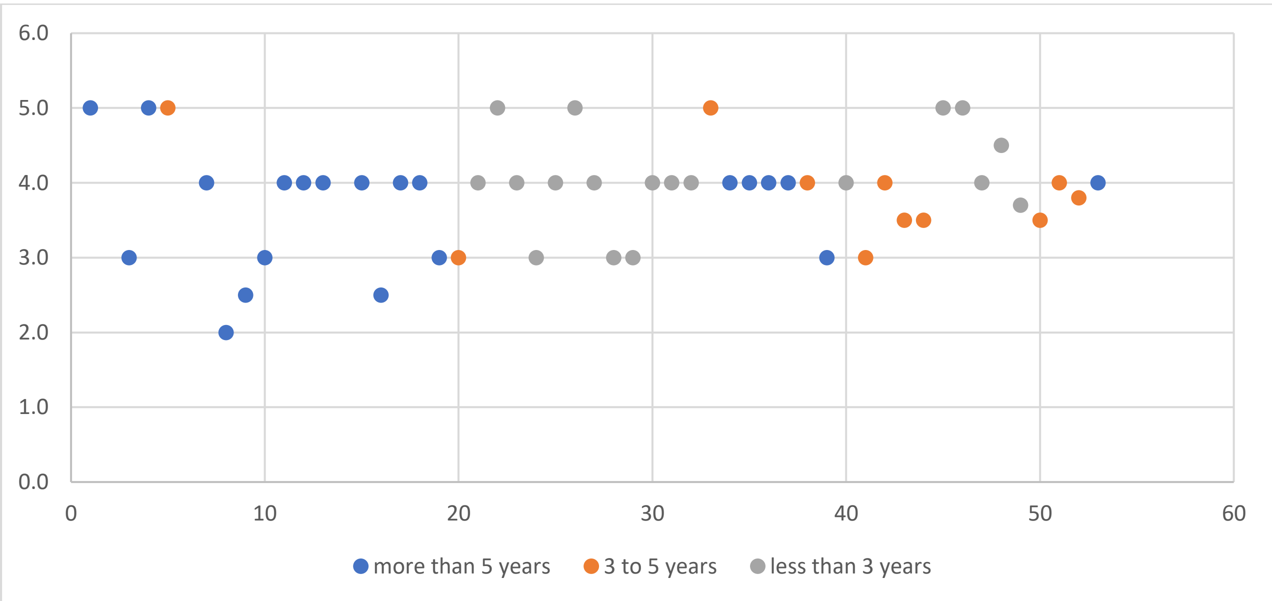


Figure 7.42: Level of Information Scatter Chart

Table 7.17 Means of Responses for the Different Groups

complete EIR								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
5 years or more	22	3.636	.7743	.1651	3.293	3.980	2.0	5.0
3 to 5 years	11	3.845	.6729	.2029	3.393	4.297	3.0	5.0
less than 3 years	18	4.067	.6535	.1540	3.742	4.392	3.0	5.0
Total	51	3.833	.7241	.1014	3.630	4.037	2.0	5.0

This question scored a high mean as total (3.83) and per group as seen in Table 7.17, with the participants with the lowest experience scoring the highest mean (4.0). Previous studies have shown the novice clients are overwhelmed by the sheer volume of information available in current practice, which leads to their confusion and ultimately prevents them from developing an EIR. As discussed in the previous question, the quality of information is perceived by the participants to be high, this question measured the level of information. Although the quality of information provided in the tool is high, still, novice users found the level of information provided to be very high, and not confusing or too much.

Table 7.18: significance test

(I) experience	(J) experience	Mean Difference (I-J)	Std. Error	Sig.
5 years or more	3 to 5 years	-.2091	.2632	.708
	less than 3 years	-.4303	.2265	.150
3 to 5 years	5 years or more	.2091	.2632	.708
	less than 3 years	-.2212	.2727	.698
less than 3 years	5 years or more	.4303	.2265	.150
	3 to 5 years	.2212	.2727	.698

How would you rate the quality and comprehensiveness of the developed final EIR document produced by OntEIR?

Beings able to provide a comprehensive EIR document with good quality is an important feature of the OntEIR tool. The final product of the tool provides the user with an excel or PDF document that contains all the answers that were input. But what OntEIR does not do, is delete the questions that are irrelevant or were not answered, and the user is given a document that contains all the information regardless of their relevancy to the project, for an example of what the final document looks like refer to Appendix G. The amount of information that is irrelevant to the user but produced in the final document has had an effect on the answers of the participants as seen in Figure 7.43. 56% of participants considered the final EIR to be “Good” in terms of comprehensives and quality, while 12% rated it to be “Excellent”. 26% of the participants gave it the rating to “Neither Good nor poor” and 6% considered it to be slightly poor. None of the respondents rated the comprehensiveness and quality of the final EIR document to be “Extremely Poor”.

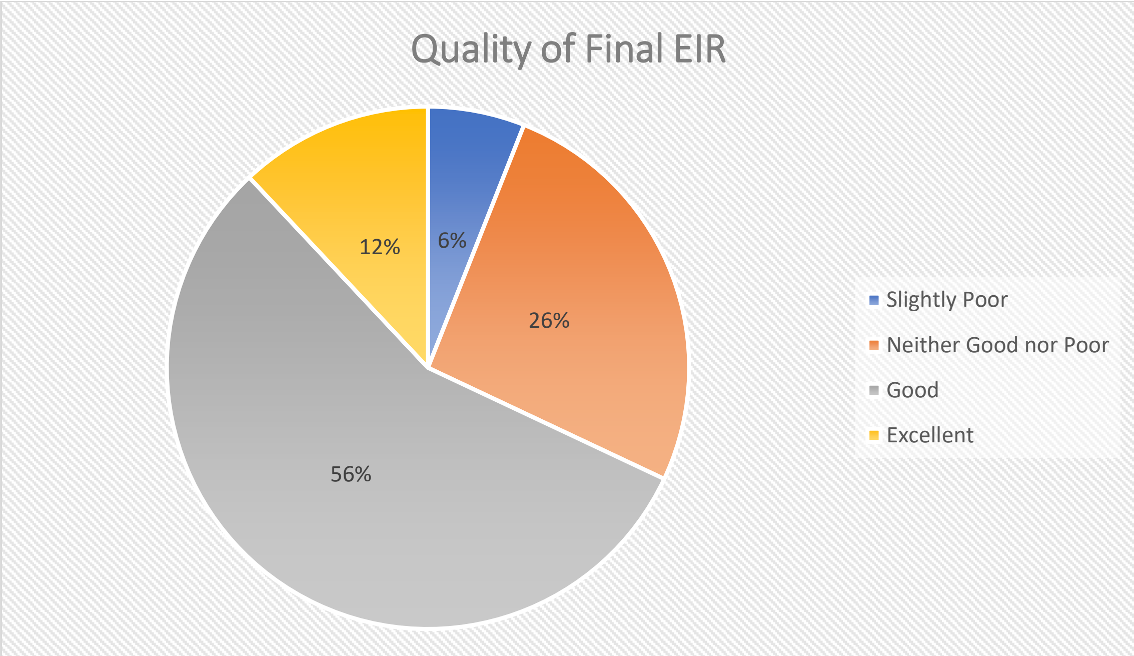


Figure 7.43: Quality and Comprehensiveness of Final EIR Document

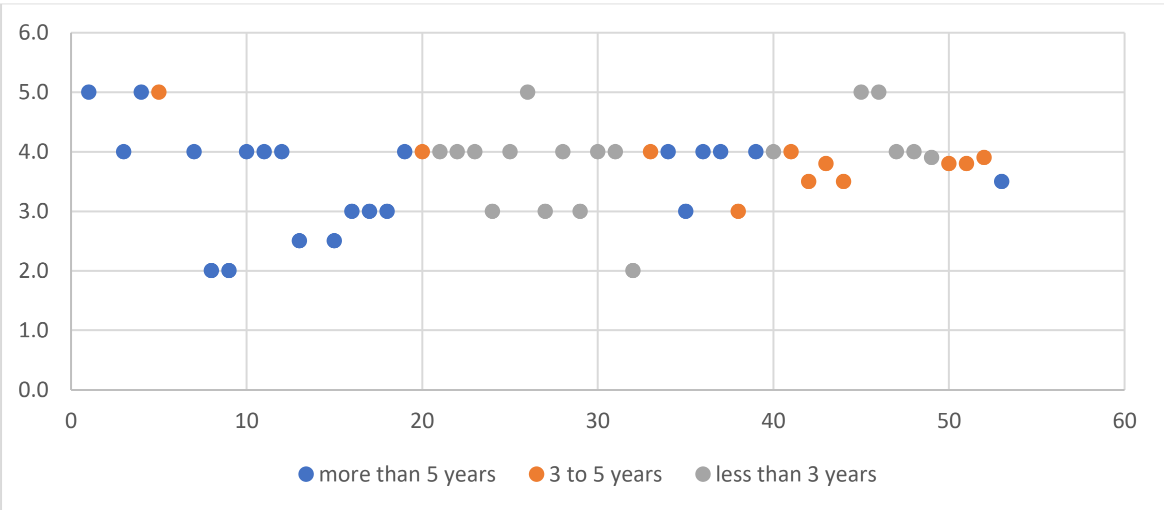


Figure 7.44: Quality and Comprehensiveness of Final EIR Document Scatter Chart

It can be seen from Figure 7.44 that participants who thought the final output of the tool was average or less, are the experienced participants. However, those are the respondents that also answered the open-ended question on how to improve the tool and suggested many ways to improve the final output as will be seen in Section 7.4.4.5.

Table 7.19 Means of Responses for the Different Groups

comprehensiveness								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
5 years or more	22	3.523	.8378	.1786	3.151	3.894	2.0	5.0
3 to 5 years	11	3.845	.4865	.1467	3.519	4.172	3.0	5.0
less than 3 years	18	3.883	.7579	.1786	3.506	4.260	2.0	5.0
Total	51	3.720	.7534	.1055	3.508	3.932	2.0	5.0

Tables 7.19 and 7.21 present the means of the answers for the different groups of experience and test the significance of those differences. Although the total mean was high with a score of 3.7, the most experienced participants scored the lowest mean of 3.5. However, as can be seen in Table 7.20, there is no significance between the different groups, and hence the difference is insignificant and there is no need for further investigations.

Table 7.20 significance test

(I) experience	(J) experience	Mean Difference (I-J)	Std. Error	Sig.
5 years or more	3 to 5 years	-.3227	.2763	.478
	less than 3 years	-.3606	.2378	.292
3 to 5 years	5 years or more	.3227	.2763	.478
	less than 3 years	-.0379	.2863	.990

less than 3 years	5 years or more	.3606	.2378	.292
	3 to 5 years	.0379	.2863	.990

7.4.4.4 Recommending OntEIR

When asked if they would recommend the tool for a colleague, an overwhelming majority of 94% said they would, opposite to 6% who said they would not.

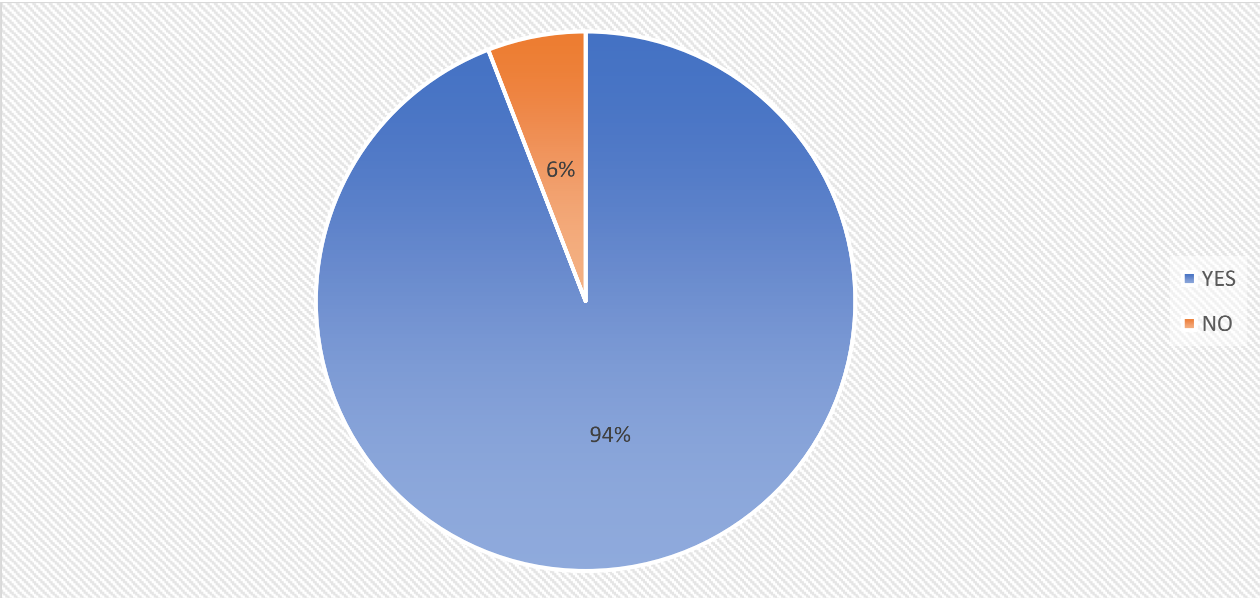


Figure 7.45: Recommending OntEIR

Comments and reasons why the respondent would or would not recommend the tool, however participants who answered they 'would not' besides the participants who answered they 'would', provided reasons for that in the comments question that will be discussed in the next section, in addition to any other comments on how to improve the tool.

7.4.4.5 Additional Comments and ways to Improve the Tool

The final question of the survey asked the participants to provide any additional comments for the improvement of the tool. Overall 18 comments were provided which count of 35% of the participants. The full comments of this question can be found in Appendix I.

Some of the quotes from the comments include:

- *"Very comprehensive tool and easy to use."*

- *“I would pick an EIR generated by this tool over most of the EIR's developed by BIM consultants in London any day.”*
- *“The tool has great potential and I invite you to continue in developing it.”*
- “*I feel this is a great concept and much needed.”*

However, many they also suggested ways to improve the tool. Some of these suggestions included:

- *“It would be good to have some more options or ability to customise some of the sections.”*
- *“The final presentation of the information could be improved.”*
- *“More work should be done to correlate information.”*
- *“The final output (pdf and csv) are not formatted in a way that can be automatically included in the ITT and shared with consultants.”*

Strengths of the tool as seen by the participants in the validation seem to fall under three categories:

1- The need for such a tool in the industry
2- The Concept behind the tool
3- Better than existing practices
4- Comprehensiveness
5- Ease of use

Also, the responders offered ways to improve the tool, these improvements fall under these categories:

1- GUI
2- The output
3- More user involvement
4- Incorporate graphics and supporting images
5- Ability to customise some requirements such as the stages and the output
6- Ownership of the model, the AIR and COBie

These issues and other ways to improve and update the tool will be addressed in the final chapter in Future Research Directions.

7.4.5 Case Study

For the purpose of this study, an EIR document was provided by a major contracting company in the UK, which represents their current practice in defining EIR. The EIR document provided by the company represents best current practices in EIR. It was developed by a governmental body for the construction of governmental schools in the UK, and is what most of EIRs for these type of projects look like.

The process was conducted by:

- Transforming all the information provided in the EIR to OntEIR
- Comparing the two documents in terms of comprehensiveness and completeness in covering requirements for EIRs.

7.4.5.1 Contents of the Provided EIR

An EIR was sponsored by a major contracting company in the UK. The EIR presented was for an educational project (school).

The existing EIR contained 36 pages, and included the following contents:

- 1.0 Introduction
- 2.0 BIM Documents and content
  - 2.1 Purpose
  - 2.2 Incorporation into tender and contract documents
  - 2.3 COBie Data set
  - 2.4 BIM Execution Plan Requirements
- 3.0 Management and Standards
  - 3.1 BIM Standards
  - 3.2 Roles and Responsibilities
  - 3.3 Collaboration, Coordination and Clash detection management
  - 3.4 Security minded approach
  - 3.5 Security and data information
  - 3.6 Disclosure of data and information
  - 3.7 Asset data
  - 3.8 Training
- 4.0 The principle of data and information generation and exchange
  - 4.1 Information exchanges
  - 4.2 Plain language questions
  - 4.3 Level of definition
  - 4.4 Master information delivery plan
  - 4.5 Information exchange file format
  - 4.6 File naming requirements
  - 4.7 Primary use
- 5.0 Technical requirements
  - 5.1 Authority software plans
  - 5.2 System performance
  - 5.3 BIM coordinates
  - 5.4 Planning the work and data segregation
- 6.0 Contractor response to requirements
- Annex A: Project Particulars

Pages 1-21 (Sections 1-6) of the document consist of guidance notes for the requirements. The actual EIR for the project are provided in Annex A of the document and under “Project Particulars” which is the projects EIR. It can be seen how the EIR in current practices can be perceived by clients as confusing, due to the large amount of unorganised information that are mainly guidance notes. The next sections will compare the information provided in the case study with the information that is provided by OntEIR.

7.4.5.2 Comparing between the Case Study and OntEIR

As mentioned in the previous section, the majority of the EIR document were guidance notes and standards, and the actual EIR of the project was provided in the Annex of that Document. It can be noticed immediately how disorganised the information is, and how much time it takes to find a certain requirement. Table 7.21 compares between the information provided in the case study and the information provided by OntEIR.

Table 7.21: Comparing EIR provided in the case study with EIR provided by OntEIR

Case Study EIR (name of requirement and definition)	**OntEIR (Equivalent name of requirement and definition)**
Not Specified	**Roles:** OntEIR defines the Roles that will participate in delivering the project, as shown previously in Figure 7.5.
Not Specified	**Responsibilities:** OntEIR defines a set of responsibilities that are needed to complete the project. Plus, it allows the user to identify the role associated with the responsibility, as seen in Figure 7.6.
Not Specified	**Ownership of the Model:** OntEIR allows the user to allow the ownership of the model, and the license as shown in Figure.
Not Specified	**Data Security Measures**
Not Specified	**Software Platform**
Not Specified	**Coordinates**
Not Specified	**AIM delivery Strategy**

Case Study EIR (name of requirement and definition)	OntEIR (Equivalent name of requirement and definition)
Generally: This consists of general information about the project such as the project title, school name, etc. **BIM standards:** This includes any additional standards not mentioned in the actual documents under "BIM standards".	**OntEIR:** This feature is also available in OntEIR under the name **Project Information,** as seen in Figure 7.6 in Section 7.3.1.1. **OntEIR:** The need "Standards" covers a big range of standards and their definition in addition to the option of adding as many standards as required, as can be seen in Figure 7.10, Section 7.3.1.1.
Security minder approach: This requires the supply chain to choose from: S1, S2, S3 and S4.	**OntEIR**: In OntEIR there are two types of security requirements: **General security requirements** in which a group of measures are put forward that the contactor should agree to comply with if ticked, as shown in Figure 7.12; and **Stage specific security requirements**, from which the client choses one security status (IL1, IL2, IL3, IL4) for each stage that the supply chain should have to comply with, as seen in Figure 7.20.
Asset Data: This defines the specific COBie requirements.	**OntEIR:** The user defines two types of information to complete the AIR and COBie Sheets: AIR: The user chooses the AIR for each stage from a large list of requirements, in addition to the LOD and LOI for the AIR, and who is

Case Study EIR (name of requirement and definition)	OntEIR (Equivalent name of requirement and definition)
	responsible for delivering the AIR, as seen in Figure 7.22. COBie: The user defines the COBie requirements, plus the type of information, i.e. geometric or non-geometric, as seen in Figure 7.23 previously.
Training: This part asks the supply chain to identify what parties need training and what the training will have to cover.	**OntEIR:** No equivalent.
Information exchange: This part requires identifying the number of information exchanges that are carried out during the project.	**OntEIR:** In OntEIR there are Data drops in each stage, with which the supply chain is required to comply, and deliver, as seen in Figure 7.18 previously.
Plain language questions.	**OntEIR:** No equivalent.
MIDP: This part requests the model production and delivery table. This includes: The project requirements and the LOD of each requirement.	**OntEIR**: The MIDP is defined by specifying the project requirements for each stage, the LOD and LOI for each requirement, and the delivery format for each requirement (2D PDF, 2D DWG, Documentation, BIM Model).

The information available in the provided EIR was transformed into OntEIR and the results showed that only 21% of the requirements provided by OntEIR were covered in the EIR provided by the sponsor. The complete information of the comparison of OntEIR versus the case study EIR is provided in Appendix G. Based on this information, Table 7.22 gives a summary of the comparison.

Table 7.22: Comparison between Information Provided by OntEIR Versus the Information Provided by the Case study EIR

Need1: Project Information	
OntEIR: fully Covered	Case study: fully covered
Need2: Roles:	
OntEIR: 11 requirements covered plus addition	Case study: 3 requirements covered
Need3: Responsibilities:	
OntEIR: 80 requirements covered	Case study: 7 requirements covered
Need 4: Software Platform	
OntEIR: 10 requirements covered plus additions	Case study: 5 requirements covered
Need 5: Ownership of the Model	
OntEIR: 4 requirements covered plus addition	Case study: No requirements covered
Need 6: Data security measures	
OntEIR: 12 requirements covered plus addition	Case study: No requirements covered
Need 7: Coordinates	
OntEIR: 7 requirements covered plus addition	Case study: No requirements covered, but recommends guidance and standard
Need 8: Communication: Coordination and Clash Detection	
OntEIR: 5 requirements covered plus addition	Case study: 4 requirements covered
Need 9: Asset Information Model Delivery Strategy:	
OntEIR: 2 requirements covered	Case study: 2 requirements covered
Need 10: Define staged	

OntEIR: 10 requirements covered	Case study: No requirements covered
Need 11: Level of Detail	
OntEIR: 6 requirements covered	Case study: 7 requirements covered
Need 12: Level of Information	
OntEIR: 6 requirements covered	Case study: No requirements covered
Need 13: Stage requirements	
OntEIR: 15 requirements covered	Case study: 8 requirements covered
Total number of information provided by OntEIR	**Total number of information provided by Case study:**
168 requirements covered	36 requirements covered

7.4.5.3 Discussion

As discussed in Section 3.5 previously, current practices and standards in developing EIR leave the client overwhelmed by the sheer volume of information provided, which makes it harder to develop a full and complete EIR. In this section, an EIR was provided by a major contractor company in the UK, and based on the current practices in developing EIR. The process of analysing this case study begun with a full review of the document and taking notes of each section including the requirements it provides. In items of organisation, the document is divided into two parts; the body of the document and the Annex. Usually the body of the EIR includes guidance notes and the standards used in developing the EIR, and a few important requirements such as some of the roles and responsibilities, as well as a few definitions. The annex contains the actual requirements for the EIR. Having the requirements scattered in the document and not in one defined place makes it harder for the stakeholders to actually identify the requirements and be able to organise them. In the current practices in EIR, there is no systematic process in defining the requirements that is popular, and makes it easy to use and follow those requirements. In OntEIR, the categorisation of the needs into general and stage related needs, and correspondingly the requirements that are included in each, makes it much easier to (1) define those requirements, (2) trace the requirements back to its original need, and (3) facilitate the organisation of the requirements in a way different stakeholder will not perceive hard to find and identify.

In terms of the actual requirements that are covered in the case study (which represents typical, current practices in EIR) the analysis process was to input all the information into OntEIR, compare the case study and OntEIR in terms of the completeness and comprehensiveness regarding the number of requirements they both covered. Results showed that the EIR from the case study only covered 21% of the requirements included in OntEIR (see Annex G and Table 7.22).

7.5 Chapter Summary

In this chapter, the fundamental elements that were necessary for the development of the OntEIR Tool were reviewed. And the process and outcomes of the tool validation were presented.

The OntEIR tool was developed based on the data collected, analysed, and validated from the OntEIR Framework, presented in Chapter 6. For the development of this tool and as discussed in this chapter, Mongo Data Base, which is a NoSQL data base was chosen and Java as used as the programming language. The tool was then uploaded on the (hbim) server with the link: www.onteir.hbim.org. Various screen shots of the tool were presented in Section 7.3.1.

For the validation process, both quantitative and qualitative methods were adopted through a structured online questionnaire for the purpose of data collection. These questionnaires included both Likert and open-ended questions that allows the participants to discuss some of their ideas. The results of this research have proven the success of OntEIR in terms of its understandability, ease of use and the quality of information it produces. 94% of the respondents said they would recommend OntEIR to a colleague.

Also, a case study was conducted to measure the success of the use of OntEIR in comparison to current practices in EIR.

The outcomes of this research in both the survey and the case study, demonstrate that OntEIR was perceived to be very useful in assisting clients in defining a full and complete EIR.

Chapter 8 Conclusions and Recommendations

8.1 Research Summary

The aim of this research was to develop an ontology-based framework and a supporting tool to assist clients of construction projects in defining the project's Employer Information Requirements (EIR). This has been achieved by meeting the research objectives set out in Chapter 1 and could be achieved by completing the following tasks:

1- Critical Literature Review:

- Conducting a through literature review about: clients, requirements, client requirements, BIM, BIM Information Delivery Life cycle in addition to all relevant information about EIRs in terms of the contents of EIR, sources of information, and the aim of EIRs
- Conducting a critical review on current practices, standards and tools in defining EIRs and identifying their weaknesses and strengths and both effective and efficient ways to address these weaknesses.

2- Developing and Validating the OntEIR Framework:

- Developing a new categorisation system for the EIR 'Needs' into Static and Dynamic that facilitates both the understanding and the elicitation of requirements.
- Elicitation of the requirements from the two types of needs, by decomposing these needs into goals and then into the more detailed, satisfying requirements.
- Presenting the information in the form of an ontology, using the Ontology Web Language (OWL); this ontology consists of classes, sub-classes, object and datatype properties to describe relationships between these, and instances of these classes.
- Further developing in detail and presenting the initial OntEIR framework for the purpose of validation by industry experts, through interviews, surveys and focus groups.
- Revisiting the initial OntEIR Framework and updating it in several iterations, based on the findings of the validation process.

3- Developing and Validating the OntEIR Tool:

- Developing an online tool based on the updated OntEIR Framework that is aimed at facilitating the definition of full and comprehensive EIR for all types of construction projects by users with various levels of expertise and experience.
- Validating the OntEIR Tool with different groups of participants that represent multiple roles in the construction industry, and with different levels of experience in the industry.
- Conducting a case study to define the weaknesses and strengths of the tool in comparison with the current practices in defining EIR.
- Reaching the final results and recommendations for further research and industrialisation work on the OntEIR Tool and Framework that will be presented in this chapter.

8.2 Key Findings

For this research to achieve its aim, which was to develop a comprehensive framework and tool to produce a full and complete EIR for BIM projects, a set of 5 objectives was formed and those were achieved step by step during the research project. The achievement of the objectives is illustrated through the key findings presented in the following sections:

8.2.1 Achieving Objective 1

'Review client requirements and their importance in a successful project delivery.'

To achieve this objective an extensive literature review was conducted on what 'Client Requirements' means and refers to in construction projects. And how proper identification of requirements leads to the delivery of successful projects. The research especially examined the importance of defining these requirements from the beginning of the project, and how good identification of requirements plays a significant role as an essential success factor of construction projects. This research also included the different definitions and categorisations of 'Client' and 'Requirements', in addition to the difference between 'Needs' and 'Requirements', which has proven useful when developing the OntEIR Framework and categorising the requirements.

8.2.2 Achieving Objective 2

'Review EIR and the contents of a full and complete set of requirements.'

For this objective, the expression EIR was examined in terms of its role in BIM projects and specifically as a corner stone for managing the information involved in the BIM Delivery Lifecycle, from the beginning of the project until the delivery of a full and complete AIM. Also, the proper specification of EIR was explored and the important role EIR plays in the success of BIM projects, in addition to the sources of information needed for a complete EIR.

Furthermore, a critical review was conducted for current practices in EIR, in identifying their weaknesses and strengths and achieve lessons learnt that were valuable for the development of the OntEIR Framework and tool.

After achieving those two objectives, it was clear that there seemed to be an urgent need in the construction industry for an EIR Framework and Tool, due to:

- The vital importance of defining proper EIR in the success of BIM projects;
- An evident lack of research on EIRs that are clear and understandable for all types of users and that can assist them in successfully defining complete EIR;
- Currently available approaches to developing EIRs make it hard for clients to effectively and efficiently define their requirements, mainly due to the sheer volume of unorganised information.

8.2.3 Achieving Objective 3

'Develop the initial EIR framework based on the literature review conducted and validate it with key experts in the field.'

Based on the literature review and the fulfilment of the first two objectives, it was possible to identify the key factors and the needs to contribute to the success of the EIR framework, which is one of the aims of this research. The initial framework presented two main concepts of the OntEIR framework, which were the classification system of the needs and related requirements into Static and Dynamic, and the concept of the decomposition of goals starting from the identified high-level needs, until a set of satisfying requirements has been elicited. Each such high-level need is considered satisfied, if all related requirements are satisfied.

After the definition of the necessary high-level needs to produce a complete EIR, and identifying the concepts used in the framework that will support the specification of the comprehensive EIR, this objective covered the presentation of the framework using ontology, and the actual elicitation of the complete package of the requirements. Classes, sub-classes, individuals and properties were introduced in the ontology, based on the framework and findings reached by fulfilling objective 3. Where main classes represented the classifications, sub-classes represented the goals, the individuals represented the requirements, and the properties represented the relations between these requirements. The first ontology-based framework identified: 2 main classes (classifications), 75 sub-classes (goals) and 395 individuals (requirements).

The validation of the framework took place with industry experts. The validation criteria were set to evaluate the framework in terms of the categorisation of requirements into static and dynamic, the quality of the requirements reached, the understandability of the elicitation process, and the completeness and comprehensiveness of the produced set of requirements.

Although the framework scored high points in each of the criteria in the questionnaires, the interviews allowed participants to give more elaborate feedback. Feedback on the framework included the need to add additional needs than the ones already reached and elaborate more on some of the existing needs by eliciting further requirements. This feedback was the basis of the update of the framework, which included adding further needs to both the static and dynamic sections and requirements to some of the existing needs, changing the stages used in the dynamic section, and adding definitions. The new update was introduced as the final OntEIR framework (in the scope of this research) and was the basis on which objective 3 was achieved, which is the development of an on-line tool for defining EIR based on the updated OntEIR framework.

8.2.4 Achieving Objective 4

'Build the OntEIR online tool based on the validated OntEIR framework and validate it with experienced and inexperienced clients and stakeholders in the industry.'

In the process of achieving objective 2, which was about critically reviewing EIR in the industry and examining challenges and studies presented to overcome them, it was noticed that there is an urgent call in the construction industry for digitalisation or computerisation particularly regarding the definition of requirements in a more user-friendly form; based on IT tools that can be used even by geographically dispersed project teams.

Although some attempts have been made in the industry to provide such tools for clients, it has been found that these tools have limitations that are still preventing the users from creating full, complete, and consistent EIRs. These limitations include the un-holistic approach these tools follow in covering the requirements needed for producing a comprehensive EIR; the not-so-user friendly style of these tools in presenting the requirements, which could be challenging for novice clients (the need to facilitate the work for such novice users was clearly identified as one of the topics the present research aimed to address). The OntEIR tool was developed to face these challenges and create a space where all the requirements needed for a complete and successful EIR exist in an understandable and user-friendly environment.

The OntEIR web tool allows the user to define all the requirements needed to create a complete EIR and MIPT. This will in turn be the basis, on which the supplier can develop the BEP. The strengths of the OntEIR tool lie in being understandable for users at different levels of experience, and being user-friendly. The new categorisation system presented in the OntEIR framework, on which the tool was based, as static and dynamic, were represented in the tool as "general" and "stage" sections; where the general requirements are presented as part 1 of the process, and the stage requirements are represented as part 2. The tool allows the user to save their work either in an excel form or PDF and edit their work for later modification. Also, more than one stakeholder could work on the same file and contribute according to their experience and role in the project, subject to the users having the username and password for the file.

Findings of the validation of the OntEIR tool showed that:

- 57% agreed that GUI was either 'Excellent' or 'Good';
- In terms of the categorisation of requirements into 'Part1: General Requirements' and 'Part2: Stage Requirements', the sheer majority of 80% either 'Extremely Agree' or 'Agree' with the system used;
- In terms of Comprehensiveness, 80% of respondents rated the level of information provided to be 'Excellent' or 'Good'; and
- 94% of participants would recommend the tool.

8.2.5 Achieving Objective 5

'Provide conclusions and recommendations for the industry and the framework, as well as further studies to be conducted.'

The final objective of the research is discussed in this chapter under Section 8.5

8.2.6 Key Findings

Key findings were either reached through literature review, or through contact with the industry's experts and stakeholders during the validation process.

Key findings from the critical literature review included:

- There is a need in the industry for a tool that will enable the clients in developing EIR in a clear and understandable way.
- Update and review should occur on existing standards and practices due to the confusion it creates for novice clients due to the sheer volume of unorganised and unclear information.
- There is not one single source, from which clients could produce a complete and comprehensive EIR.

Key findings gained from the interviews, surveys and direct contact in general with the industry's experts and stakeholders included:

- Existing standards do not sufficiently guide novice clients in a step by step clear process in defining EIR.
- The existing categorisation system of requirements into management, technical and commercial requirements should be updated, and simpler clearer categorisations should be used.
- Experts in the industry encourage the development of new frameworks for defining EIRs.
- Any new tool should be made very user-friendly and clear especially for novice clients to encourage them in developing EIRs, given the importance they have in managing a successful BIM project.

8.3 Contribution to Knowledge

Due to the increase of BIM adoption in the construction industry, there is an apparent need to find a system or tool that enables stakeholders to define more complete and consistent requirements that will help to plan and guide the whole lifecycle, which will result in a reduction of waste, costs and lead times.

The aim of this research was to produce a framework and tool that will enable clients of BIM projects to define their requirements and produce a high quality EIR, that is understandable, complete and user friendly.

As expected in Section 1.5.1, the research managed to contribute to knowledge through

- The identification of an elicitation system that allows the definition of more requirements than current studies and standards. Through presenting new ideas of distinction between the high-level needs of EIR and the requirements, and the decomposition of goals to extract the requirements from the high level needs, OntEIR was able to identify 3 times more requirements than current practices, which contributes to a more detailed and relevant EIR
- The contribution to Ontology, the research presented new concepts in eliciting requirements using an ontology-based framework and supporting, web-based tool that have been validated and concept-proven through two iterations with experts from within the construction industry.
- Contribution to the industry through providing a state-of-the-art tool on defining EIR that is able to solve problems identified in the gaps of knowledge in the current practices.

Also, the research was able to contribute to knowledge in different aspects, such as:

- This research provided a deeper understanding of the BM information delivery cycle and the requirements needed to plan and organise this cycle.
- The research refers to key factors that affect the definition of client requirements and EIRs in the industry.

- This research conducted a critical review of the existing situation in the industry and the challenges facing the existing practices; and put forward solutions to manage these challenges both more effectively and efficiently.
- The main aim achieved by this research was fulfilled by developing a successful framework and tool for defining EIRs, which was a contribution to the industry in terms of supporting the definition of complete sets of EIRs in an easy, understandable and user-friendly way.
- As a result of conducting this research, 4 publications were produced, i.e. two journal papers, one conference paper and one book chapter, as shown in the (List of Publication Section).

8.4 Research Limitations

Although the research was able to achieve its aims by fulfilling all the objectives set out, a number of limitations have to be noted:

- Although the framework was developed by studying the existing UK BIM industry and the available standards and studies, other research and other practices and standards worldwide may be worthwhile considering. In other words, the research was focused on the construction industry in the UK only.
- The validation process and thereby key parts of the research were based on the personal views and perceptions of domain experts and professionals in the UK construction industry.
- Although both the framework and tool were validated and evaluated positively, and feedback was used to update and further improve the framework, there are some comments and other feedback that will be taken into consideration for future research on and industrialisation of the framework and tool.

8.5 Recommendations and Future Works

Based on the finding of this research, two types of recommendations could be put forward, recommendations for the construction industry, and recommendations for future research.

8.5.1 Recommendations for the construction industry

Based on the literature reviews conducted and the findings of this research, the following recommendations can be put forward to improve the definitions of EIRs:

- It was found that there is an obvious lack in the industry in terms of available frameworks and tools for defining requirements for BIM projects. There should be clearer and more understandable standards and tools for defining EIR that are also directed at less experienced clients.
- The definition of requirements should be more pro-actively supported by means of digital technology, in particular regarding the development of EIRs.

8.5.2 Recommendations for further research

Although the feedback from the validation processes was overall very positive, some of it could not be addressed as part of the present research due to the limited time available. This feedback is presented here as recommendations for future research and work:

- Further development and industrialisation of the OntEIR tool could incorporate BEPs in the framework, to allow suppliers to develop the plan according to the clients' requirements expressed in the EIR.
- Update the OntEIR framework and tool to adapt to Level 3 BIM.
- Learn from BIM industries around the world in creating and developing EIRs and develop a framework that could work to any BIM project, not only UK based ones.
- Incorporate mixed reality in defining the requirements, which will enable clients, especially novice clients, in defining exactly what they want as an end result of the BIM project.
- Enhance the outcome of the BIM tool, the way information is presented in the final document, and customise the output, so that it can be imported into the CDE.
- Define customisable templates for projects.
- Add the option of adding an attachment, so that it could be included in the final EIR.
- Develop the tool further into a 'smart' tool. Where the generated EIR is custom made for the client capabilities and business objectives of the project. This will help in getting rid of any irrelevant information, save time and produce a successful EIR tailored for the project and client.

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Appendices

Appendix A: The decomposition of the static needs into goals and requirements

Static Needs	Goals	Requirements
Tasks (responsibilities)	Task1- CDE	Advise on a CDE
		Provide a CDE
		Set up the CDE
		Maintain the CDE
		Download/upload all project information from/to the CDE
	Task2- Recourses	Appoint consultants, including Information Manager
		Ensure that the necessary software and hardware are in place within the organisation to support efficient delivery of the project
		Assess all sub-contracted organisations (design or construct) according to the BIM assessment criteria contained in the Capability Assessment
		Report any emerging skill gaps within the team

		Provide guidance to assist in procuring the right type of training from credible industry professionals
		Co-ordinate training for your own organisation
	Task3- Geometry	Create a site set-up model with coordinated, measurements and bearings to be used disseminated to all design team members
		Incorporate sub-contract (design and construct) models
		Ensure that all drawings are derived from the information models
		Export and publish files according to file data exchange schedule
		Provide a virtual model according to the Levels of Development, the MPDT and the non-geometric requirements
		Share information models for coordination

		Implement the BEP within the organisation
		Full coordination of the design and design team
		Provide energy analysis model(s) for evaluation by the project team
		Provide structural analysis model(s) for evaluation by the project team
		Create clash detection reports of the federated models
		Ensure the implementation of BIM acknowledges Facilities Management (FM) and operation and maintenance deliverables
	Task4-Data	Specify data requirements including the purpose for the information required and the timing of its delivery
		Provide data about facility in both its spatial and physical aspects according to the COBie requirements of the EIR

		Provide data specific to a particular system or component in line with individual scope of works
		Delegate aspect of the EIR downwards to the next tier
		Create, acquire and store required information
		Review and approve the data deliverable prior to submission
	Task5-ConstructionManagement	Provide 4D construction phasing
		Provide 4D construction sequencing
		Provide 4D logistics simulations including crane strategy
		Update all 4D simulated models to reflect current project conditions and to illustrated progress
		Report on residual risks within the model space and share via the CDE

		Compile a digital health and safety file
	Task6-QualityAssuranceAndControl	Adhere to the QA/QC procedure contained within the EIR
		Ensure all dataset requirements are completed in full according to the Level Of Definition stage for use in CAFM
		Report on changes to budget, cost and design
		Audit and coordinate virtual models, including full intermittent clash detection according to the BIM programme
		Report on general model quality in terms of geometry, materiality and metadata
		Report on adherence to the project BEP with regards to model Level Of Definition, model completeness and BIM standards compliancy

		Report on functionality of the model for 4D and 5D use by other consultants
		Review of received data against the EIR data requirements
		Support the Lead Designer by undertaking third party 3D coordination and clash detection processes to assist design coordination reviews
	Task7-Meetings	Make use of information models during design team and the Employers team meetings
		Hold BIM workgroup meetings
		Hold key work stage BIM steer meetings
		Hold lessons learned meeting following completion of phases
	Task8-ReportingAndGovernance	Provide monthly status reports of BIM development using project pro-forma
		Provide monthly procurement model

		highlighting work packages which have been let and/or procured
		Provide monthly model showing actual programme progress against planned
		Report on supply chain performance during construction
	Task9-Project strategy	Establish BIM requirements for the project, long term
		Responsible for ensuring that all subcontracted organisations (design or construct) meet the requirements set forth in the EIR
		Provide any existing information including historical data and existing conditions models.
		Develop, implement and update as necessary the post-contract BEP, which all project team members need to agree to and use
		Agree and implement the data structure and

		maintenance standards for the information models
		Acquire and update as necessary the post-contract BEP to include construction responsibilities
		Develop and implement the information delivery plan, sufficient to ensure all deliverables are accounted for
		Acquire and update the MPDT indicating model progression in respect of work packages including Level Of Definition with dates of delivery
		Develop and implement the BIM implementation programme
		Develop and implement the information exchange protocol
		BIM guidance and monitoring of the project team
Roles		Employer
		BIM Leader

		Information Manager
		Lead Designer
		Design Team
		Main Contractor
		Specialist Contractor
		Project Manager
		Facilities Manager
		CDM
		Cost Manager
Standards	Collaborative production of architectural, engineering and construction information. Code of practice, the naming of data as well as a process for exchanging data.	BS 1192:2007+A2:2015
	Specification for information management for the capital/delivery phase of construction projects using building information modelling	PAS 1192-2:2013
	Specification for information management for the operational phase of	PAS 1192-3:2014

	assets using building information modelling (BIM)	
	Exchange requirements using COBie. Code of practice	BS 1192-4:2014
	Specification for security-minded building information modelling, digital built environments and smart asset management	PAS 1192-5:2015
	Design management systems. Guide to managing design in construction	BS 7000-4:2013
	Briefing for design and construction. Code of practice for facilities management (Buildings infrastructure)	BS 8536-1:2015
	Classification embedded within the NBS Toolkit. Uniclass2015 is a unified classification for the UK industry covering all construction sectors.	UniClass 2015
	Delivery plan embedded within the NBS Toolkit	Digital Plan of Work

	Building Information Model (BIM) Protocol	CIC/BIM Pro first edition 2013
	Library objects for architecture, engineering and construction. Identification and classification. Code of practice	BS 8541-1:2012
	Library objects for architecture, engineering and construction – Recommended 2D symbols of building elements for use in Building Information Modelling	BS 8541-2:2011
	Library objects for architecture, engineering and construction – Shape and measurement	BS 8541-3:2012
	Library objects for architecture, engineering and construction – Attributes for specification and assessment	BS 8541-4:2012
	Library objects for architecture, engineering	BS 8541-5:2015

	and construction – Assemblies	
	Library objects for architecture, engineering and construction – Product Declarations	BS 8541-6:2015
	Outline Scope of Services for the Role of Information Management	CIC/INF MAN/S first edition 2013
	Practical implementation of BIM for the UK Architectural, Engineering and Construction (AEC) industry	AEC (UK) BIM Technology Protocol Version 2.1.1 June 2015
	Data structures for electronic product catalogues for building services. Concepts, architecture and model	BS ISO 16757-1:2015
Ownership of the model	Design Stage	OWNED BY AND LISCENCED TO
	Tender Period	OWNED BY AND LISCENCED TO

	Post Tender Period	OWNED BY AND LISCENCED TO
	During First Year Of Occupation	OWNED BY AND LISCENCED TO
Data security measures and guidelines	Home and Mobile Working	Develop a mobile working policy and train staff
		Apply the secure baseline building to all devices
		Protect data both in transit and at rest
	User Education and Awareness	Produce safer security policies covering acceptable and secure use of the organisations systems
		Establish a staff training programme
		Maintain user awareness of the cyber risks
	Incident Management	Establish an incident response and disaster recover capability
		Produce and test incident management plans

		Provide specialist training to the incident management team
		Report criminal incidents to law enforcement
	Information Risk Management Regime	Establish and effective governance structure and determine risk appetite
		Maintain the boards engagement with the cyber risk
		Produce supporting information risk management policies
	Managing User Privileges	Establish account management processes and limit the number of privileged accounts
		Limit user privilege and monitor user activity
		Control access to activity and audit logs
	Secure Configuration	Apply security patches and ensure that the secure configuration of the ICT system is maintained

		Create a system inventory and define baseline built for ICT devices
	Malware Protection	Produce a relevant policy and establish anti-malware defences that are applicable and relevant to all business areas
		Scan for malware across the organisation
	Network Security	Protect your network against external and internal attacks
		Manage the network parameter
		Filter out unauthorised access and malicious content
		Monitor and test security controls
Software platforms	2D Drawing	TBC
	Collaboration	TBC
	Coordination & Review	TBC
	Data Exchange	TBC
	Facilities Management	TBC
	3D design Modelling	TBC

Coordinates	Intersection of grids XX and YY	TBC
	Intersection of grids AA and BB	TBC
	Ground floor FFL	TBC
	Origin rotation	TBC
	Offsets	TBC
	Datum information	TBC
	Units to be used	TBC
Coordination and clash detection	Frequency of information exchange	TBC
	Clash detection process	TBC
	Clash resolution process	TBC
	Responsibility	TBC
AIM delivery strategy	Information Exchange Format	TBC
	Standard Classification System	TBC
LOD and LOI		

Appendix B: List of classes and individuals in the OntEIR Framework

Main class (Classification)	Sub Class 1 (Need)	Sub Class 2 (Goal)	Individual (requirement)
Generic EIR	Coordinates		Intersection of grids XX and YY
			Intersection of grids AA and BB
			Ground floor FFL
			Origin rotation
			Offsets
			Datum information
			Units to be used
	Coordination and clash detection		Coordination and clash detection
	Data Security	Security measures	Security measure 1
			Security measure 2
			Security measure 3
			Security measure 4
			Security measure 5
			Security measure 6
			Security measure 7
			Security measure 8
			Security measure 9
			Security measure 10
			Security measure 12
			Security measure 13
			Security measure 14
			Security measure 15
			Security measure 16

			Security measure 17
			Security measure 18
			Security measure 19
			Security measure 20
			Security measure 21
			Security measure 22
			Security measure 23
			Security measure 24
		Security status	Status-IL1
			Status-IL2
			Status-IL3
			Status-IL4
		Security guidelines	Guideline 1
			Guideline 2
			Guideline 3
			Guideline 4
			Guideline 5
			Guideline 6
			Guideline 7
			Guideline 8
	Ownership of the model		O1-OwnershipOfTheModel-DesignStage
			O2-OwnershipOfTheModel-TenderPeriod
			O3-OwnershipOfTheModel-PostTenderPeriod
			O4-OwnershipOfTheModel-DuringFirstYearOfOccupation
	Generic roles		Role 1

			Role 2
			Role 3
			Role 4
			Role 5
			Role 6
			Role 7
			Role 8
			Role 9
			Role 10
			Role 11
			Role 12
	Generic task	Task 1-CDE	Responsibility-CDE-1
			Responsibility-CDE-2
			Responsibility-CDE-3
			Responsibility-CDE-4
			Responsibility-CDE-5
		Task 2-Resources	Responsibility-Recources-1
			Responsibility-Recources-2
			Responsibility-Recources-3
			Responsibility-Recources-4
			Responsibility-Recources-5
			Responsibility-Recources-6
		Task 3-project strategy	Responsibility-ProjectStrategy-1
			Responsibility-ProjectStrategy-2
			Responsibility-ProjectStrategy-3
			Responsibility-ProjectStrategy-4
			Responsibility-ProjectStrategy-5

			Responsibility-ProjectStrategy-6
			Responsibility-ProjectStrategy-7
			Responsibility-ProjectStrategy-8
			Responsibility-ProjectStrategy-9
			Responsibility-ProjectStrategy-10
			Responsibility-ProjectStrategy-11
	Task 4 geometry		
			Responsibility-Geometry-1
			Responsibility-Geometry-2
			Responsibility-Geometry-3
			Responsibility-Geometry-4
			Responsibility-Geometry-5
			Responsibility-Geometry-6
			Responsibility-Geometry-7
			Responsibility-Geometry-8
			Responsibility-Geometry-9
			Responsibility-Geometry-10
			Responsibility-Geometry-11
			Responsibility-Geometry-12
	Task 5-data		Responsibility-Data-1
			Responsibility-Data-2
			Responsibility-Data-3
			Responsibility-Data-4
			Responsibility-Data-5
			Responsibility-Data-6
	Task 6-construction management		Responsibility-ConstructionManagement-1

			Responsibility-ConstructionManagement-2
			Responsibility-ConstructionManagement-3
			Responsibility-ConstructionManagement-4
			Responsibility-ConstructionManagement-5
			Responsibility-ConstructionManagement-6
	Task 7 – Quality Assurance And Control		Responsibility-QualityAssuranceAndControl-1
			Responsibility-QualityAssuranceAndControl-2
			Responsibility-QualityAssuranceAndControl-3
			Responsibility-QualityAssuranceAndControl-4
			Responsibility-QualityAssuranceAndControl-5
			Responsibility-QualityAssuranceAndControl-6
			Responsibility-QualityAssuranceAndControl-7
			Responsibility-QualityAssuranceAndControl-8
			Responsibility-QualityAssuranceAndControl-9
	Task 8-meetings		Responsibility-Meeting-1
			Responsibility-Meeting-2
			Responsibility-Meeting-3
			Responsibility-Meeting-4

	Task 9-reporting and governance		Responsibility-ReportingAndGovernance-1
			Responsibility-ReportingAndGovernance-2
			Responsibility-ReportingAndGovernance-3
			Responsibility-ReportingAndGovernance-4
	HSE & CDM Compliance		Health And Safety-Standards
		CDM data drops	CDM-DataDrops-Drop2a-OutilneRiskAssesment
			CDM-DataDrops-Drop2b-PreConstructionInformation
			CDM-DataDrops-Drop3-ProjectConstructionHSplan
			CDM-DataDrops-Drop4-OperationMaintenanceManuals
			CDM-DataDrops-Drop5-UploadBLGmanualsOnCDE
			CDM-DataDrops2b-ProjectSpecificOutline
	Software platforms	2D drawing	Software
			Version
		Collaboration	Software
			Version
		Coordination and review	Software
			Version
		Data exchange	Software
			Version

		Facilities management	Software
			Version
		3D design modelling	Software
			Version
	Standards		BS 1192:2007+A2:2015
			PAS 1192-2:2013
			PAS 1192-3:2014
			BS 1192-4:2014
			PAS 1192-5:2015
			BS 7000-4:2013
			BS 8536-1:2015
			UniClass 2015
			Digital Plan of Work
			BS 8541-1:2012
			BS 8541-2:2011
			BS 8541-3:2012
			BS 8541-4:2012
			BS 8541-5:2015
			BS 8541-6:2015
			CIC/INF MAN/S first edition 2013
			AEC (UK) BIM Technology Protocol Version 2.1.1 June 2015
			BS 8541-1:2012
			BS ISO 16757-1:2015
Phase EIR	AIR-COBie Fields	AIR-component sheet	Name
			created by

			created on
			type name
			space name
			description
			Ext system
			Ext object
			Ext identifier
		AIR contact sheet	E-mail
			Created by
			created on
			category
			company
			Phone
			Ext system
			Ext object
			Ext identifier
			department
			organisation code
			given name
			family name
			Street
			postal box
			Town
			Country
		AIR deliverable type	E-mail
			Created by

			created on
			Category
			Company
			Phone
			Ext system
			Ext object
			Ext identifier
			Department
			organisation code
			given name
			family name
			Street
			postal box
			Town
			country
		Faculty sheet	Name
			created by
			created on
			category
			project name
			site name
			linear units
			area units
			volume units
			area measurement
			external system
			external project object
			external site identifier

			external facility identifier
			description
			site description
		Floor sheet	Name
			created by
			created on
			Category
			Ext system
			Ext object
			Ext identifier
			Description
			Elevation
			Height
		Space sheet	Name
			created by
			created on
			Category
			floor name
			Description
			Ext system
			Ext identifier
			room tag
			usable height
			gross area
			net area
		System sheet	name
			created by

			created on
			Category
			component name
			Ext system
			Ext object
			Ext identifier
			Description
		Type sheet	Name
			created by
			created on
			Category
			Description
			asset type code
			ext system
			ext object
			ext identifier
			nominal width
			nominal length
			model reference
			Shape
			Size
			Colour
			Finish
			Grade
			material
			consistuents
			features
			accessibilty performance

			code peformance
			sustainability performance
		Zone sheet	Name
			created on
			created by
			category
			space name
			Ext system
			Ext object
			Ext identifier
			description
	Data drops		Develop Health & Safety Plan
			Develop Initial Cost Estimation
			Develop Initial Structure Building Design
			Overall Building Massing
			Size Shape Orientation
			CostEstimation
			SpatialDesign
	Deliverable format		2D PDF
			2D DWG
			Documantation
			BIM model
	LOD & LOI		LOD2
			LOD3
			LOD4
			LOD5
			LOD6

			LOI1
			LOI2
			LOI3
			LOI4
			LOI5
			LOI6
	Project requirements	Overall Form and content	MaintenanceAccess
			SpacePlanning
			Surveys
			BuildingAndSiteSections
			Specifications
			SiteAndContex
			ExternalFormAndAppearance
			internal layouts
			Fire
			PhysicalSecurity
			DisabledAccess
		Elements Materials and Components	Building
			MEP Systems
			Structural
			Specifications
		Performance	5DCostAnalysis
			4DProgrammingAnalysis
			AcousticAnalysis
			Buidling
			MEPsystems

			RegulationsComplianceAnalysis
			Structural
			ThermalSimulations
			ServicesCommisioning
			SusutainabilityAnalysis
		Design Strategies	DisabledAccess
			Fire
			MaintenanceAccess
			PhysicalSecurity
		Construction Proposals	Phasing
			SiteAccessSiteSet-up
			SiteSet-up
		Health and Safety	DesignConstruction
			Construction
			Design
			Operation
	Project team		Architect
			Civil
			SE
			MEP
			Buidling Service Engineer
			FMA
			Ground Worker
			Planning Depatrment
	Stages		Stage 2- Concept Design

			Stage 3- Developed Design
			Stage 4- Technical Design
			Stage 5- Construction
			Stage 6- Handover & Closeout
			Stage 7- In-Use
	Stage tasks	Stage 2	Task 1
			Task 2
			Task 3
			Task 4
			Task 5
			Task 6
			Task 7
			Task 8
			Task 9
			Task 10
		Stage 3	Task 1
			Task 2
			Task 3
			Task 4
		Stage 4	Task 1
			Task 2
			Task 3
			Task 4
			Task 5
			Task 6
			Task 7
			Task 8
			Task 9

			Task 10
			Task 11
			Task 12
			Task 13
			Task 14
			Task 15
			Task 16
			Task 17
			Task 18
		Stage 5	Task 1
			Task 2
			Task 3
			Task 4
			Task 5
			Task 6
			Task 7
		Stage 6	Task 1
			Task 2
			Task 3
		Stage 7	Task 1
Total: 2	Total: 22	Total: 53	Total: 395

Appendix C: Survey 1-the OntEIR Framework

Q1 **Introduction**

Welcome to the evaluation of the OntEIR (Ontology based framework for defining Employer Information Requirements) framework, to assist employers (clients) in defining their Employer Information Requirements (EIR). The aim of this framework is to define the needs and requirements of the EIR.
This form is part of the validation for the OntEIR framework. You are asked to fill in this questionnaire that will enable the researcher to get feedback for the development of the tool.

Confidentiality
No personal information will be collected that would identify you, and all your data will be anonymous. All data will be stored in a password protected electronic format. To help protect your confidentiality, the surveys will not contain information that will enable to identify you. Non-identifiable results of this study will be used for scholarly purposes and may be shared with the research team.

Participation
Please note that your participation in this study is completely voluntary. You may choose not to participate. However, if you do choose to participate, you may withdraw at any time while completing the form. If you don't want to answer any of the questions you don't have to. By submitting this survey, you are agreeing to participate and cannot withdraw after this point. If you decide to withdraw at any point, you will not be penalised.
Questions about the research or your rights as participants. If you have any questions or concerns, feel free to contact the owner of this study at: **Shadan.dwairi@uwe.ac.uk**

Consent

Please confirm that you understand and agree to the following:

I am over the age of 18 have read through the information above and received enough information about the research. I understand that by consenting to taking part in this study, I can still withdraw at any time without being obliged to give reasons. I understand by submitting this survey, I cannot withdraw my data anymore. I understand that I will not be personally identified at any report, and my name will be replaced by a number so that all the data can remain confidential. I understand that this information will be used only for the purpose set out in the information page, and my consent is conditional upon the university complying with the duties and obligation under the Data Protection Act

By consenting to take part in this study you are acknowledging that you understand that you are confirming to the agreement above. Do you agree to take part in this study?

YES

NO

Q2 Job Title

Q3 Please provide your area of business

Q4 How comprehensive is the OntEIR framework in defining the requirements for EIR? (This question is to evaluate the extent of the OntEIR framework in dealing with all aspects and requirements of the Employer Information Requirements. Comprehensive means Complete)

Q5 Does OntEIR contain the right level of requirements?
(This question is to measure whether OntEIR has got too many or too little details or just the right amount)

Q6 If not, which requirements could be added?

Q7 If not, which requirements could be removed?

Q8 Do you agree that the categorisation between static and dynamic requirements is right for EIR? (This question is to check whether having two types of requirements (static and dynamic) is justified. Static requirements are the requirements that are defined at the beginning of a project and do not change according to the stage
Dynamic requirements are the requirements that change and develop according to the stage the project is in)

Q9 Is there a need for another category? if yes what is it?

Q10 In the Static Section, how well is the static requirements' distinction between needs and requirements justified?
(This question is to measure how clear the distinction was between "static needs" and "static requirements" and if it complemented the understandability of the EIR)

Q11 Does static requirements contain the right level of needs?
(This question is to check the completeness of the static needs)

Q12 If not, which needs could be added?

Q13 If not, which needs could be removed?

Q14 Does the static section contain the right level of requirements?
(This question is to check the completeness of the static requirements)

Q15 If not, which requirements could be added?

Q16 If not, which requirements could be removed?

Q17 In the dynamic Section, How well is the dynamic requirements' distinction between needs and requirements justified?
(This question is to measure how clear the distinction is between "dynamic needs" and "dynamic requirements" and if it complemented the understandability of the EIR

Q18 Does the dynamic section contain the right level of needs?
(This question is to check the completeness of the Dynamic needs)

Q19 If not, which needs could be added?

Q20 which needs could be removed?

Q21 Does the dynamic section contain the right level of requirements?
(This question is to check the completeness of the dynamic requirements)

Q22 If not, which requirements could be added?

Q23 Which requirements could be removed?

Q24 Additional comments on the overall OntEIR framework?

Q25 What do you think is the strongest feature of the OntEIR framework?

Q26 What do you think is the weakest feature of the OntEIR framework?

Appendix D Excel sheets providing information for the development of the OntEIR tool

Section 1: Project Information	
1.a Project Name	[text]
1.b Project Description	[text]
1.c Project Address	[text]

Section 2: Roles		
Include Role	Role	Name
Check Box for Yes	Employer	Short Text
Check Box for Yes	BIM Leader	Short Text
Check Box for Yes	Information Manager	Short Text
Check Box for Yes	Lead Designer	Short Text
Check Box for Yes	Design Team	Short Text
Check Box for Yes	Main Contractor	Short Text
Check Box for Yes	Specialist Contractor	Short Text
Check Box for Yes	Project Manager	Short Text
Check Box for Yes	Facilities Manager	Short Text
Check Box for Yes	CDM	Short Text

Check Box for Yes	Cost Manager	Short Text
Check Box for Yes	Add Role...	Short Text

	Question 3: Responsibilities				
Include Task	Task: CDE	Authorised By	Responsibility Of	Consulted By	Informed By
Check Box for Yes	Advise on a CDE	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Provide a CDE	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Set up the CDE	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Maintain the CDE	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Download/upload all project information from/to the CDE	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
	Task Recourses				
Check Box for Yes	Appoint consultants, including Information Manager	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Ensure that the necessary software and hardware are in place within the organisation to support efficient delivery of the project	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Assess all sub-contracted organisations (design or construct) according to the BIM assessment criteria contained in the Capability Assessment	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Report any emerging skill gaps within the team	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Provide guidance to assist in procuring the right type of training from credible industry professionals	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Co-ordinate training for your own organisation	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
	Task Project Strategy				
Check Box for Yes	Establish BIM requirements for the project, long term	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Responsible for ensuring that all subcontracted organisations (design or construct) meet the requirements set forth in the EIR	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Provide any existing information including historical data and existing conditions models.	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Develop, implement and update as necessary the post-contract BEP, which all project team members need to agree to and use	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Agree and implement the data structure and maintenance standards for the information models	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Acquire and update as necessary the post-contract BEP to include construction responsibilities	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Develop and implement the information delivery plan, sufficient to ensure all deliverables are accounted for	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Acquire and update the MPDT indicating model progression in respect of work packages including Level Of Definition with dates of delivery	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Develop and implement the BIM implementation programme	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Develop and implement the information exchange protocol	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	BIM guidance and monitoring of the project team	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
	Task Geometry				
Check Box for Yes	Create a site set-up model with coordinated, measurements and bearings to be used disseminated to all design team members	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Incorporate sub-contract (design and construct) models	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Ensure that all drawings are derived from the information models	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Export and publish files according to file data exchange schedule	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Provide a virtual model according to the Levels of Development, the MPDT and the non-geometric requirements	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Share information models for coordination	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Implement the BEP within the organisation	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Full coordination of the design and design team	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Provide energy analysis model(s) for evaluation by the project team	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Provide structural analysis model(s) for evaluation by the project team	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Create clash detection reports of the federated models	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Ensure the implementation of BIM acknowledges Facilities Management (FM) and operation and maintenance deliverables	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
	Task5-Data				
Check Box for Yes	Specify data requirements including the purpose for the information required and the timing of its delivery	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Provide data about facility in both its spatial and physical aspects according to the COBie requirements of the EIR	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Provide data specific to a particular system or component in line with individual scope of works	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Delegate aspect of the EIR downwards to the next tier	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Create, acquire and store required information	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Review and approve the data deliverable prior to submission	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
	Task6-ConstructionManagement				
Check Box for Yes	Provide 4D construction phasing	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Provide 4D construction sequencing	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Provide 4D logistics simulationsincluding crane strategy	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Update all 4D simulated models to reflect current project conditions and to illustrated progress	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Report on residual risks within the model space and share via the CDE	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Compile a digital health and safety file	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
	Task7-QualityAssuranceAndControl				
Check Box for Yes	Adhere to the QA/QC procedure contained within the EIR	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Ensure all dataset requirements are completed in full according to the Level Of Definition stage for use in CAFM	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Report on changes to budget, cost and design	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Audit and coordinate virtual models, including full intermittent clash detection according to the BIM programme	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Report on general model quality in terms of geometry, materiality and metadata	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Report on adherence to the project BEP with regards to model Level Of Definition, model completeness and BIM standards compliancy	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Report on functionality of the model for 4D and 5D use by other consultants	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Review of received data against the EIR data requirements	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Support the Lead Designer by undertaking third party 3D coordination and clash detection processes to assist design coordination reviews	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
	Task8-Meetings				
Check Box for Yes	Make use of information models during design team and the Employers team meetings	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Hold BIM workgroup meetings	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Hold key work stage BIM steer meetings	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Hold lessons learned meeting following completion of phases	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
	Task9-ReportingAndGovernance				
Check Box for Yes	Provide monthly status reports of BIM development using project pro-forma	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Provide monthly procurement model highlighting work packages which have been let and/or procured	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Check Box for Yes	Provide monthly model showing actual programme progress against planned	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2
Check Box for Yes	Report on supply chain performance during construction	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2	Multiple Choice from "Role List", checked boxes question 2 in page 2

Include	Project team role	Name
check box if yes	Architect	[text]
check box if yes	Civil	[text]
check box if yes	SE	[text]
check box if yes	MEP	[text]
check box if yes	Building Service Engineer	[text]
check box if yes	FMA	[text]
check box if yes	Ground Worker	[text]
check box if yes	Planning Department	[text]
check box if yes	add role…	[text]

Section 5: Ownership of the model		

Stage	Owned by	Lisenced to
Design Stage Stage	multiple choice from "roles list" on page 2	multiple choice from "roles list" on page 2
TenderPeriod	multiple choice from "roles list" on page 2	multiple choice from "roles list" on page 2
PostTenderPeriod	multiple choice from "roles list" on page 2	multiple choice from "roles list" on page 2
DuringFirstYearOfOccupation	multiple choice from "roles list" on page 2	multiple choice from "roles list" on page 2

Question 6: Software Platform		
Use	Software	Version
2D Drawing	[Text]	[Text]
Collaboration	[Text]	[Text]
Coordination & Review	[Text]	[Text]
Data Exchange	[Text]	[Text]
Facilities Management	[Text]	[Text]
3D design Modelling	[Text]	[Text]

Question 7: Standards		
Yes/No	Satndard	Use for
Check Box if "yes"	AECUK-BIM-Protocol	multiple choice from [Standard uses list]
Check Box if "yes"	BS10012	multiple choice from [Standard uses list]
Check Box if "yes"	BS1192-4:2014	multiple choice from [software uses list]

Check Box if "yes"	BS1192:2007	multiple choice from [Standard uses list]
Check Box if "yes"	BS1197:2007	multiple choice from [Standard uses list]
Check Box if "yes"	BS7000Series	multiple choice from [Standard uses list]
Check Box if "yes"	BS8534:2011	multiple choice from [Standard uses list]
Check Box if "yes"	BS8541-1:2012	multiple choice from [Standard uses list]
Check Box if "yes"	CDM-2015	multiple choice from [Standard uses list]
Check Box if "yes"	CIC-BIM-Protocol	multiple choice from [Standard uses list]
Check Box if "yes"	CICBIM_INS	multiple choice from [Standard uses list]
Check Box if "yes"	PAS1192-2:2013	multiple choice from [Standard uses list]
Check Box if "yes"	PAS_1192-5	multiple choice from [Standard uses list]
Check Box if "yes"	PAS_55-1-2008	multiple choice from [Standard uses list]
Check Box if "yes"	RICS-NRM1-NewRulesOfMeasurement	multiple choice from [Standard uses list]
Check Box if "yes"	UoCSpaceMeasuringGuide	multiple choice from [Standard uses list]
Check Box if "yes"	Add Standards	multiple choice from [Standard uses list]

Part 2:

Section 1: Define Stages			
	Stage	Date of Start	Date of Finish
	Stage 2- Concept	Date of Start	[Date Format]
	Stage3-Definition	[Date Format]	[Date Format]
	Stage4-Design	[Date Format]	[Date Format]
	Stage5-BuildAndCommission	[Date Format]	[Date Format]
	Stage6-HandoverAndCloseout	[Date Format]	[Date Format]
	Stage7-OperationAndEndLife	[Date Format]	[Date Format]

Section 2-1 Stage 2- Requirements			
a- Data Drops			
Check Box	Data Drops:		
Check box for yes	Develop Health & Safety Plan		
Check box for yes	Develop Initial Cost Estimation		
Check box for yes	Develop Initial Struture Building Design		
Check box for yes	Overall Building Massing		
Check box for yes	Size Shape Orientation		
b- Performed By	Multiple Choice from Project Team List, part 1 page 2		
c- COBie			
COBie Deliverable Exchange Format	TEXT		

COBie Deliverable	TEXT		
COBie Deliverable Type	TEXT		
COBie Deliverable Version	TEXT		
COBie Responsibility	Multiple Choice from "ROLE LIST" Part 1 page 2		
d- Project Requirements			
Overall Form and Content	LOD		
Multiple choice from form and content list	one choice from LOD list		
Elements Materials and Components	LOD		
Multiple choice from "elements and materials list"	one choice from LOD list		
Performance	LOD		
Multiple choice from "Performance List"	one choice from LOD list		
Design Strategies	LOD		
Multiple choice from "Design Strategies List"	one choice from LOD list		
Construction Proposals	LOD		
Multiple choice from "Construction Proposals List"	one choice from LOD list		
Health and Safety	LOD		
Multiple choice from "Health and Safety List"	one choice from LOD list		

e-Asset Information Requirements	Responsibility of		
	multiple choice of "project team list"		
Contact Sheet	Type		
Multiple choice from "Contact Sheet List"	One Choice from "Type List"		
Faculty Sheet	Type		
Multiple choice from "Faculty sheet List"	One Choice from "Type List"		
Floor Sheet	Type		
Multiple choice from Floor sheet list	One Choice from "Type List"		
Space Sheet	Type		
Multiple choice from Space sheet list	One Choice from "Type List"		
Zone Sheet	Type		
Multiple choice from Zone Sheet List	One Choice from "Type List"		
Type Sheet	Type		
Multiple choice from Type Sheet List	One Choice from "Type List"		
Component Sheet	Type		
Multiple choice from Component Sheet List	One Choice from "Type List"		
System Sheet	Type		

Multiple choice from System Sheet List	One Choice from "Type List"		
LOI	Responsibility of	Delivery Format	
One choice from LOI list	multiple choice of "project team list"	multiple choice of "Delivery Format list"	
LOI	Responsibility of	Delivery Format	
One choice from LOI list	multiple choice of "project team list"	multiple choice of "Delivery Format list"	
LOI	Responsibility of	Delivery Format	
One choice from LOI list	multiple choice of "project team list"	multiple choice of "Delivery Format list"	
LOI	Responsibility of	Delivery Format	
One choice from LOI list	multiple choice of "project team list"	multiple choice of "Delivery Format list"	
LOI	Responsibility of	Delivery Format	
One choice from LOI list	multiple choice of "project team list"	multiple choice of "Delivery Format list"	
LOI	Responsibility of	Delivery Format	
One choice from LOI list	multiple choice of "project team list"	multiple choice of "Delivery Format list"	

Lists:

Project Team List			Overall Form and content list			
Architect			MaintenanceAccess			
Civil			SpacePlanning			
SE			Surveys			
MEP			BuildingAndSiteSections			
Buidling Service Engineer			Specifications			
FMA			SiteAndContex			
Ground Worker			ExternalFormAndAppearance			
Planning Depatrment			internal layouts			
add role…			Fire			
			PhysicalSecurity			
			DisabledAccess			
Elements Materials and Components List						Performance List
Building						5DCostAnalysis
MEP Systems						4DProgrammingAnalysis
Structural						AcousticAnalysis
Specifications						Buidling
						MEPsystems
						RegulationsComplianceAnalysis
						Structural
						ThermalSimulations
						ServicesCommisioning
						SusutainabilityAnalysis
Design Strategies				Health and Safety List		
DisabledAccess				DesignConstruction		

Fire		Construction
MaintenanceAccess		Design
PhysicalSecurity		Operation
Construction Proposals list		Delivery Format List
Phasing		2D PDF
SiteAccessSiteSet-up		2D DWG
SiteSet-up		Documantation
		BIM model
contact sheet	faculty sheet	
E-mail	name	
Created by	created by	
created on	created on	
category	category	
company	project name	
phone	site name	
Ext system	linear units	
Ext object	area units	
Ext identifier	volume units	
department	area measurement	
organisation code	external system	
given name	external project object	
family name	external site identifier	
street	external facility identifier	
postal box	description	

town			site description			
country						
floor sheet		space sheet				
name		name				
created by		creaated by				
created on		created on				
category		category				
Ext system		floor name				
Ext object		description				
Ext identifier		Ext system				
description		Ext identifier				
elevation		room tag				
height		usable height				
		gross area				
		net area				
zone sheet		type sheet				
name		name				
created on		created by				
created by		created on				
category		category				
space name		description				
Ext system		asset type code				
Ext object		ext system				
Ext identifier		ext object				
description		ext identifier				
		nominal width				

component sheet	nominal length			
name	model reference			
created by	shape			
created on	size			
type name	colour			
space name	finish			
description	grade			
Ext system	material			
Ext object	consistuents			
Ext identifier	features			
	accessibilty performance			
system sheet	code peformance			
name	sustainability performance			
created by				
created on	Type List			
category	Geometric			
component name	Non Geometric			
Ext system				
Ext object				
Ext identifier				
description				

Appendix E Roles of Participants in Survey 2

ID	Title	Experience
1	Supplier	More than 5 years
2	null	null
3	Project Manager	More than 5 years
4	BIM Developer	More than 5 years
5	Supplier	3 to 5 years
6	BIM Specialist	More than 5 years
7	BIM Manager	More than 5 years
8	Project Manager	More than 5 years
9	BIM Coordinator	More than 5 years
10	BIM Consultant	More than 5 years
11	BIM Manager	More than 5 years
12	BIM Manager	More than 5 years
13	BIM Consultant	More than 5 years
14	null	null
15	BIM Consultant	More than 5 years
16	BIM Advisor	More than 5 years
17	BIM Manager	More than 5 years
18	BIM Consultant	More than 5 years
19	Building Services	More than 5 years
20	Building Services	3 to 5 years
21	BIM Consultant	Less than 3 years
22	Supplier	Less than 3 years
23	BIM Consultant	Less than 3 years
24	BIM Consultant	Less than 3 years

25	Client Representative	Less than 3 years
26	Client Representative	Less than 3 years
27	Client Representative	Less than 3 years
28	Client Representative	Less than 3 years
29	Client Representative	Less than 3 years
30	Client Representative	Less than 3 years
31	Client Representative	Less than 3 years
32	Client Representative	Less than 3 years
33	BIM Specialist	3 to 5 years
34	Project Manager	More than 5 years
35	BIM Director	More than 5 years
36	BIM Consultant	More than 5 years
37	BIM Consultant	More than 5 years
38	Client Representative	3 to 5 years
39	Client Representative	More than 5 years
40	Client Representative	Less than 3 years
41	BIM Specialist	3 to 5 years
42	BIM Specialist	3 to 5 years
43	Client Representative	3 to 5 years

44	Client Representative	3 to 5 years
45	BIM Consultant	Less than 3 years
46	Client Representative	Less than 3 years
47	Client Representative	Less than 3 years
48	Client Representative	Less than 3 years
49	BIM Consultant	Less than 3 years
50	BIM Advisor	3 to 5 years
51	BIM Coordinator	3 to 5 years
52	BIM Consultant	3 to 5 years
53	Supplier	More than 5 years

Title	Experience 1 ≥ 5 Years	3 years≤ Experience 2<5 years	Experience 3<3 Years
Project Manager	3	0	0
BIM Developer	1	0	0
Supplier	2	1	1
BIM Specialist	1	3	
BIM Manager	4	0	0
BIM Coordinator	1	1	0
BIM Consultant	6	1	5
BIM Advisor	1	1	0
Building Services	1	1	0
Client Representative	1	3	12
BIM Director	1	0	0
	22	11	18
	Experience ≥ 5 Years	3 years≤ Experience <5 years	Experience <3 Years
Part pants' Experiences	22	11	18

Appendix F Questionnaire for validation of the OntEIR tool

A

Introduction

Welcome to the evaluation of the OntEIR (Ontology based framework for defining Employer Information Requirements) framework, to assist employers (clients) in defining their Employer Information Requirements (EIR). The aim of this framework is to define the needs and requirements of the EIR.
This form is part of the validation for the OntEIR framework. You are asked to fill in this questionnaire that will enable the researcher to get feedback for the development of the tool.

Confidentiality
No personal information will be collected that would identify you, and all your data will be anonymous. All data will be stored in a password protected electronic format. To help protect your confidentiality, the surveys will not contain information that will enable to identify you. Non-identifiable results of this study will be used for scholarly purposes and may be shared with the research team.

Participation
Please note that your participation in this study is completely voluntary. You may choose not to participate. However, if you do choose to participate, you may withdraw at any time while completing the form. If you don't want to answer any of the questions you don't have to. By submitting this survey, you are agreeing to participate and cannot withdraw after this point. If you decide to withdraw at any point, you will not be penalised.
Questions about the research or your rights as participants. If you have any questions or concerns, feel free to contact the owner of this study at: **Shadan.dwairi@uwe.ac.uk**

Consent

Please confirm that you understand and agree to the following:

I am over the age of 18 have read through the information above and received enough information about the research. I understand that by consenting to taking part in this study, I can still withdraw at any time without being obliged to give reasons. I understand by submitting this survey, I cannot withdraw my data anymore. I understand that I will not be personally identified at any report, and my name will be replaced by a number so that all the data can remain confidential. I understand that this information will be used only for the purpose set out in the information page, and my consent is conditional upon the university complying with the duties and obligation under the Data Protection Act

By consenting to take part in this study you are acknowledging that you understand that you are confirming to the agreement above. Do you agree to take part in this study?

- ○ YES
- ○ NO

B Job Title

____

C Area of Business

____

D Experience in BIM and/or EIR

- ○ more than 5 years
- ○ 2 to 5 years
- ○ less than 2 years

Q1 How is your first impression of the tool in terms of graphical user interface?

Terrible Excellent

1 2 3 4 5

Q2 How straightforward is the tool? (easy to understand)

Extremely difficult Extremely easy

1 2 3 4 5

Q3 to what extent does the tool provide you with the appropriate level of information to develop a full and complete EIR?

Not at all useful Extremely useful

1 2 3 4 5

Q4 How would you rate the quality of the information presented?

Not at all useful Extremely useful

1 2 3 4 5

Q5 How clear was the classification and transition between general (static) requirements and stage (dynamic) requirements?

Extremely unclear Extremely clear

1 2 3 4 5

Q6 How easy was it to select and define a certain requirement in the tool?

Extremely difficult   Extremely easy

1   2   3   4   5

Q7 How would you rate the quality and comprehensiveness of the developed final EIR document produced by OntEIR?

Terrible   Excellent

1   2   3   4   5

Q9 Would you recommend the tool?

○ Yes

○ No

Q10 In order to improve the tool, please provide any additional comments?

____

Appendix G: OntEIR Versus Case Study

PROJECT INFORMATION	
Project number	Confidential
Short project description	Confidential
Project name	Confidential
Project address	Confidential
Client name	Confidential
Contact details	Confidential
Design start date	Confidential
Construction start date	Confidential
Completion date	Confidential
Handover date	Confidential
ROLES	
BIM Leader	NOT SPECIFIED
CDM	NOT SPECIFIED
Cost Manager	NOT SPECIFIED
Design Team	NOT SPECIFIED
Employer	NOT SPECIFIED
Facilities Manager	NOT SPECIFIED
Information Manager	NOT SPECIFIED
Lead Designer	NOT SPECIFIED
Main Contractor	NOT SPECIFIED
Project Manager	NOT SPECIFIED

Specialist Contractor	NOT SPECIFIED

RESPONSIBILITIES		
Task 1: Common Data Environment	Advise on a CDE	Confidential
	Download\/upload all project information from\/to the CDE	Confidential
	Maintain the CDE	NS
	Provide a CDE	NS
	Set up the CDE	NS
Task 2: Resources	Appoint consultants including Information Manager	NS
	Assess all sub-contracted organisations (design or construct) according to the BIM assessment criteria contained in the Capability Assessment	NS
	Coordinate training for your own organisation	NS
	Ensure that the necessary software and hardware are in place within the organisation to support efficient delivery of the project	NS
22	Provide guidance to assist in procuring the right type of training from credible industry professionals	NS
	Report any emerging skill gaps within the team	NS
Task 3: Project Strategy	Acquire and update the MPDT indicating model progression in respect of work packages including Level Of Definition with dates of delivery	NS

	Agree and implement the data structure and maintenance standards for the information models	NS
	Develop and implement the BIM implementation programme	NS
	Develop and implement the information delivery plan; sufficient to ensure all deliverables are accounted for	NS
	Develop and implement the information exchange protocol	NS
	Develop; implement and update as necessary the post-contract BEP; which all project team members need to agree to and use	NS
	Establish BIM requirements for the project; long term	NS
	Provide any existing information including historical data and existing conditions models	NS
	Responsible for ensuring that all subcontracted organisations (design or construct) meet the requirements set forth in the EIR	NS
Task 4: Geometry	Create a site set-up model with coordinated; measurements and bearings to be used disseminated to all design team members	NS
	Create clash detection reports of the federated models	NS
	Ensure that all drawings are derived from the information models	NS
	Ensure the implementation of BIM acknowledges Facilities Management (FM) and operation and maintenance deliverables	NS

	Export and publish files according to file data exchange schedule	NS
	Full coordination of the design and design team	NS
	Implement the BEP within the organisation	NS
	Incorporate sub-contract (design and construct) models	NS
	Provide a virtual model according to the Levels of Development; the MPDT and the non-geometric requirements	NS
	Provide energy analysis model(s) for evaluation by the project team	NS
	Provide structural analysis model(s) for evaluation by the project team	NS
	Share information models for coordination	NS
Task 5: Data	Create; acquire and store required information	NS
	Create; acquire and store required information	NS
	Delegate aspect of the EIR downwards to the next tier	NS
	Provide data about facility in both its spatial and physical aspects according to the COBie requirements of the EIR	NS
	Provide data specific to a particular system or component in line with individual scope of works	NS
	Review and approve the data deliverable prior to submission	NS
	Specify data requirements including the purpose for the information required and the timing of its delivery	NS

Task 6: Construction Management	Compile a digital health and safety file	NS
	Provide 4D construction phasing	NS
	Provide 4D construction sequencing	NS
	Provide 4D logistics simulations including crane strategy	NS
	Report on residual risks within the model space and share via the CDE	NS
	Update all 4D simulated models to reflect current project conditions and to illustrated progress	NS
Task 7: Quality Assurance And Control	Adhere to the QA\/QC procedure contained within the EIR	NS
	Audit and coordinate virtual models; including full intermittent clash detection according to the BIM programme	NS
	Ensure all dataset requirements are completed in full according to the Level Of Definition stage for use in CAFM	NS
	Report on adherence to the project BEP with regards to model Level Of Definition; model completeness and BIM standards compliancy	Confidential
	Report on changes to budget; cost and design	NS
	Report on functionality of the model for 4D and 5D use by other consultants	NS
	Report on general model quality in terms of geometry; materiality and metadata	NS
	Review of received data against the EIR data requirements	NS

	Support the Lead Designer by undertaking third party 3D coordination and clash detection processes to assist design coordination reviews	NS
Task 8: Meetings	Hold BIM workgroup meetings	NS
	Hold key work stage BIM steer meetings	NS
	Hold lessons learned meeting following completion of phases	NS
	Make use of information models during design team and the Employers team meetings	NS
Task 9: Reporting And Governance	Provide monthly model showing actual programme progress against planned	NS
	Provide monthly procurement model highlighting work packages which have been let and\/or procured	NS
	Provide monthly status reports of BIM development using project pro-forma	NS
	Report on supply chain performance during construction	NS
Data Security		
Home and Mobile Working	Apply the secure baseline building to all devices	NS
	Develop a mobile working policy and train staff	NS
	Protect data both in transit and at rest	NS
	Establish an incident response and disaster recover capability	NS
Incident Management	Produce and test incident management plans	NS

	Provide specialist training to the incident management team	NS
	Report criminal incidents to law enforcement	NS
Information Risk Management Regime	Establish and effective governance structure and determine risk appetite	NS
	Maintain the boards engagement with the cyber risk	NS
	Produce supporting information risk management policies	NS
Malware Protection	Produce a relevant policy and establish anti-malware defences that are applicable and relevant to all business areas	NS
	Scan for malware across the organisation	NS
Managing User Privileges	Control access to activity and audit logs	NS
	Establish account management processes and limit the number of privileged accounts	NS
	Limit user privilege and monitor user activity	NS
Network Security	Filter out unauthorised access and malicious content	NS
	Manage the network parameter	NS
	Monitor and test security controls	NS
	Protect your network against external and internal attacks	NS
Secure Configuration	Apply security patches and ensure that the secure configuration of the ICT system is maintained	NS
	Create a system inventory and define baseline built for ICT devices	NS

User Education and Awareness	Establish a staff training programme	NS
	Maintain user awareness of the cyber risks	NS
	Produce safer security policies covering acceptable and secure use of the organisations systems	NS
Software Platform		
2D Drawing 83	Software	Confidential
	Version	Confidential
3D design Modelling	Software	NS
	Version	NS
Collaboration	Software	NS
	Version	NS
Coordination and Clash Detection	Software	NS
	Version	NS
Data Exchange	Software	NS
	Version	NS
Facilities Management	Software	Confidential
	Version	NS
Open File Format		Confidential
Intelligent Read Only format		Confidential
File Naming Requirements		
Ownership of the Model	NS	

Coordinates		
1- Intersection of grids XX and YY	NS	
2- Intersection of grids AA and BB	NS	
3- Ground floor FFL	NS	
4- Origin rotation	NS	
5- Offsets	NS	
6- Datum information	NS	
7- Units to be used	NS	
Communication: Coordination and Clash Detection		
CDE	Confidential	
Clash Detection Responsibility	NS	
Clash Resolution Responsibility	NS	
Clash detection process	Confidential	
Clash resolution process	Confidential	
Frequency of information exchange	Confidential	
Asset Information Model Delivery Strategy		
Information Exchange Format	Confidential	
Standard Classification System	Confidential	
Stages		
Stage 2- Concept Design	Date of Finish	NS
	Date of Start	NS
Stage 3- Developed Design	Date of Finish	NS
	Date of Start	NS

Stage 4- Technical Design	Date of Finish	NS
	Date of Start	NS
Stage 5- Construction	Date of Finish	NS
	Date of Start	NS
Stage 6- Handover and Closeout	Date of Finish	NS
	Date of Start	NS
Stage 7- In-Use	Date of Finish	NS
	Date of Start	NS
Level of Detail		
LOD 2 (Conceptual)	Confidential	
LOD 3 (Approximate Geometry)	Confidential	
LOD 4 (Precise Geometry)	Confidential	
LOD 5 (Fabrication)	Confidential	
LOD 6 (As Built)	Confidential	
LOI	NOT SPECIFIED	
Stage 2		
a- Data Drops	Confidential	
	Confidential	
b-Performed by	NS	
Project Requirements		
Overall Form and Content[0]	Confidential	
	Confidential	
	Confidential	

	Confidential	
	Confidential	
Data Security Status	NS	
Health and Safety Requirements	Confidential	
Responsibility	Confidential	
Project requirements	Confidential	
Delivery format	NS	
LOD	Confidential	
LOI	NS	
Responsibility	NS	
AIR	Confidential	
Responsibility	NS	
COBie	Confidential	

Appendix H Details of the Participants in the OntEIR Framework Validation

Participant ID	Title	Area of business
R1-1	Project-Manager	Facility Management /Buildings and Construction
R1-2	AutoCAD assistant	Space Management and Master Planning
R1-3	BIM Manager	Client - Higher Education
R1-4	Lecturer in BIM	BIM and Project Management
R1-5	Project Manager	BIM and project management
R1-6	BIM Manager	Main contractor
R1-7	Building Services Advisor	Central Government
R1-8	Revit technician	Engineering
R1-9	Architectural Technologist	Construction
R1-10	BIM leader	BIM smart cities
R1-11	BIM Manager	Architecture

R1-12	Senior Lecturer	Architecture and construction
R1-13	BIM Leader	Smart cities
R1-14	Architectural technologist	Construction
R1-15	Revit technician	Engineering
R1-16	Requirements Manager	Requirements Management, Validation and Verification Management
R1-17	Facility and Real Estate Manager	Office and Manufacturing Buildings and related services.
R1-18	Construction Project Manager	Industrial facilities and services
R1-19	Project Manager	Manufacturing Engineering
R1-20	BIM Manager	Main contractor

Appendix I Comments of Respondents on the OntEIR Tool

Comment 1: there should be an option to change the stages according to what the client uses	**Ways to improve:** More user involvement on Stage requirements
Comment 2: The tool is easy to use, the interface is simple and the final product is rich with information. However, the matrix of the design stages needs to elaborate. Thanks	**Strengths:** Ease of use Comprehensive final document **Ways to improve:** More elaborate dynamic req.
Comment 3: Final document could be presented more clearly	**Ways to improve:** The final document
Comment 4: Add charts to show the progress, and print friendlier PDF file.	**Ways to improve:** The GUI The final document
Comment 5: Change Font Type	**Ways to improve:** The GUI
Comment 6: It would be helpful to provide a diagram that explains the inputs and the outputs and their order.	**Ways to improve:** The GUI
Comment 7: Get the feedback of the employer	**Ways to improve:** More user involvement

<table>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Comment 8:

Very comprehensive tool and easy to use. My only reservation with this approach is that it whilst ticks all the boxes of an EIR, it's quite technical and potentially difficult to read if you are a layman Employer. My approach in developing EIR's has always been to incorporate graphical explanations for the various R&R's, model scopes, requirements, etc. We have worked hard at Allies and Morrison to make sure that BIM is not exclusive to technical people and that all stakeholders can engage in the process.</td></tr>
<tr><td>Strengths:

Comprehensive.

Ease of use</td><td>Ways to improve:

Increase understandability especially for novice clients

GUI</td></tr>
<tr><td rowspan="2">Comment 9:

I would pick an EIR generated by this tool over most of the EIR's developed by BIM consultants in London any day, but just feel that this approach perhaps removes the conversations with the end-user that are vital in getting BIM working on a project.</td><td>Strengths:

Better than existing practices</td></tr>
<tr><td>Ways to improve:

More user involvement</td></tr>
<tr><td>Comment 10:

The tool has great potential and I invite you to continue in developing it. Please consider all my comments in a positive way as suggestions to improve the work.: 1) it is too rigid and it does not allow the flexibility and customisation options required e.g. it is possible to select only one software per use when in reality you can use more than one. Moreover, not always RIBA stages are followed. It really depends on the type of procurement. 2)</td><td>Ways to improve:

More customisation options

AIR and COBie

The output</td></tr>
</table>

more work should be done to correlate information e.g. it is possible to include a completion date prior to the start one. 3) the AIR section is quite critical as it is not clear which classification is following. Moreover, it is not clear the relation between AIR and COBie. 4) the final output (pdf and csv) are not formatted in a way that can be automatically included in the ITT and shared with consultants. I hope my comments can help for your future research. Keep up the work!	
Comment 11: I feel this is a great concept and much needed. It would be good to have some more options or ability to customise the some of the sections in stage 2, in particular the Level of Definition sections, it could perhaps be useful to follow the plan of works, rather than trying to categorise by discipline or responsibility, as this may not be known at this stage, also when lumping together things like MEP, this can become restrictive, as these are really separate disciplines, with many sub disciplines and complexities, with very different requirements and outputs. It would be good if the final presentation of the information could be improved.	**Strengths:** The Concept behind the tool The need for such a tool in the industry **Ways to improve:** More customisation options The output
Comment 12: A consideration must be to be able to define templates for projects and also customise the output so that it can be added to a CDE and be compatible so that the information becomes part of the CDE as such. but good work.	**Ways to improve:** More customisation options

Comment 13: it's a great little tool. I would find it useful to sit with a client and use something like this. I think what would really differentiate something like this, if you want to have commercial success is to provide additional information about specifically what you need to buy, how it needs to be monitored i.e. the work involved, the benefits etc.. so that a client can hopefully understand what they're filling in and it's consequences a bit better. Education is what's really required right now.	
Comment 14: Nothing major. I would like to see the BS1192 codes for disciplines added to the roles tab.	**Ways to improve:** Involvement of more codes and standards
Comment 15: GUI improvements (specifically when it exports to pdf).	**Ways to improve:** GUI The output
Comment 16: Mobile friendly	**Ways to improve:** Mobile friendly
Comment 17: Model ownership assumes single model for project-functionality can be incorporated for multiple model scenarios; I am not expert on coordinates but I think they model-specific, project level specifications should be tailored to specific model uses; Asset information model strategy not clear perhaps because	**Ways to improve:** Ownership of the model Incorporate more graphics

there are no options under it; LOD LOI can be supported by images	